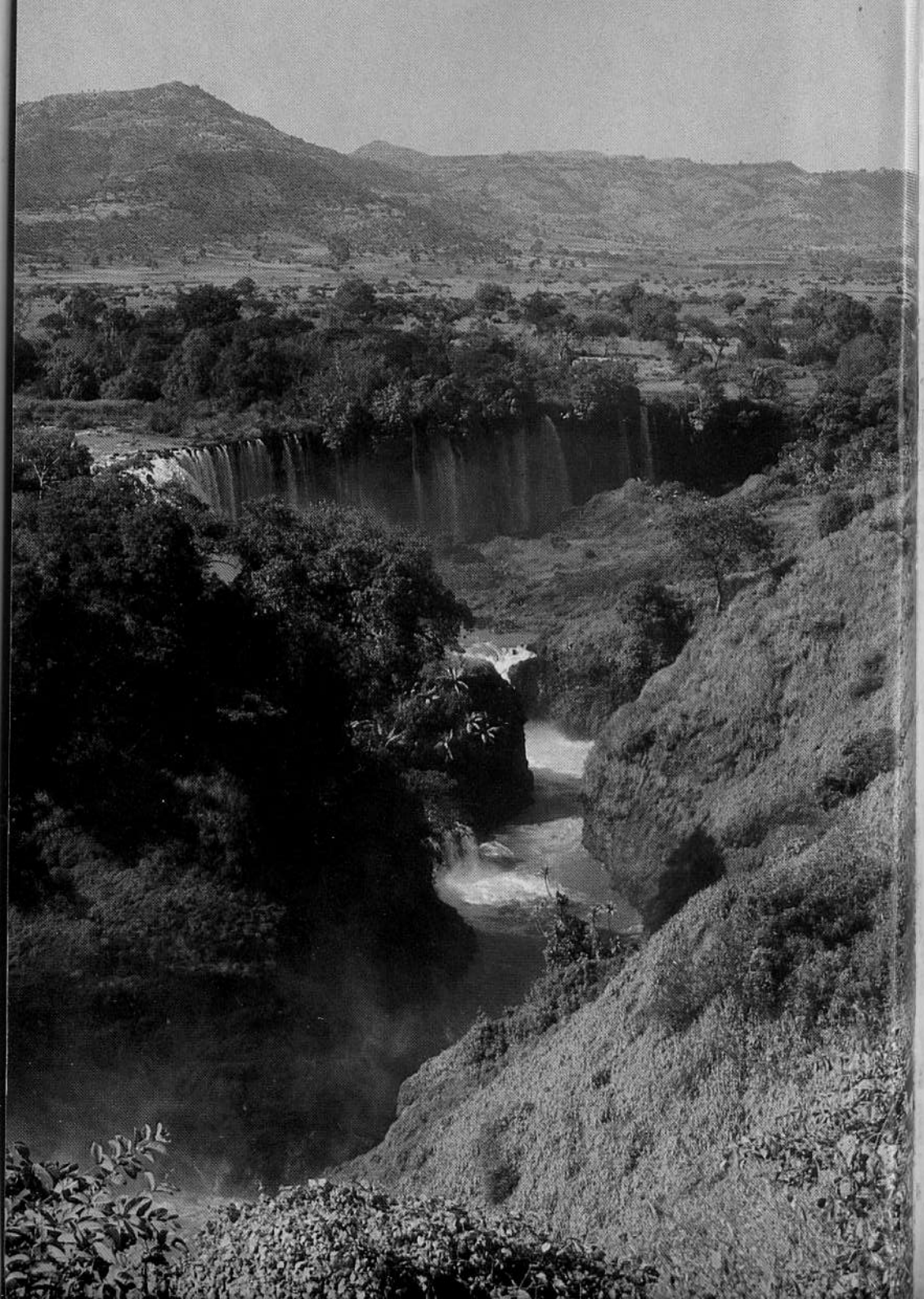


THE SAHARA AND THE NILE

Quaternary environments and prehistoric occupation in northern Africa

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In memory of W.W.Bishop, G.F.Maglione and W.H.Morton

Frontispiece:

The Tisisat Falls between Lake Tana and the Blue Nile gorge, Ethiopia, December 1971.
Photograph: M.A.J.Williams

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Preface

There are several reasons why an up-to-date and scholarly account of Quaternary environments and prehistoric occupation in the Sahara and the Nile Valley seems to us both appropriate and timely.

As might be expected, the scientific literature on the geology, biology and prehistoric archaeology of the Sahara and the Nile is vast, scattered and multilingual. A sad but inevitable outcome of this *embarras de richesses* is over-selective reading. Many major monographs relating, for example, to Saharan prehistory, or palynology, or diatom palaeoecology, or stratigraphy, are seldom studied by scholars outside these particular disciplines. When they are, it is not easy for the non-specialist to evaluate them with the same degree of critical acumen that he brings to bear within his own discipline.

Furthermore, our concepts have changed as our techniques have improved. The development of radiocarbon dating in 1948 revolutionalised our knowledge of events in the Sahara and Nile during the last 40 000 years or so. Our understanding will be refined a great deal further once very precise radiocarbon dating back to 100 000 years and more becomes routinely available, and not simply the exciting possibility that it is today.

Certain implications of plate tectonics offer us far clearer insights into the history of uplift and rifting in the Nile headwaters than has been the case hitherto. Analysis of deep-sea cores from the Mediterranean, besides confirming the antiquity of the Nile, has shown the close interrelationships between northward movement of the African plate, Antarctic glaciation, sea-level lowering, and desiccation of the Mediterranean some six million years ago. We have long known of the deeply buried valley of the pre-Pliocene Nile, but until the recent discovery of the late-Miocene drying-out of the Mediterranean, we were at a loss for an adequate explanation.

Precise dates and detailed local studies of the fossil flora and fauna of the Sahara and Nile have made possible broad palaeogeographical reconstructions of the entire region at particular moments in time. The wealth of Neolithic sites scattered throughout the Sahara has provoked much speculation as to how green was our greatest desert. We are now in a position to replace these earlier speculations with a closer approximation to the truth. The vexed issue of how far man has contributed to Saharan devegetation remains open. Our own view is

that Neolithic pastoralists probably helped to accelerate the tendency towards biological deterioration already initiated by middle Holocene climatic desiccation. Certainly, an accurate knowledge of late Quaternary climatic oscillations in the Sahara and Nile valley is a useful antidote to some of the more dismal modern soothsayers who see in man's activities the root cause of every recent drought.

It is perhaps worth pointing out what this volume does and does not attempt to do. Each chapter tries to give a balanced and reasonably comprehensive account of the more significant results of field investigations which in many cases are still continuing. The volume is intended more as a synthesis of recent research than as a review of work already widely published, although critical reappraisals of earlier studies are presented wherever relevant. A contributed volume like this one is not, and cannot claim to be, a comprehensive systematic or regional account of the Quaternary history of the Sahara and Nile. Our aims are to assemble recent evidence from geology, biology, climatology and prehistory, and to examine the prehistoric links between our largest desert and our longest river. The essays in this volume throw new light on early man's response to environmental change in northern Africa during the Quaternary, and in particular during the past 40 000 years for which we have an accurate chronology based upon a growing body of radiocarbon dates.

Our dedication to Bill Bishop, Gilbert Maglione and Bill Morton is not simply in recognition of their distinguished contribution to our understanding of so many aspects of the geology, palaeogeography and geochemistry of Africa. We were personally enriched through having known them as inspiring colleagues and unselfish friends. R.I.P.

During the early stages of this work, we benefitted greatly from the counsel of the late Professor W.W.Bishop as well as from the advice of Professor Glynn Isaac, Dr T.R.Hays and Mr Patrick Carter. Particular thanks go to Mrs Frances Williams for help with the index, and to Mr Dean Oliver for drawing many of the figures. Without the study leave from Macquarie University which enabled Martin Williams to work with Hugues Faure in the C.N.R.S. Laboratoire de Géologie du Quaternaire during 1975, this volume would never have been conceived or written. The leave also allowed us to discuss our ideas in person with many of the contributors, thus making for a more coherent and useful final volume.

Each contributor was invited to submit a translated abstract. Except for Chapters 4, 5 part two and 15, the editors either prepared or translated the chapter summaries. In so doing, we trust that we have not strayed too far from the spirit of each contribution. We also accept responsibility for the English of Chapter 5, and thank our contributors for their good-humoured and often punctual adherence to our guidelines. Our grateful thanks go to Professor Pierre Rognon, Dr Don Adamson and Miss Carol Simpson for help with the summaries and index.

Paris and Marseilles
January 1979

Martin Williams
Hugues Faure

Préface

Une synthèse approfondie et bien à jour sur les milieux quaternaires et l'occupation préhistorique du Sahara et de la vallée du Nil nous semble utile, voire même nécessaire, pour plusieurs raisons.

En effet, la bibliographie scientifique sur la géologie, la biologie et la préhistoire du Sahara et du Nil est très importante mais très éparpillée, et rédigée en plusieurs langues. Cette abondance crée une situation regrettable mais inévitable, car très peu de chercheurs s'efforcent de lire les travaux hors de leur spécialité, par exemple la préhistoire du Sahara ou la palynologie, la paléoécologie des diatomées, la stratigraphie . . . Et quand il fait l'effort d'être pluridisciplinaire, le généraliste constate qu'il ne préserve pas toujours cet esprit critique et rigoureux qu'il a pour sa propre discipline.

En outre, nos idées ont changé au fur et à mesure que nos techniques se sont améliorées. La mise au point en 1948 de la méthode de datation par le radiocarbone a révolutionné nos connaissances sur les variations écologiques au Sahara et dans la vallée du Nil au cours des quarante derniers millénaires. Notre compréhension sera encore meilleure lorsque les datations par le carbone 14 remontant jusqu'à cent mille ans deviendront habituelles alors que, pour l'instant, elles sont encore au stade des promesses.

La tectonique des plaques nous fournit aussi des notions bien plus précises, aujourd'hui, concernant le soulèvement et la fracturation sur le pourtour du haut bassin du Nil. L'analyse des carottes méditerranéennes confirme l'ancienneté de la vallée du Nil et montre en outre les liens très étroits qui existent entre le mouvement vers le Nord de la plaque africaine, la croissance de la calotte glaciaire de l'Antarctique, l'abaissement du niveau marin, et l'assèchement de la Méditerranée vers six millions d'années avant l'actuel. Nous savons depuis longtemps que le Nil pré-pliocène a entaillé une vallée très profonde qui fut ensuite submergée, mais l'explication finale n'est survenue qu'avec la découverte récente de la dessication fini-miocène de la Méditerranée.

Des datations précises et des études locales détaillées de la flore et de la faune fossiles du Sahara et du Nil ont permis de grandes reconstitutions paléogéographiques de cette région à des époques déterminées. L'abondance des gisements néolithiques situés à travers le Sahara a provoqué maintes discussions sur la verdure de notre plus grand désert. Ces spéculations antérieures ont servi, mais

nous pouvons maintenant les remplacer par des notions plus proches de la réalité. Le problème assez épineux de la culpabilité humaine vis-à-vis de la désertification du Sahara n'est pas résolu. Nous pensons ici que les pasteurs néolithiques ont vraisemblablement accéléré la tendance à la dégradation biologique déjà amorcée par l'aridification climatique de l'Holocène moyen. Certes, les données précises sur les variations climatiques au Sahara et dans la vallée du Nil pendant le Quaternaire supérieur nous incitent à nous méfier de ces tristes prophètes qui voient l'action de l'homme dans chaque épisode de sécheresse récente.

Il serait peut-être utile de signaler les buts de ce livre ainsi que ce que nous n'envisageons pas de faire. Chaque chapitre fournit en principe une étude objective et complète des recherches faites sur le terrain, et dont la plupart se poursuivent de nos jours. Ce livre a pour objectif une synthèse des recherches récentes et non une revue d'oeuvres déjà bien connues. Néanmoins, la remise en question des études antérieures est abordée là où cela a paru nécessaire. Une collection d'essais telle que la nôtre n'est pas, et ne peut être, une étude systématique ou régionale de l'évolution quaternaire du Sahara et du Nil. Nos aspirations sont plus modestes, et consistent surtout à réunir les données récentes tirées des études de géologie, de biologie, de climatologie et de préhistoire, et à retracer les liens préhistoriques entre notre plus grand désert et notre plus long fleuve. Les exposés que nous présentons ici aident à comprendre les rapports entre les hommes et les milieux préhistoriques à l'échelle spatiale de l'Afrique du Nord et à l'échelle temporelle du Quaternaire. Tout particulièrement pour les derniers quarante mille ans, nous disposons d'une chronologie précise, établie d'après un nombre croissant de datations au radiocarbone.

La dédicace de ce livre à la mémoire de Bill Bishop, Gilbert Maglione et Bill Morton n'est pas seulement inspirée par leurs remarquables contributions à la paléogéographie, à la géochimie et à la géologie de l'Afrique. Ils étaient pour nous des amis sincères et des collègues dynamiques et nous ressentons tout le privilège que nous avons eu à les connaître. R.I.P.

Les conseils de nos collègues W.W.Bishop, Glynn Isaac, T.R.Hays et Patrick Carter ont facilité la naissance de cette oeuvre. Frances Williams a assisté à la preparation de l'indexe, et Dean Oliver a dessiné la plupart des graphiques: nous les remercions tous deux. Sans l'année subbatique qui donna à Martin Williams l'occasion de s'absenter de Macquarie University et de travailler avec Hugues Faure dans le Laboratoire de Géologie du Quaternaire du C.N.R.S. en 1975, cette oeuvre n'aurait été ni conçue ni achevée. Cette année nous a permis également d'établir des contactes fructueux avec la plupart des auteurs, aboutissant à une oeuvre plus cohérente, et, espérons-le, plus utile.

Exception faite des chapitres 4, 5 (résumé) et 15, nous avons préparé les traductions et les résumés, et nous espérons n'avoir pas trahi l'esprit des participants, que nous remercions tous de leur coopération. Nous remercions Pierre Rognon, Don Adamson et Carol Simpson de leur collaboration avec les résumés et l'indexe.

Paris et Marseille
Janvier 1979

Martin Williams
Hugues Faure

Foreword

It is doubtless in honour of my years that I am privileged to add a few introductory lines to this important work, for my first experience of the Sahara dates back over half a century, 57 years to be precise.

Let me begin by expressing the joy experienced by an old mehariste, who still belongs to the 'age of camels', on discovering this rich collection of ideas and facts. *Transibunt et augebitur scientia* proclaims Cuvier's sundial in the Jardin des Plantes . . .

Yes, indeed, science progresses as the means of research improve. I had for long to work with maps which were mere reconnaissance sketches, and of course without aerial photographs. At that time, we still knew very little, having to content ourselves with 'rough hewing' and 'clearing the ground'. Indeed, the wonder surely is not that we were sometimes wrong, but rather that our inevitable mistakes were not more frequent or more serious . . .

Our fragmentary and solitary discoveries, gleaned during the course of our camel journeys, were by their very nature exploratory. Times have changed, for today veritable battalions of researchers, no longer ill-equipped, and working for the most part in teams, are now able to launch an intensive attack on the problems in the field.

The specialist has at long last entered the arena, and the present volume is welcome and eloquent witness to such an outcome, and a cause for congratulation.

Nevertheless, we would be unwise to delude ourselves that the time is ripe for a definitive account. The Sahara is as large as the ocean, and the sites studied in depth remain mere pin-pricks upon its surface. Many issues remain unresolved, notably the detailed chronology of climatic changes and of Pleistocene stratigraphic sequences. The working hypothesis still has a major role to play, and honesty requires us to recognise this fact.

This state of affairs should be no cause for complaint; rather, it is a powerful incentive, nay, inspiration, to carry out further detailed field investigations, for it is stone by stone, set one upon another, that a wall is built. Even though the base of our wall is now broader and firmer than heretofore, the building is still very far from completion.

Despite its very broad title, this work does not set out to be a comprehensive account or treatise, but simply, and more usefully, a collection of essays devo-

ted to the Quaternary landforms, sediments, climates and prehistory of the Sahara. The aim of this volume is to present the results of recent research and to evaluate the status of a number of current problems, without seeking to propose premature generalisations, let alone definitive conclusions based on local studies.

It is so easy and so tempting to believe that we have found 'The Key' or 'The Solution'. The presumption that there is only one answer to a problem – that advocated by the interested party, runs counter to our experience of the natural world, where several keys may fit the same lock, so that no one theory, however original or attractive, can ever claim to represent more than a very modest and provisional part of reality.

There are still far too many local investigations that need to be carried out in the Sahara, and far too many cautious regional conclusions still to be drawn, before we can even begin to think of 'The' Sahara as a uniform and autonomous entity.

This is, of course, the goal of the essays in this volume, thanks to which we have made a new and significant advance in our knowledge, and that is saying a great deal. We, therefore, have good reason to be grateful to the two scientific editors and their colleagues for such a useful piece of work.

The volume is limited in its geographical scope, for it does not deal with the whole Sahara. The western Sahara, in particular, seems to be less well covered than the other regions. However, we will soon have available the results of the excavations at Tichitt-Aghrejit directed by H.J.Hugot, of a major work on the Atlantic littoral of the Sahara edited by N.Petit-Maire, and of new data on the shell-middens around Nouakchott (N.Lambert et al.).

We can extend our knowledge of the region discussed in this book eastwards with *The environmental History of the Near and Middle East since the last Ice Age* (W.C.Brice, ed., 1978), and further still with *The Prehistory and Palaeogeography of the Great Indian Desert* (B.Allchin, A.Goudie & K.Hedge, 1978).

The vast north-tropical Eremian zone which extends from the Atlantic to India and Central Asia (although botanists distinguish 'Saharo-Sindian' from 'Irano-Touranian') has today become the focus of a peaceful offensive in grand style. Needless to say, we will never know everything, but we already know a great deal, and we learn more every year.

I conclude with the deep joy of an old Saharan of yesteryear, happy indeed to see so much of his ignorance and fumbling replaced by solidly founded inferences and already by occasional certainties . . .

Théodore Monod

Avant-propos

C'est sans doute au seul privilège de l'âge mon premier contact avec le Sahara remonte à plus d'un demi-siècle, 57 ans pour être précis, que je dois l'honneur de pouvoir apporter à cet important ouvrage quelques lignes d'introduction.

Et pour dire, d'abord, la joie qu'éprouve un vieux méhariste, appartenant encore à la 'période cameline', à découvrir ce riche assemblage de faits et d'idées; TRANSIBUNT ET AUGEBITUR SCIENTIA proclame le cadran solaire de la maison de Cuvier, au Jardin des Plantes . . .

Eh oui, la science progresse, avec l'amélioration des conditions matérielles de la recherche: j'ai dû longtemps travailler en guise de cartes avec de simples 'eroquis de reconnaissance', et sans photos aériennes, évidemment . . . On savait alors, bien sûr, peu de choses encore, il fallait se contenter de 'déblayer' et de 'dégrossir' et, au fond, l'étonnant n'est sans doute pas tant que l'on se soit parfois trompé mais plutôt que ces inévitables erreurs n'aient été ni plus fréquentes, ni plus graves . . .

Nos sommaires constatations solitaires, glanées au long de nos filiformes itinéraires chameliers, relevaient encore d'une méthode redoutablement extensive: aujourd'hui tout a changé et de vrais bataillons de chercheurs, groupés le plus souvent en équipes et désormais adéquatement outillés, peuvent se livrer à une attaque intensive des sites et des problèmes.

La parole est maintenant, enfin, au spécialiste et déjà les résultats affluent, comme en témoigne avec une particulière éloquence, le présent volume. On ne peut évidemment que s'en féliciter.

Il serait cependant imprudent d'imaginer que l'heure des synthèses véritables a déjà sonné: le Sahara est d'une ampleur océanique, les lieux sérieusement étudiés y demeurent punctiformes, il subsiste encore nombre d'incertitudes, notamment dans le détail des chronologies paléoclimatiques ou des stratigraphies du Pléistocène. Il faut l'avouer: la part de l'hypothèse reste nécessairement très considérable, on doit honnêtement le reconnaître.

Non certes pour le regretter ou s'en plaindre, mais pour y découvrir de nouvelles raisons de sans cesse intensifier le travail sur le terrain: c'est pierre à pierre, assise par assise que se construit le mur. Mais si la base de ce dernier se fait aujourd'hui plus épaisse, et plus solide, on est encore bien loin d'en avoir achevé l'édification.

Malgré son titre, très général, il ne s'agit donc nullement d'une somme ou d'un traité mais, plus simplement, et plus utilement, d'un recueil d'articles consacrés au Quaternaire saharien (géomorphologie, stratigraphie, paléoclimats, occupations humaines, etc), destinés à exposer les résultats de recherches récentes, en fait l'état actuel d'un certain nombre de questions, mais évidemment sans vouloir – comme sans pouvoir – aboutir ni même à des conclusions locales définitives ni à des généralisations à coup sûr prématurées.

Il est si facile et si tentant de croire que 'la' clef est découverte, que 'la' solution est trouvée, comme si d'ailleurs il ne pouvait y en avoir qu'une, précisément celle que son défenseur préconise, alors que dans les choses de la nature, il arrive qu'une même serrure admette plusieurs clefs, et que, par conséquent, une seule théorie, fut-elle la plus séduisante, ou la plus nouvelle, ne puisse prétendre à représenter davantage qu'une modeste vérité partielle et provisoire.

Il reste beaucoup trop de recherches locales à effectuer au Sahara, beaucoup trop de prudentes conclusions *régionales* à formuler avant de pouvoir légitimement songer à parler 'du' Sahara comme d'une entité autonome et homogène.

C'est bien entendu le but auquel tendent les présentes études et grâce à elles la connaissance aura connu de nouveaux et substantiels progrès et c'est beaucoup.

Aussi doit-on savoir gré de leur si utile travail aux deux éditeurs (*anglico sensu,* of course) et à leurs collaborateurs.

Géographiquement aussi, l'ouvrage avait ses limites, car il ne concerne pas tout le Sahara. En particulier le Sahara occidental s'y trouve, semble-t-il, moins bien représenté que les autres: on disposera d'ailleurs bientôt des résultats des fouilles de Tichitt-Aghréjit (H.J.Hugot *et al.*), d'un important volume sur le Sahara atlantique (N.Petit-Maire, éd.), d'observations nouvelles sur les kjökken de la région de Nouakchott (N.Lambert, etc.).

La région couverte par ce livre se voit, d'autre part, prolongée vers l'Est par 'The environmental History of the Near and Middle East since the last Ice Age' (W.C.Brice, ed., 1978) et, plus loin encore, par 'The Prehistory and Palaeogeography of the Great Indian Desert' (B.Allchin, A.Goudie & K.Hedge, 1978).

La grande zone érémienne nord-tropicale, qui s'étend de la côte atlantique à l'Inde, et même à l'Asie centrale (bien que le botaniste tienne à distinguer 'saharo-sindien' et 'irano-touranien'), se trouve donc aujourd'hui l'objet d'une pacifique offensive de grand style: nous ne saurons jamais tout, cela va sans dire, mais nous savons déjà beaucoup, et chaque année davantage.

Profonde joie pour un vieux saharien 'd'avant hier', si heureux de voir tant de ses ignorances et de ses balbutiements remplacés par des conclusions solidement étayées, parfois déjà par des certitudes.

Théodore Monod

Part One: The Sahara
Première partie: Le Sahara

In keeping with the original Arabic term for wilderness, the word Sahara brings to mind vistas of emptiness, of endless sand dunes, and of lost oases. Our sense of wonder is heightened by reports of rock paintings, of defunct lakes and rivers, of fossil hippo and Nile perch, of prehistoric camping sites complete with pottery, bone harpoons and stone arrow heads . . . in the centre of what is now our largest desert, prompting us to enquire how the Sahara as we now know it first came into being.

The physiographic setting of both the Sahara and the Nile basin is related to northward movement of the African plate leading, directly or indirectly, to swell uplift, volcanism and rifting in East Africa, to volcano-tectonic activity in Tibesti, the Hoggar, Jebel Marra and the Aïr, and to the formation of major sedimentary basins in Libya, Sudan, Chad and Niger.

In the introductory chapter, A.T.Grove describes the close relationship between geological history and major landforms, after which Mainguet, Canon and Chemin make effective use of remote-sensing data to analyse the influence of wind regime and relief upon Saharan sandflow patterns.

M.F.Talbot focuses our attention upon the fixed dunefields of the Sahel and West Africa. He argues that reactivation of dunes between 20 000 and 12 000 B.P. reflects a decrease in rainfall and stronger Trade Winds rather than any significant change in atmospheric circulation. During the humid interval from 12 000 to 8 000 B.P., the rivers and lakes of the Sahel received runoff from the Saharan uplands as well as from the summer monsoonal rains. With progressive reduction in runoff from their northern slopes, the rivers and lakes of the Sahel became seasonal, often drying out completely after 4 000 B.P.

The combined stratigraphic and palaeoecological studies of M. and S.Servant in the Chad basin add significant detail to Talbot's account, and extend it back into the late Tertiary, which is when the Sahara first became truly arid. Reconstructions of the precipitation-evaporation regime in the Chad basin over the past 40 000 years reveal a complex sequence of wetter and drier, cooler and warmer phases. For example, the diatom flora indicates lower minimum lake temperatures during 26 000-20 000 and 12 000-7 000 B.P., both of which coincide with times of high lake level.

More compelling than the depositional evidence of late Tertiary aridity is

the sub-fossil pollen legacy of earlier plant associations which Maley reviews in some detail. The early Tertiary flora of the Sahara remained equatorial in character until the late Eocene. From Oligocene until Miocene times, the Sahara was hot and seasonally-moist in contrast to Southern Africa and Zaire, which were semi-arid to arid. Desiccation of the Sahara began during the late Miocene, and was accentuated during the early Pliocene. This trend towards aridity seems to be linked to global cooling, for the early Pliocene was also a time of ice-cap expansion in both hemispheres. The Pliocene flora of the Sahara came from two distinct sources, both of which were pre-adapted to aridity. The Saharan holarctic flora originated in the drier parts of Asia during the Tertiary, and the xerophytic tropical flora emanated from the 'Rand Flora' of the Cape early in the Tertiary.

The geomorphic impact of climatic changes upon the mountains of the Sahara and its borders is traced in some detail by Messerli and Winiger, who evaluate the effects of past and present glacial and periglacial processes, and by P.Rognon, who discusses the changing pattern of late Quaternary piedmont sedimentation.

Attempts at reconstructing environmental changes in the Sahara are often hampered by a lack of datable material and by a dearth of fossils. Balout and Roubet approach this problem as prehistorians. They point out that analysis of prehistoric stone tool assemblages may be a useful adjunct to stratigraphic investigation, and so help our interpretation of Saharan palaeoenvironments.

The historical record offers equally valuable insights into the pattern of shorter term climatic oscillations in the Sahara and adjacent areas. Sharon Nicholson assesses the information contained within African chronicles and travellers' accounts, and concludes that the southern borders of the Sahara were perceptibly wetter during the 16th to 18th centuries, at about the time of the Little Ice Age in northwest Europe. She also cites limited data in support of wetter conditions along the northern margin of the desert at this time, possibly related to a greater incidence of rainbearing depressions in spring and autumn.

In the light of the geological and biological evidence reviewed in these eight chapters, it is reasonable to conclude that the gross characteristics of the modern Sahara reflect the interplay of tectonic, climatic and geomorphic factors at varying scales in time and space. A corollary to this is that man did not create the desert, although this is not to deny his very real influence upon the plant and animal life therein.

D'après son sens originel, le mot arabe Sahara désigne des régions inexplorées et désertiques. Il évoque un paysage vaste et vide, à dunes interminables avec de rares oasis perdues dans l'immensité du désert. Or, à notre grand étonnement, nous trouvons dans ce milieu aride, de belles peintures rupestres, des lacs et des fleuves fossiles, des restes d'hippopotame et de perche du Nil, des gisements préhistoriques contenant des tessons de poterie, des harpons en os, des pointes de flèches . . . Toutes ces découvertes nous amènent à nous demander comment s'est créé le Sahara que nous connaissons de nos jours.

Le contexte morphologique du Sahara et du bassin du Nil est lié au mouvement vers le nord de la plaque africaine. Ce mouvement est associé, directement ou indirectement, au soulèvement, au volcanisme, et à la formation des rifts en Afrique de l'Est; à l'activité volcanotectonique au Tibesti, au Hoggar, au Jebel Marra et dans l'Aïr; et à la formation de grands bassins sédimentaires en Libye, au Soudan, au Tchad et au Niger.

Dans son chapitre d'introduction, A.T.Grove décrit les liens étroits qui existent entre l'évolution géologique et la morphologie. Par la suite, M.Mainguet, L.Canon et M.C.Chemin utilisent les images satellites et les photos aériennes pour étudier les rapports entre le régime des vents, le relief, et les courants de sable au Sahara.

M.F.Talbot fait ensuite un exposé sur les dunes fixées du Sahel et de l'Afrique de l'Ouest. D'après les arguments qu'il présente, la réactivation des dunes entre 20 000 et 12 000 B.P. n'est pas une conséquence d'un grand changement de la circulation atmosphérique, mais provient surtout d'une augmentation de l'intensité des alizés et d'une diminution de la pluviosité à cette époque. Au cours de la phase humide entre 12 000 et 8 000 B.P. les fleuves et les lacs perénnes du Sahel ont reçu des écoulements provenant des massifs sahariens ainsi que des pluies estivales en provenance du Sud. Puis une diminution progressive du ruissellement sur les flancs de ces massifs septentrionaux a entraîné une modification du régime lacustre et fluvial saisonnier, puis un assèchement total après 4 000 B.P.

Les études stratigraphiques et paléoécologiques effectuées par M. et S.Servant dans le bassin du Tchad fournissent des données plus précises encore, et remontent jusqu'à la fin de l'ère tertiaire, époque à laquelle l'aridité est apparue. La

reconstitution des rapports précipitation-évaporation dans le bassin du Tchad pendant les quarante derniers millénaires met en évidence des variations climatiques assez complexes oscillant entre l'humide et l'aride, le chaud et le froid. La flore diatomitique montre, par exemple, que les températures minima étaient plus basses vers 26 000-20 000 et vers 12 000-7 000 B.P., époques qui coïncident avec de hauts niveaux lacustres.

Plus frappants encore que les dépôts témoignant de l'aridité fini-tertiaire, sont les pollens dérivés des anciennes associations végétales décrites en détail par J. Maley. La flore tertiaire du Sahara est restée de caractère équatorial jusqu'à la fin de l'Eocène. De l'Oligocène au Miocène, le Sahara était chaud et humide pendant au moins une partie de l'année, alors que l'Afrique du Sud et le Zaïre étaient au contraire arides ou semi-arides. L'assèchement du Sahara a commencé au cours du Miocène supérieur et s'est accentué pendant le Pliocène inférieur. Cette tendance vers l'aridité semble être liée à un refroidissement global, car le Pliocène inférieur a été aussi l'époque où les calottes glaciaires se sont développées dans les deux hémisphères. La flore pliocène du Sahara provient de deux sources bien définies, qui étaient toutes les deux pré-adaptées à l'aridité. La flore holarctique du Sahara dérive de la flore tertiaire des régions arides de l'Asie, et la flore tropicale xérophytique provient de la flore du Rand d'âge tertiaire inférieur.

Les effets morphologiques des changements climatiques dans les montagnes du Sahara et de ses bordures sont étudiés en détail par Messerli et Winiger, qui évaluent les effets des processus glaciaires et périglaciaires actuels et inactuels sur le modelé, et par P.Rognon qui analyse les modalités de la sédimentation sur les bordures de ces massifs vers la fin du Quaternaire.

La reconstitution des variations écologiques au Sahara est souvent rendue difficile par le manque de dépôts contenant des fossiles ou de la matière organique qui puissent être datés. L.Balout et C.Roubet ont abordé ce problème en tant que préhistoriens. Ils montrent en effet que l'analyse des ensembles d'outils préhistoriques est utile pour les études stratigraphiques et donc pour l'interprétation des paléoenvironnements sahariens.

Les renseignements historiques nous fournissent également des données utiles quant aux modalités des oscillations climatiques de courte durée dans le Sahara et sur ses bordures. Sharon Nicholson examine l'information fournie par les chroniques africaines et les récits de voyageurs. Elle en déduit que les bordures sud du Sahara étaient notablement plus humides pendant le seizième jusqu'au dix-huitième siècle, donc à peu près synchrones du 'petit âge glaciaire' de l'Europe du NW. Elle apporte aussi des informations plus limitées concernant l'existence d'un climat plus humide sur les bordures septentrionales du désert à cette époque, liée probablement à une plus grande fréquence des dépressions pendant les mois de printemps et d'automne.

Compte-tenu des données géologiques et biologiques présentées dans ces huit chapitres, il est certain que les grands traits du Sahara actuel sont hérités des mécanismes tectoniques, climatiques et morphologiques, qui ont joué un rôle variable dans le temps et l'espace. La conclusion qui en ressort est que l'homme n'a certainement pas créé le désert, quoiqu'il ait eu une influence importante sur sa flore et sa faune.

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1

Geomorphic evolution of the Sahara and the Nile

Evolution du paysage saharien et du bassin du Nil

Les grandes lignes des côtes dans cette région sont le résultat de l'ouverture de l'Atlantique au début de la période triasique, suivie par la formation du bassin de la Méditerranée avant la fin de la période miocène, et la séparation de la péninsule arabique pendant la dernière partie du cénozoïque. Les modifications des rivages quaternaires ont été plus marquées en Afar ainsi qu'en Mauritanie et au Sénégal. Aujourd'hui, la plupart des activités tectoniques se situent dans les régions montagneuses et autour du système de 'rift valleys' au sud-est.

Les roches sous-jacentes comprennent des roches sédimentaires glaciaires ordoviciennes. Les grès datant de la période paléozoique et des périodes plus récentes ont constitué des sources de sable pour la formation des ergs et jouent un rôle important dans la formation des escarpements. Les grès et calcaires mésozoiques, disposés horizontalement ou faiblement inclinés, forment des plateaux étendus et peu élevés, couverts d'encroûtements et entourés par des escarpements longs et peu élevés. La datation isotopique des roches volcaniques permet des études quantitatives pour établir la vitesse d'érosion et de sédimentation, particulièrement en Ethiopie. Depuis la régression de la Tethys au début de la période cénozoique, l'évolution du paysage saharien a entraîné l'érosion des régions plus élevées et la sédimentation dans les bassins peu profonds, dans des conditions qui deviennent plus arides mais avec des fluctuations marquées dans la période quaternaire.

L'érosion des roches sédimentaires plus jeunes a exhumé un paysage d'inselbergs de même que des terrains glaciaires de l'Ordovicien. Le Nil en Nubie est en train de se surimposer dans les roches cristallines, soubassement des grès nubiens. Tracer l'évolution de cette rivière est difficile en raison des lacunes dans les vestiges sédimentaires et aussi des problèmes qui existent dans l'interprétation des dépôts alluviaux.

1.1 LIMITS AND EXTENT

The region comprising the Sahara and the Nile occupies about half of the entire African continent (Fig. 1.1). On three sides it is bounded by the sea and by the Atlas ranges; its southern limits are much less definite. For the purposes of this chapter, we include the lower Senegal river, the great northward loop of the Niger, Lake Chad, the Sudd, Ethiopia and Somalia, so that a great circle passing through Dakar, 15° N, and the mouth of the Juba river almost on the equator is a convenient boundary. This leaves out of account the headwaters of the White Nile on the Lake Plateau of East Africa, which are discussed in detail in chapters 9 and 14.

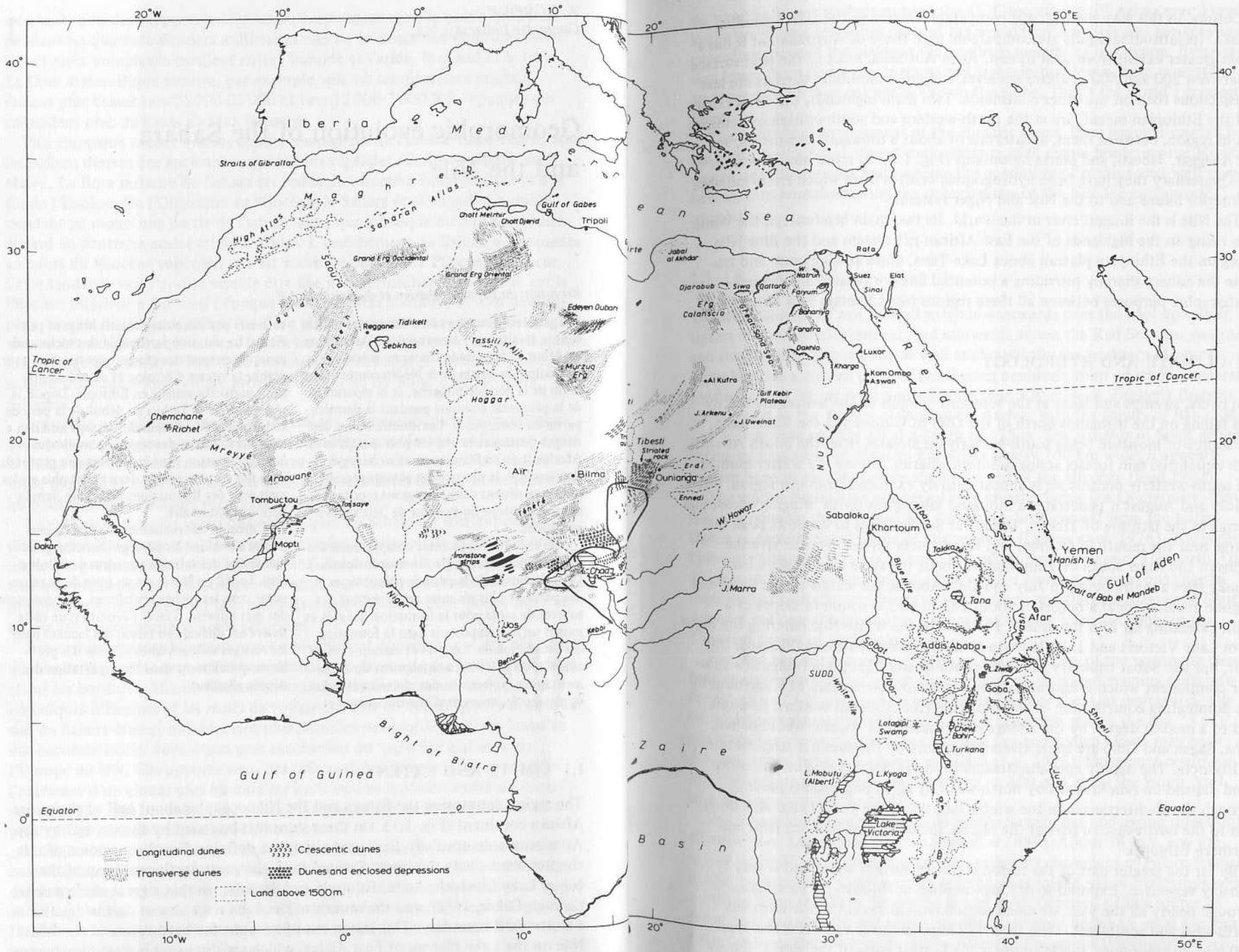


Figure 1.1 Physiographic map of the Sahara and the Nile

Defined in this way the region is comparable in area to the USA including Alaska. Its latitudinal limits are comparable with those of Australia but it has a much greater extent from west to east. As in Australia, most of the land surface is between 200 and 500 m above sea-level, and great mountain barriers are less conspicuous than on the other continents. Two main highlands, the Atlas ranges and the Ethiopian massif, are at the north-western and south-eastern extremities of our region; between them, at intervals of about a thousand kilometres, are the Ahaggar, Tibesti, and Marra mountains (Fig. 1.1). In more humid periods of the Quaternary they have been hydrographic centres from which rivers radiated to interior basins and to the Nile and Niger systems.

The Nile is the longest river in the world. Its two main headwaters, the White Nile rising in the highlands of the East African rift system and the Blue Nile rising on the Ethiopian plateau about Lake Tana, unite at Khartoum and traverse the Sahara thereby providing a potential link for palaeoclimatic and stratigraphic purposes between all these regions (see Chapters 9 to 15).

1.2 CLIMATE AND HYDROLOGY

The rivers, swamps and lakes at the southern margins of the Sahara are fed by rain falling on the highlands north of the Gulf of Guinea and the Zaire basin, the source of moisture being south-westerly air streams from the South Atlantic, with equatorial rain forests acting as intermediaries. During the winter months the south-westerly oceanic air is almost entirely excluded from our region, but in July and August it penetrates a thousand kilometres north bringing occasional storms to the latitude of Tibesti. The lower Senegal rises to reach its peak discharge near the mouth in October and floodwaters spread over the riverine plains of the Niger south of Tombouctou about the same time. Lake Chad usually rises a metre between July and December as the waters of the Shari and Logone accumulate at a height of about 282 m on the southern slopes of a basin extending far into the desert. The flow of the White Nile entering the Sudd from Lake Victoria and Lake Mobutu is fairly evenly distributed through the year, but the Sobat tributary, draining south-western Ethiopia brings in a summer component which is enormously accentuated downstream of Khartoum by the dominating contribution of the Blue Nile (the Abbai of western Ethiopia), and to a modest degree by the Atbara or Tekazze. The Awash, Webi Shebeli, Juba, Sagan and Omo are lesser rivers fed mainly by the summer tropical rains of Ethiopia. The mainly episodic streams from the Atlas region on the other hand depend on rain brought by north-westerly air in depressions moving through the Mediterranean in the winter months of the year. These also bring rain to the north-eastern part of the region, including the Red Sea Hills and northern Ethiopia.

By far the greater part of the region is free of surface water and is very sparsely vegetated. Exposed to dry, descending, north-easterly air streams through nearly all the year, its mean annual rainfall except in the extreme north-west and south-east is less than 400 mm, and over vast areas less than 100 mm. Furthermore, this is amongst the hottest parts of the world. Rarely

do temperatures elsewhere exceed the 45 °C recorded at El Azizia near Tripoli in the north, and few other parts of the world have mean annual temperatures exceeding those of the plains at the southern margins of our region. Evaporation losses from free water surfaces and transpiration losses from vegetated areas are greater than anywhere else on the globe. This is the world's greatest desert.

The latitudinal arrangement of the climatic zones, from summer rainfall in the south to the Sahel, desert, and winter rainfall region bordering the Mediterranean, is rather regular and presents the possibility of making east-west correlations, thus complementing the potentialities of the Nile for north-south correlations.

1.3 THE COASTS

The tropical zone of low rainfall extends westwards over the cool upwelling waters of the Canaries current, and eastwards across the Red Sea into Arabia and further east. Structurally as well as climatically the northern Maghreb resembles the southern parts of the Iberian peninsula from which it is separated by straits only 20 km wide and no more than 320 m deep. Ethiopia finds its counterpart in the Yemen of south-west Arabia, with the Straits of Bab el Mandeb 35 km wide and the sill at a depth of 125 m. The isthmus of Suez, giving access by land through Sinai to Euro-Asia is only 160 km wide; it appears to have been in existence since about the end of the Miocene (Said 1962).

The marine limits have not varied very greatly during the Quaternary, though it is just possible that the Red Sea trough has been cut off from the Indian Ocean at certain glacial stages of low sea-level (Deuser et al. 1976). The earlier Cenozoic history of the ocean borders is much more dramatic. The north Atlantic opened in Triassic and Jurassic times as the North American continental mass shifted westwards; similarities in the fauna and flora of Africa and South America indicate the separation further south came later, probably in the Turonian period of the Cretaceous.

The Red Sea and the Gulf of Aden on the other side of the region are clearly fault-bounded troughs of which the margins can be traced running deep into the interior of Ethiopia and forming the borders of the Afar depression. The two continental areas of Africa and Arabia separated within the last 23 m.y. and a marine connection between the Red Sea and Indian Ocean may have come as late as some 3.5–4 m.y. ago (Hsü et al. 1976). Movement continues with faulting recurring into the Holocene in Afar and along the Wonji fault belt further south (Mohr 1973).

It is now widely accepted that the Mediterranean has undergone catastrophic changes since Late Miocene times (Hsü et al 1977). About 14 m.y. ago the mountain building associated with the northward movement of Africa formed a barrier between the Mediterranean and the great inland sea of Paratethys which stretched from the Black Sea to the Sea of Aral. Deprived of this source of freshwater and sink for salt water, the Mediterranean became a great evaporating basin for sea-water entering from the Atlantic. Enormous thicknesses of salt

were deposited and then at a later stage, when flow from the Atlantic ceased some 6.5 m.y. ago, the sea-floor became a great salt desert. Rivers entering the basin cut deep gorges, that of the Nile extending as far upstream as the First Cataract at Aswan (see Chapter 11). Animals were able to migrate between Africa and Europe and plants became adapted to the arid conditions of the basin. Flooding by sea water took place on more than one occasion and minor basins in the eastern Mediterranean were at times occupied by brackish water, possibly coming from Paratethys, before the final inundation at the beginning of the Pliocene.

Isostatic readjustments caused subsidence in the vicinity of the Nile delta and tectonic activity has continued on the Mediterranean floor and along its coasts up to the present. As a result the coastal forms related to Quaternary sea level changes are not found at uniform heights today. The raised shorelines of the Maghreb have received much attention since the end of the last century, but more attention has been paid in the last two decades to the lower Atlantic coasts of Mauritania and Senegal and to the sedimentary record provided by the Nile delta.

1.4 EARLY EVOLUTION OF THE STRUCTURE AND RELIEF

Very ancient and very new structures and landforms are found in some cases side by side in this region. The Afar depression of Ethiopia is one of the most unstable parts of the world, with several active volcanoes, and the faulted southern margins of the Atlas region are liable to severe seismic activity. Vast areas of sediments in the great structural basins of the Sahara have been shaped by events of Late Quaternary times. But the structures and the major features of the relief over much of the desert are ancient and have scarcely changed over long periods of geological time. Much of the west consists of a craton, one of the old stumps of the continent, comprised of rocks folded and crushed 2 000 m.y. ago. The gneisses, granites, quartzites and phyllites were planed off and deeply weathered early in the Cambrian period about 525 m.y. ago, then, at a time when eastern USA fitted against Morocco and Mauritania, the sea advanced eastwards over the region and marine sediments accumulated.

1.5 ORDOVICIAN GLACIATION

From palaeomagnetic evidence it would appear that the South Pole was located in the early Palaeozoic about the centre of our region. During the 1960s evidence was accumulated by French geologists which showed that the Sahara was glaciated in Ordovician times (Beuf et al. 1971).

In the Tassili n'Ajjer, for instance, the glacial surface cuts across a greenish siltstone containing trilobites and other Ordovician marine fossils, indicating cold marine conditions. The glacial surface was covered by silts and sands which have been largely stripped away leaving remarkably well preserved striations, crescentic gouges and erratic boulders. The glacial lineations are even apparent

on satellite imagery (Fairbridge 1970). Outwash from the ice-cap was laid down over the north-western Sahara and was eventually converted into sandstone as later marine and continental sediments accumulated on top of them.

1.6 SAHARAN SANDSTONES

The glacial beds and succeeding formations of Silurian and Carboniferous age were folded in the earth movements called Hercynian in Europe. Surviving masses form great escarpments north and east of Ahaggar, steep-sided massifs supporting the volcanic ranges of Tibesti and sandstone plateaux extending south-east to Erdi and Ennedi. In the Jurassic period, sandstones and limestones accumulated extensively in the Horn of Africa.

Sediments eroded from the Palaeozoic formations contributed to the sediments that accumulated in continental basins in Triassic and early Mesozoic times to give the rocks known collectively as the Continentale Intercalaire in the western Sahara and as the Nubian Sandstone in the lands bordering the Nile. They are distinguished from the Lower Palaeozoic rocks in containing great quantities of fossil wood and the remains of fish and reptiles.

Sandy sediments derived from these sandstones and accumulating in Cenozoic basins are the main sources of the material forming the sand seas, the ergs, shaped by the wind in arid stages of the Quaternary.

1.7 MARINE INCURSIONS

As the Southern Atlantic opened in early Mesozoic times, Africa and South America moved apart, first separating in the extreme south and finally in the region of the Bight of Biafra. Crustal melting gave Jurassic granites which today form the bastions protecting the Jos Plateau and the prominent rocky peaks of Aïr. A rift developed for a time, running north-east from the Biafran gulf along the line of the Benue to the Ounianga area south of Tibesti. The sea flooded the rift and spreading northwards into the Saharan region between Ahaggar and Tibesti probably linked up with seas extending south from Tethys. The central Sahara was at that time a shallow equatorial sea in which marine clays and limestones accumulated. They have since been stripped away from wide areas but extensive beds remain that are usually horizontally disposed or only gently folded and tilted, except in the Benue valley and south-east Nigeria where they were affected by partial closure of the rift.

For the most part, the Mesozoic continental and marine formations form low plateaux and *hamadas* of bare rock, or plains thinly mantled with sand and pebbles, called *serir* or *reg*. Commonly they are bounded by long, low escarpments. In some places they have been elevated into domes or form basin structures as a result of mid-Cenozoic earth movements. Where they have been stripped away, the sub-Cretaceous surface has been revealed, with inselbergs and koppies which may have been little altered since these very early times.

By the early Cenozoic, seas still occupied wide areas in the north and north-

west as well as the Chad basin and Somalia. The waters retreated and by the Miocene the coast had reached the approximate position of the present Mediterranean coastline. The Atlas region, folded in Cretaceous and Early Cenozoic times as the African plate pushed north, was uplifted in the Miocene and Pliocene, its denudation yielding arenaceous sediments that accumulated in basins to the south.

At the southern end of the Red Sea, vast quantities of alkaline basalts were extruded in the Cenozoic over a surface planed across crystalline basement and Jurassic sedimentary rock. Upwarping, possibly in Pliocene and Plio-Pleistocene times produced the broad Afro-Arabian dome which fractured to give the triple junction of the Red Sea, Gulf of Aden and East African Rift (see Chapters 9 and 10). To the west downwarping took place in the vicinity of the Albertine rift and in what is now the southern part of the Sudan Republic, with rivers bringing in sediments particularly from the east and south (Chapters 9, 10 and 14).

Another important volcanic centre was Tibesti. Volcanoes remain active in the Afar depression and activity has not entirely ceased in the Toussidé area and in some other parts of Tibesti.

1.8 CENOZOIC EROSION AND DEPOSITION

Since the early Palaeozoic, the South Pole had moved south relative to Africa, and in the early Cenozoic the equator is believed to have been still about 10° to 15°north of its present position. The South Atlantic was narrower than today, global relief was increasing, but global temperatures were high and climatic zoning less marked than at the present time. The early Cenozoic was probably a period of deep weathering, especially in the southern Saharan region, and rapid erosion was restricted to the Atlas and Ethiopian highlands. Attempts have been made by McDougall et al. (1975) to assess the rate of denudation in the headwaters of the Blue Nile and Tekazze (Atbara) in Ethiopia (see Chapter 9). Basing their calculations on dates of about 23.5 m.y. for the extrusion of the top flow of plateau basalts in western Ethiopia they calculate the rate of removal of material over the period since then, checking their estimates of the amount of erosion against the yield of sediment, most of which is assumed to have come to rest in the Nile delta. They calculate that the mean rate of lowering of the surface over the past 23.5 m.y. was around 15 mm per thousand years which, as they note, is a very low figure for an active region of high relief, only about one tenth or one twentieth of the present rate. From this they are led to conclude that episodic uplift was interspersed with prolonged stable intervals, and this finding is likely to be widely applicable.

The progress of sedimentation in Late Cenozoic times has been studied in some detail in the Turkana basin which lies between the Ethiopian and Kenyan updomings. It came into existence in Miocene times and was faulted in the early Pliocene, since when volcanic, fluvial and lacustrine material have accumulated in a subsiding half-graben reaching a thickness of over 950 m at the northern end of the lake (Fitch & Vondra 1976). These sediments are derived from the

Omo valley which originates some 80 km south of Addis Ababa, roughly 600 km north-east of the Omo delta. The sediments on the east side of the lake are about 325 m thick; the streams entering from the east are short, with the exception of an overflow from the Stephanie basin which has at times been fed from Lake Abaya and Chamo by way of the Sagan river, but the sediments from this direction were probably trapped by Chew Bahir (Stephanie) where it is suspected that they are several hundreds of metres thick. The Turkana basin sediments contain rich fossil faunal assemblages, including hominids. Furthermore they afford excellent opportunities for dating and tracing evolutionary sequences and landscape changes in detail through time. The sedimentary successions are subdivided by layers of volcanic tuff which are traceable as marker horizons over extensive areas and have been dated in several instances by K-Ar and palaeomagnetic reversal analyses. The tuff layers are not continuous, there being only ten in the area east of Lake Turkana as compared with 120 in the Omo sediments. Each layer defines an ancient landscape and the presence of pollen allows attempts to be made to reconstruct the palaeoenvironment. It appears that the vegetation of the lower Omo 2 m.y. ago was not very different from that of the present day, with shrubs and trees and grassland on the plains, and with forest near the main streams and in the mountains (Bonnefille 1976).

1.10 EARLY HISTORY OF THE NILE VALLEY

Away from the volcanic areas, dating of the continental deposits and the erosion surfaces on the intervening uplands is extremely uncertain so that the Cenozoic history of landscape evolution is known only very sketchily over most of the Sahara. For much of the Cenozoic era the climate was probably less arid than at present but the Nile was the only deeply incised valley flooded by the transgression in the Mediterranean at the beginning of the Pliocene and the northern Sahara may already have been semi-arid by that time.

A proto-Nile is visualised by Berry & Whiteman (1968) as having been initiated on a surface cut across the Nubian formation in the central Sudan and flowing northwards to a Cenomanian Sea which extended south from Tethys as far as Aswan (Chapter 11). North of the Sabaloka gorge, which corresponds with the highest cataract about 60 km downstream of the Blue and White Nile confluence, a formation known as the Hudi Chert indicates the existence of a freshwater lake in the early Cenozoic (see also Chapter 9). As the sea retreated north in Oligocene times so the Nile cut down through the Chert and the Nubian formation. The contact between the basement and the sedimentary cover is highly irregular with a relief of 400 m and more and where the river reached the crystalline basement its course was controlled in detail by the joints and faults in igneous and metamorphic rocks of the Basement Complex (Chapter 10). Superimposition of the drainage may well explain such features as the Sabaloka Gorge where the river cuts across a ring complex, giving hills of resistant rock, instead of following a course to one side or the other. Where the Nubian sandstone was not penetrated, the Nile formed a wider trough with extensive pediments stretching a few tens of kilometres away from the river and overlooked by scarps some 50 m high.

Some writers such as Butzer & Hansen (1968) and de Heinzelin & Paepe (1964) regard the Nile as having become an integrated river system at a later stage with modern hydrographic conditions not fully established until the Middle Pleistocene, the Paleo-Sudd maintaining an internal drainage system and the Howar basin of northern Sudan draining towards the Red Sea possibly as late as that time (see also Chapter 9). However Butzer & Hansen would agree that the Nubian Nile is of very great antiquity having followed approximately the course of the present river from the Sudanese border to the course below Aswan since Pliocene times. As preservation of all but Late Pleistocene deposits is poor outside the tectonic basins, regional correlation of the sequence of events is difficult to trace over the 70 m.y. of the Cenozoic. Indeed there is still disagreement as to the significance of the geomorphic and sedimentary record over the last 25 000 years (see Chapter 11) and since the late Pleistocene record of Lower Nubia is now lost beneath the artificial lake held back by the High Dam, it may be that the lacustrine records of Ethiopia and East Africa (Chapters 14 and 15) are more likely to throw light on the origin of the Nile terraces in Egypt and Nubia than the fluviatile deposits of the Nile itself.

I wish to acknowledge the drafting of Figure 1.1 by Mr H.A.Shelley.

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2

Le Sahara: géomorphologie et paléogéomorphologie éoliennes

Aeolian landforms of the Sahara

At the present time, wind is the most active geomorphic agent in the Sahara. In addition, fixed dunes along the margins of the desert testify to the former extent of wind action during times of even drier climate.

Satellite images and air photos support the view that from the Red Sea to the Atlantic the Sahara operates as a dynamic unit with respect to wind action. The movement of sand is in harmony with the trade wind circulation, except where the sand flows around major topographic obstacles, with the result that individual sand currents may be moving counter to the regional wind direction. Certain instances of sand diversion caused by topographically-induced changes in wind direction have been misinterpreted as legacies of a former wind regime.

Wind action along the major sectors of wind- and sand-flow is characterised by a distinctive and often contrasted suite of landforms. Sectors where sand transport is dominant alternate with sectors where sand deposition is the norm. Yardangs, wind-abraded ridge-and-swale systems, and deflation zones with barkhan dunes are all diagnostic of the transportational sectors. In the sand seas or ergs of the depositional reaches, specific types of dunes reflect the interplay of a specific set of aeolian processes. Once vegetated, the form of these dunes changes in response to a new and distinctive set of geomorphic processes.

There is a general decrease in sand particle size from the centre of the Sahara out towards the Sahel, which probably accounts for the successful cultivation of cereal grasses within the Sahel.

Les actions éoliennes constituent actuellement au Sahara le mécanisme morphogénétique le plus actif. L'héritage d'actions semblables réalisées lors de phases sèches paléoclimatiques est également considérable.

L'exploration des images satellites et aériennes a permis des progrès considérables dans l'étude des phénomènes éoliens grâce à deux nouvelles propositions:

– Le Sahara, dans son ensemble, de l'Atlantique à la Mer Rouge, constitue, du point de vue des phénomènes éoliens, une vaste et seule unité fonctionnelle. Le cheminement des sables est conforme à la circulation de l'harmattan mais se divise en courants selon le décor d'obstacles topographiques, avec des cheminements qui peuvent même être SW-NE, dans des sections où les trajectoires sont rebroussées par rapport aux directions de l'harmattan. Des circulations simplement dûes à des perturbations engendrées par les obstacles (Mainguet & Canon 1975) ont pu être parfois interprétées comme consécutives à un changement paléoclimatique des vents.

– Les effets de cette unité se sont prolongés pendant les paléophases climatiques plus sèches que l'actuelle en dehors de la zone aride vers la zone actuellement sahélienne et sur les océans (Rapp 1976).

2.1 L'UNITE FONCTIONNELLE EOLIENNE DU SAHARA

La limite des dunes vives, qui correspond en gros à l'isohyète 150 mm, peut aussi être prise comme critère du passage Sahara-Sahel.

Les photographies aériennes et les images par satellites révèlent que plus des 9-10e de ce désert sont affectés par les mécanismes éoliens, qui sont les phénomènes actuels les plus importants dans cette partie du globe. N'en sont exclus que les hauts sommets, inaccessibles à la migration des sables:

– Le coeur du Hoggar, région s'étendant du Tahalra au Tassili N'Ajjer, à une altitude toujours supérieure à 1 000 m, dominée par les sommets de l'Atakor (Monts Tahat, 3 003 m) et de l'Issakamarène (Mont Serkout, 2 306 m).

– La région volcanique du Tibesti, entourant et comprenant, au nord-ouest, le pic Toussidé (3 265 m), au nord, l'Ehi Moussou (3 100 m), au nord-est, le Tarso Toon (2 625 m) et, au sud, l'Emi Koussi (3 415 m).

– Une région moins vaste: l'Aïr, s'étendant des monts Tamgak (1 800 m) au nord, au massif de Takolokouzet (1 500 m) à l'est, aux monts Agalak (1 700 m) à l'ouest, aux monts Baguezane (1 900 m) au sud.

– Le massif des Eglab, culminant vers 709 m. Les chaînes ghourdiques de l'erg Iguidi se terminent juste au pied de ses premiers contreforts; les deux ergs Iguidi et Chech évitent les Eglab probablement à cause de la raideur du versant au vent et de la petitesse du massif qui lui permet d'être contourné.

2.1.1 *Les effets dynamiques du vent s'expriment de trois manières* (Bagnold 1941; 1946) (Dubief 1951; 1952)

– Par un effet de prise en charge de particules, c'est à dire un balayage éolien que l'on appelle aussi déflation.

– Par un effet de sculpture ou corrasion, lorsque le vent transporteur de sable agit comme un abrasif ou comme un rabot, émousse et sculpte des formes spécifiques.

– Par un effet de construction: le vent dépose alors sa charge et construit des édifices sableux.

2.1.2 *Dans les paysages, ces trois familles de mécanismes se traduisent par des modelés spécifiques*

2.1.2.1 *Les aires de déflation.* Ce sont de grandes surfaces planes, comme le Sérir au nord du Tibesti, ou la région qui sépare l'Ahnet de l'Adrar des Ifoghas, balayées par du sable mobile transporté grain par grain sous forme de manteau de saltation ou sous forme de dunes très mobiles de type barkhanique.

2.1.2.2. *Les aires de corrasion.* Tout vent ayant atteint une vitesse suffisante, de 4 à 6 m/s – selon la taille des particules – devient transporteur de sable.

Lors de son transport éolien par saltation et traction, le sable sculpte les roches, en particulier les roches à texture sableuse de type grès, en laissant au sol des traces permettant de suivre à l'échelle du Sahara les trajectoires empruntées. Or, les bassins sédimentaires à dépôt terrigène paléozoïques, mésozoïques et tertiaires du Continental Terminal abondent au Sahara et offrent un matériau qui se prête de façon optimale à la corrasion éolienne.

Celle-ci se produit sur des surfaces horizontales, ou faiblement inclinées, où les effets sont:

a) Un grattage superficiel, parfaitement décelable surtout lorsque les roches portent un enduit désertique. L'abrasion par le vent chargé de sable y produit des traînées de corrasion s'opposant par leur teinte claire aux teintes foncées de l'enduit.

Les grès dans tout le Sahara sont teintés par des enduits désertiques de type patine. Le vent de sable agit en faisant disparaître les patines et le grès clair affleure selon des bandes préférentielles bien visibles sur les images satellites dans le désert égyptien et le nord du Borkou (nord du Tchad). Ces bandes, parallèles au vent dominant, matérialisent les trajectoires du vent et sont un des critères qui ont permis le diagnostic des trajectoires éoliennes.

b) A l'abri de certains reliefs résiduels comme ceux que l'on trouve au nord-est de l'Adrar des Ifoghas, sous le vent des lambeaux de plateaux du Tassili Tan Ti-m-Missaou (21°25′ à 22°N et 3° à 3°15′ E) ou sous le vent des plateaux résiduels des Koutous et de Tanout dans le Sahel du Niger, apparaissent en noir des aires triangulaires allongées, aires de conservation des enduits désertiques, dont la base s'appuie sur le versant sous le vent de la butte et qui s'effilent sous le vent; la médiane du triangle donne la direction du vent moyen résultant ou dominant (Figure 2.1) (Mainguet, Canon, Chapelle & Chemin, 1977).

Ces formes en fer de lance sont le deuxième critère de diagnostic des courants éoliens.

c) Une striation plus profonde déterminant des ensembles de gouttières qui constituent le paysage de sculpture éolienne par excellence. Le plus impressionnant que nous connaissions actuellement à la surface de la terre est le système du Borkou au nord du Tchad (Figure 2.2): entre 16 et 23°N et 14 et 23°E s'étendent 650 000 km² de grès façonnés en un système de crêtes et de couloirs concentriques au massif volcanique du Tibesti. Ces grès constituent au pied oriental de ce massif la bordure sud de la cuvette des Erdis, succession d'auréoles paléozoïques et mésozoïques qui plongent du sud-ouest au nord-est vers le bassin de Koufra et s'appuyent au sud, en Ennedi, sur le massif du Ouaddaï (Hagedorn 1971; Mainguet 1972). La texture des grès, roche privilégiée car la plus apte à la désagrégation granulaire, apportant à la fois l'outil et le substrat nécessaire à la corrasion, explique l'ampleur du phénomène.

Ce système de crêtes et de couloirs est périodique, l'homogénéité locale de la dimension des crêtes étant expliquée par les données structurales: des cassures

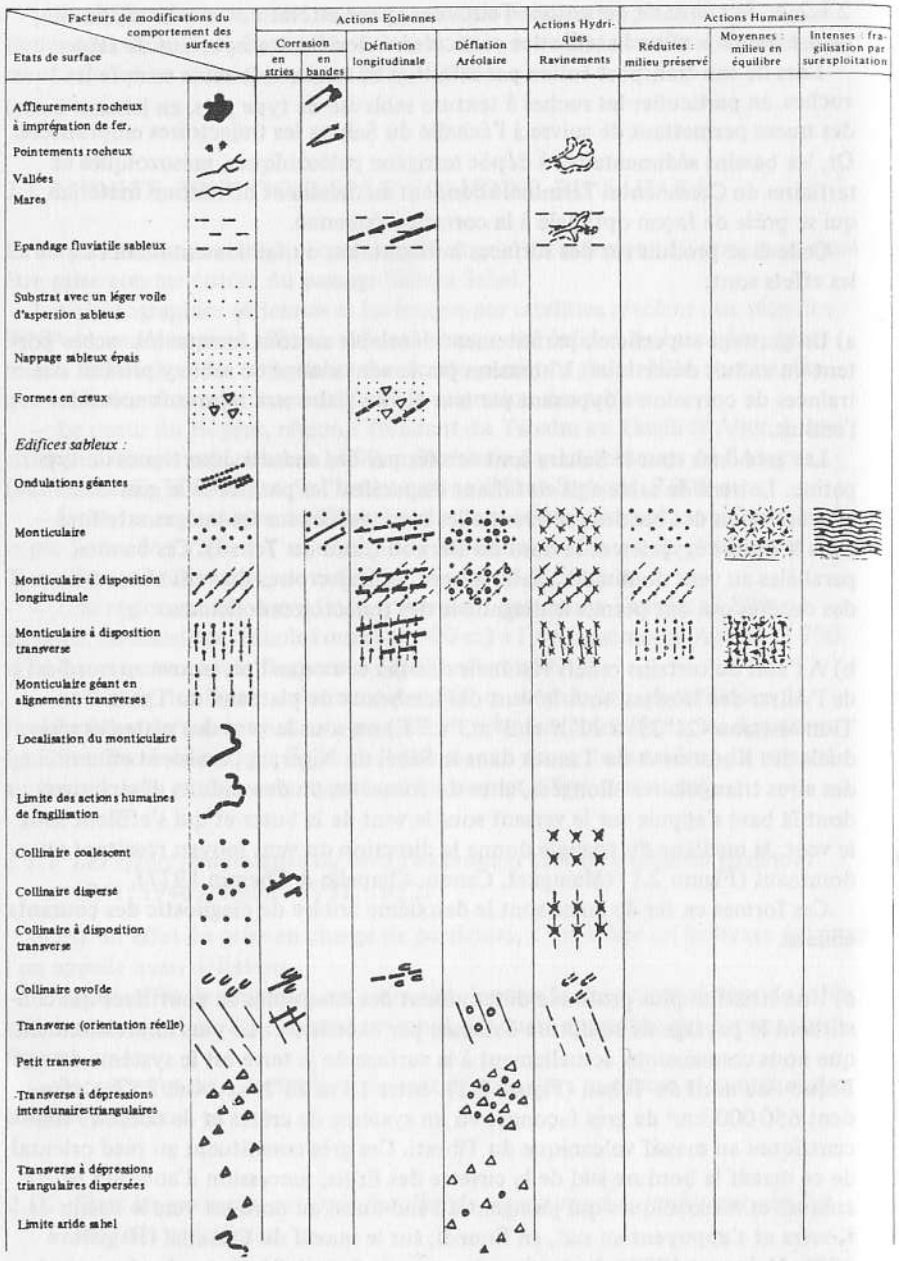


Figure 2.1 Extrait de la carte au 1:1 000 000 'Les mécanismes naturels (érosions éolienne et hydrique) et la dégradation des paysages sableux. République du Niger'. Mainguet & Canon (1977) in C.R. (inédit) de la seconde mission de reconnaissance morphodynamique de l'Unité Expérimentale de Serkin Haoussa (Niger).

Le manteau sableux de l'erg Hausa, dont les états de surface sont représentés sur la carte selon les différents modèles de dunes, est discontinu, dominé par deux lambeaux de plateaux gréseux dépourvus de sable, les massifs de Tanout et de Koutous, sous le vent desquels apparaissent des figures en forme de fer de lance. Les études de terrain ont montré que ces formes, décelées grâce à leur faible réflectance (le sable même vêtu ayant une forte réflectance) sur les images de Landsat l'correspondent à des bandes dépourvues de dépôts sableux où les grès du Crétacé affleurent, fortement teintés par un enduit de type désertique de couleur rouge à brun. La longueur (270 km) de cette figure éolienne, la plus méridionale à l'abri du massif de Koutous, montre l'effet d'abri gigantesque d'un obstacle même mineur.

Document réalisé d'après les images du satellite Landsat 1.

périodiques en nombreux faisceaux, réponse du grès à la surcharge isostatique engendrée par le volcanisme du Tibesti. La densité des cassures est élevée, les photographies aériennes permettent d'en dénombrer 40/km². L'élargissement des couloirs croît lorsque l'écart primitif entre la direction des diaclases et celle du vent moyen annuel croît, jusqu'à un angle de tolérance de cinq grades, vérifiable sur les photographies aériennes; au-delà de cette valeur, le vent emprunte un autre cheminement. Les changements brutaux de périodicité correspondent indirectement aux variantes topographiques, elles-mêmes reflets des changements de bancs, chaque banc apportant, selon ses caractères physiques, sa périodicité spécifique de diaclasage.

Lorsque la coïncidence vent-cassure est imparfaite, dans un premier temps, la corrasion s'adapte à la cassure, puis dans une étape suivante, le vent l'adapte à sa direction en l'élargissant en couloir, donnant ainsi un second moyen de diagnostic des circulations sableuses.

d) C'est dans la même région du Borkou, aux confins septentrionaux du Tchad, que se trouvent d'impressionnants yardangs gréseux plusieurs fois métriques. Les yardangs, formes aérodynamiques, sont façonnés dans le grès par le vent. Le front au vent des yardangs peut avoir des formes variées, plan et vertical, convexo-concave, en marches d'escalier, irrégulier avec des rentrants de corrasion différentielle ou précédé d'une masse éboulée. Leur profil transversal est le plus souvent convexe, le profil longitudinal s'abaisse dans le sens du vent (Figure 2.3).

L'axe longitudinal du yardang et ses lignes de subdivision sont deux nouveaux modes de diagnostic de la direction et du sens d'un courant éolien.

2.1.2.3 *Les aires de dépôt.* Le long des courants définis par les figures précédemment analysées alternent des secteurs où dominent tantôt le transit et la corrasion, tantôt l'accumulation: transport lorsque le courant est divisé par un obstacle, et accéléré autour de celui-ci; dépôt et accumulation au vent d'un obstacle ou, lorsque après l'obstacle, les deux courants issus de la division se rejoignent, confluent en retrouvant la direction de l'alizé et forment certains grands ergs sahariens.

Les grands ergs du Sahara sont disposés selon deux latitudes préférentielles (au nord de 28°30′N, et au sud de 23°30′N) entre lesquelles le Sahara est pauvre en dépôts sableux (Capot Rey 1970; Clos Arceduc 1969).

Les grands ergs sahariens sont le domaine de l'atterrissage et du stockage du sable, ceci selon des durées variables. Il est fondamental de noter que, si un erg est une aire à dominante de dépôt, il est disposé le long d'un courant de transport, ce qui revient à dire que même dans un erg le sable circule. Il y circule lentement, mais du sable y rentre d'un côté, l'amont, au vent, et en sort de l'autre, l'aval, ce qui infirme l'hypothèse que les ergs ne sont qu'un paysage modelé par le vent à partir d'une accumulation sableuse fluviatile dans un bassin.

Chaque section des grands courants s'accompagne d'édifices éoliens spécifiques et de fonctionnement différent:

– Dans les aires de transport, les dunes de type barkhanique, corps sableux mobiles en relief, comportent deux familles différentes: résultant du dépôt seul

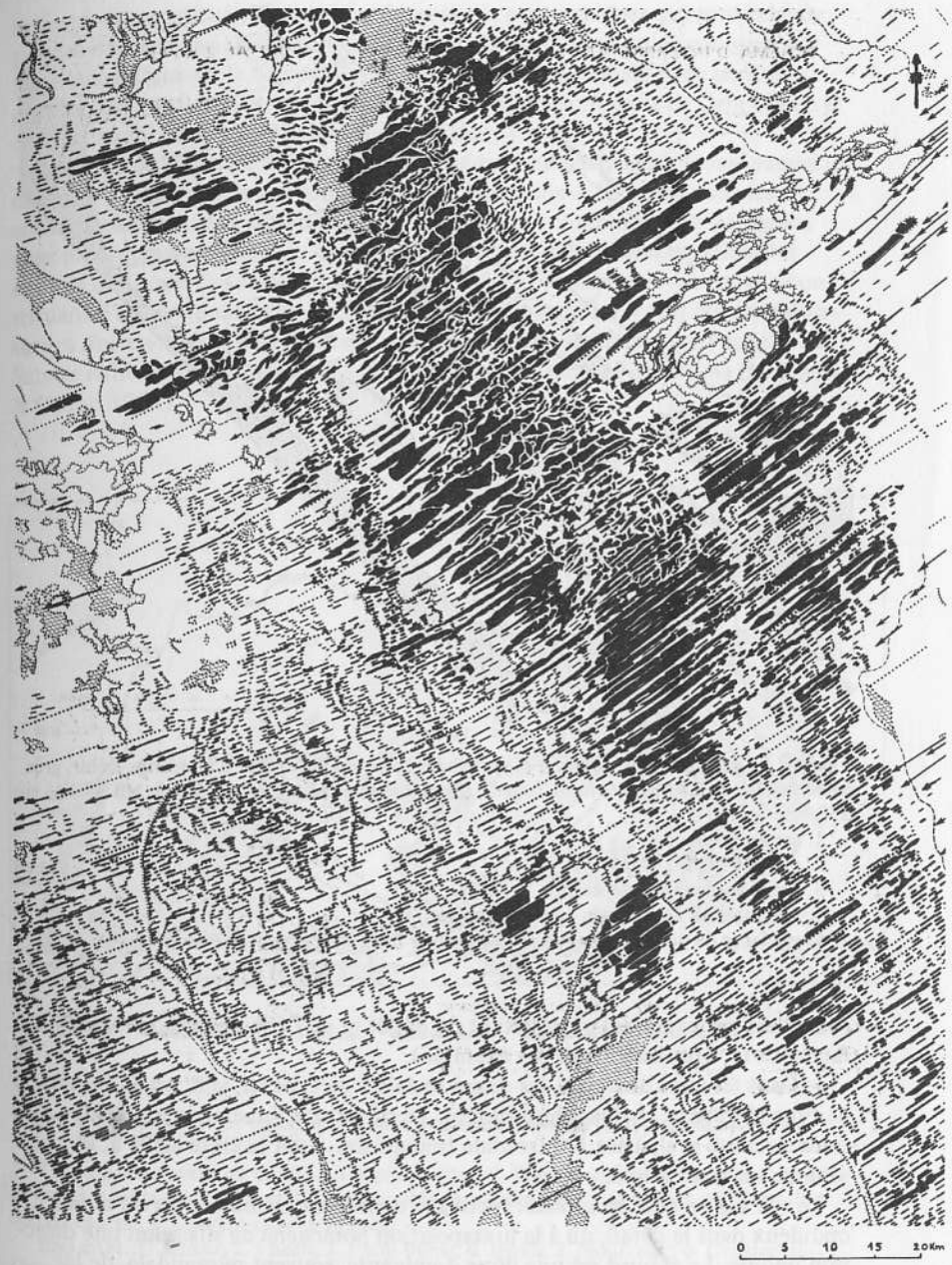


Figure 2.2 Système crêtes-couloirs périodiques du Borkou (extrait de la carte du Borkou au 1:500 000 in Mainguet, Le modelé des grès, 1972, Thèse). Les grès paléozoïques du Borkou sont façonnés en un système de gouttières et de crêtes du type Kalut du désert du Lut; l'axe de migration des barkhanes matérialisé par les flèches montre qu'il a une direction conforme à celle du système de corrasion en général. L'ensemble dessine un mouvement circulaire au piémont sud-ouest du massif du Tibesti.

Document réalisé à partir des photographies aériennes.

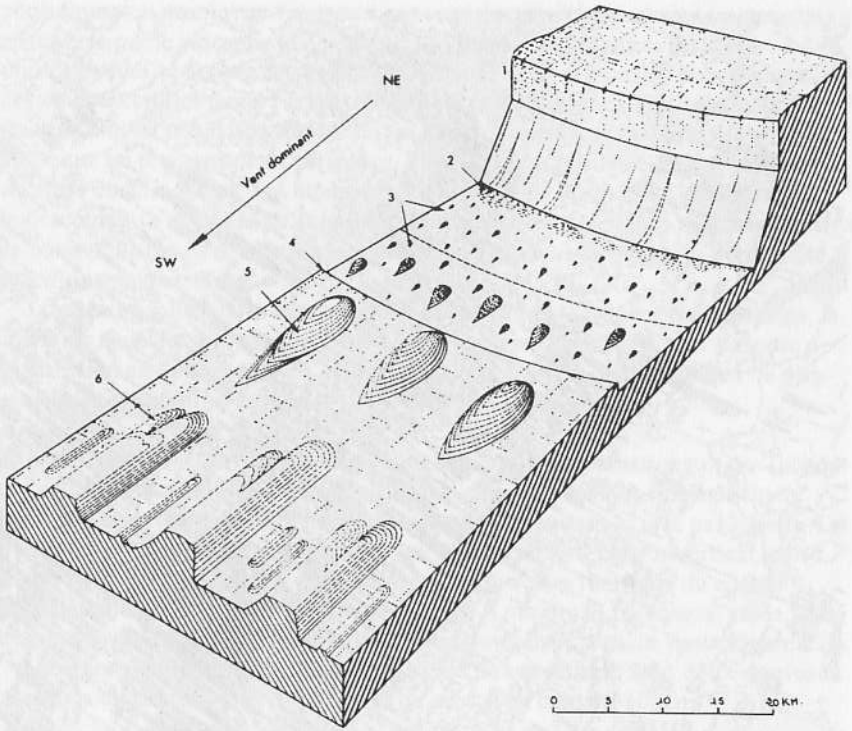


Figure 2.3 Croissance des yardangs et système crêtes-couloirs au sud d'Ounianga Kébir, grès paléozoïques du Bembéché (nord Tchad). (Photographies aériennes AE 54-55, NE 34 XV, no. 352 à 354).

1. escarpement
2. plaine à dépôts lacustres
3. petits yardangs de dépression
4. remontée au vent vers la marche suivante
5. yardangs de plateau relayés sous le vent par des crêtes et des couloirs (6).

(boucliers par exemple) ou résultant du dépôt et de l'éboulement le long de la face sous le vent (barkhanes par exemple).

– Dans les aires de dépôt, les dunes linéaires de type sif, silk, ou en pyramide de type ghourd et chaînes ghourdiques. Le sif est une dune allongée, effilée à son extrémité aval, à section frontale triangulaire, dont la crête aigüe a, en général, un tracé arqué.

Le silk est un cordon sableux rectiligne dans son ensemble, plus ou moins onduleux dans le détail, dû à la juxtaposition homogène de sifs selon une direction unique. Le ghourd est une dune dominante, souvent pyramidale, de laquelle s'échappent des silks dans des directions multiples.

De la périphérie au coeur de l'erg, les dunes apparaissent dans l'ordre donné ci-dessous (Mainguet 1976). Des édifices barkhaniques et des barkhanes constituent l'auréole externe, des silks sur un nappage sableux l'auréole suivante,

le coeur est constitué par des ghourds en semis ou en chaînes qui sont relayés par des ondulations géantes ou cordons périodiques. Leur point commun est l'existence d'une crête vive sauf pour les ensembles périodiques de cordons sableux longitudinaux dont les plus longs au Sahara sont ceux de l'erg Chech et de l'erg Iguidi (Besler 1977; Mainguet & Callot 1978).

Les axes de symétrie des barkhanes et les gassi de balayage éolien séparant les cordons sableux géants qui canalisent – vu leur taille – les vents dans les couloirs commandant ainsi leur propre circulation, combinés avec les figures vues précédemment (bandes de déflation, axe des aires de conservation des enduits en forme de fer de lance, systèmes crêtes – couloirs et yardangs), constituent d'autres moyens de diagnostic des courants de transport éolien visibles sur les documents aériens et satellites qui ont permis de dessiner à l'échelle du Sahara entier les principaux axes de circulation du sable (Figure 2.4) (Mainguet & Canon 1975).

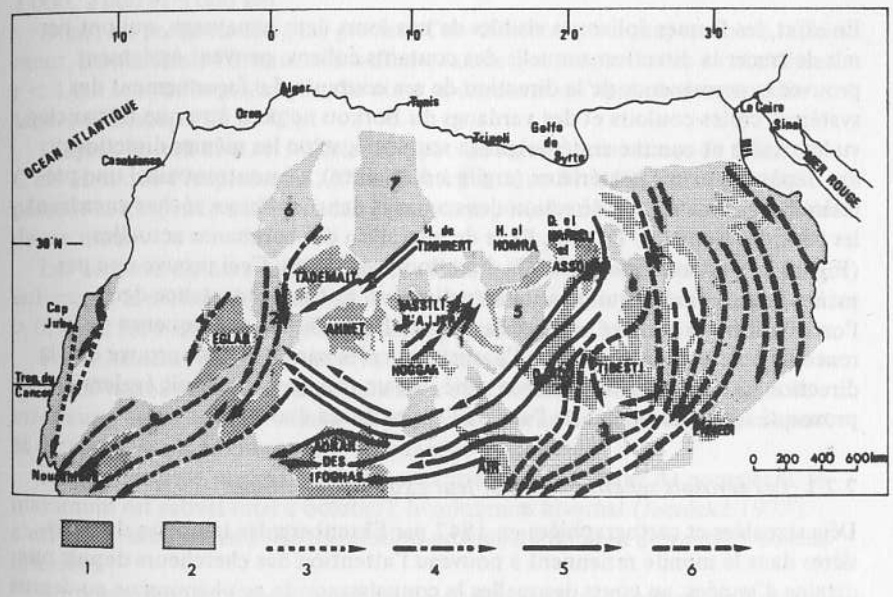


Figure 2.4 Trajectoires de transport du sable au Sahara (téléinterprétation des images de NOAA3).

1. Obstacles au vent ou zones sans dépôt sableux; 2. Ergs ou surfaces à nappage sableux; 3. Courant sableux atlantique; 4. Courant sableux occidental; 5. Circulation cellulaire du Sahara central; 6. Courant sableux oriental.

Ergs cités: 1. Admer; 2. Chech; 3. Fachi-Bilma; 4. Iguidi; 5. Mourzouk; 6. Occidental; 7. Oriental; 8. Rebiana; 9. Makteir.

Les courants principaux conformes à l'harmattan sont défléchis par les obstacles lorsque ceux-ci sont élevés. Noter la subdivision des courants à l'est et à l'ouest du Tibesti, le mouvement circulaire autour du pied méridional des massifs du Hoggar et de l'Ahnet, la division des courants de part et d'autre des Eglab, leur déviation sénestre en Mauritanie enfin.

2.2 PROBLEME DE LA PERMANENCE DU SCHEMA DE CIRCULATION ACTUELLE ET DE SES PROLONGEMENTS ATLANTIQUES ET SAHELIENS

Reste à poser la question de la permanence, d'une phase sèche à l'autre, d'un tel schéma et de son débordement en dehors de la zone aride. Pendant les phases sèches quaternaires et même tertiaires, deux types de circulation sont possibles au Sahara:

– Une circulation méridienne avec vent d'ouest dûe à une translation vers le sud de la zone méditerranéenne.

Sans rejeter cette hypothèse, rien ne nous permet, dans l'étude du vent et de ses effets morphologiques pris en tant que paramètres de connaissance des changements climatiques, de la retenir.

– Un schéma identique à l'actuel, de direction alizée avec une circulation NE-SW ou inverse, perturbée par les obstacles topographiques, respectée même pendant des phases arides plus arides que l'actuelle, semble vraisemblable.

En effet, les formes éoliennes visibles de nos jours dans le paysage, qui ont permis de tracer la direction annuelle des courants éoliens, peuvent également prouver la permanence de la direction de ces courants. Le façonnement des systèmes crêtes-couloirs et des yardangs du Borkou ne peut être que très ancien, vu leur taille et comme en témoigne la sculpture, selon les mêmes directions, des dépôts lacustres postérieurs (argile à diatomite), démontrant ainsi une première permanence de la direction des courants dans les phases sèches encadrant les périodes lacustres. De plus, l'axe de migration des barkhanes actuelles (Figure 2.2) est aussi parallèle à la direction précédente. Ceci prouve une permanence plus grande qui persiste actuellement. Enfin, la constance dans l'orientation des édifices sableux de l'erg de Fachi Bilma, conséquence de la rencontre des deux branches de l'harmattan crées par le Tibesti, prouve que la direction de cet harmattan n'a pas varié, car un changement aurait également provoqué un déplacement de l'axe de l'erg et de ses dunes.

2.2.1 *Les aérosols saharo-sahéliens: leur exutoire atlantique*

Déja signalées et cartographiées en 1847 par Ehrenberg, les tempêtes de poussières dans le monde retiennent à nouveau l'attention des chercheurs depuis une dizaine d'années, au cours desquelles la connaissance de ce phénomène au-dessus de l'Atlantique a fait de gros progrès.

Le Sahara constitue la source principale des aérosols minéraux transportés à longue distance sur l'océan Atlantique. L'intense insolation du Sahara est responsable de vents de surface violents et d'une convection à large échelle qui peut soulever des particules de poussières et de sables fins jusqu'à 6 000 m. Environ 260 x 10^6 tonnes de poussières d'un diamètre, compris entre 0,3 et 50 μm quittent le Sahara vers l'ouest chaque année, mais d'autres exutoires existent vers le proche Orient, l'Europe et la mer des Caraïbes (Schütz 1977).

Le matériel est pris en charge par l'harmattan et entraîné vers l'océan Atlantique: la masse d'air saharien chargée de poussières circule au-dessus de l'inversion des alizés à 1 500 m d'altitude. Celle-ci définit la limite inférieure de la couche d'air enrichie en poussières. Le mode et la durée du transport des particules varient avec le diamètre de celles-ci. En effet, selon le modèle de Schütz (1977), la zone de sédimentation est limitée aux mille premiers kilomètres de transport, le long desquels les grosses particules tombent. Le taux de concentration des particules, dont le diamètre $r > 10$ μm, croît jusqu'au seuil de 200 km du départ, puis décroît ensuite rapidement. A mille kilomètres leur valeur est environ de quelques percentiles. Plus loin, encore, leur part dans le total transporté est négligeable. Les particules moyennes au diamètre compris entre 1 μm et 10 μm croissent en quantité jusqu'à 1 500 km, où elles représentent un maximum de 50%. Pour des distances supérieures à 1 000 km, leur concentration décroît mais reste la partie principale du volume minéral transporté sur de longues distances. Les plus petites voient leur pourcentage augmenter lentement avec la distance, mais jusqu'à une distance de 6 000 km, elles représentent quelques percentiles du total. Au départ, les particules de diamètre 50 μm sont les plus nombreuses, puis celles de 10, 4 et 1 μm à des distances respectives de 1 000, 2 000 et 5 000 km.

Donc, les particules les plus grosses, d'un diamètre $r > 1$ μm, tombent rapidement, insensibles à l'inversion des alizés, tandis que les particules au diamètre $r < 1.\mu$m sont influencées par elle et ne se déposent qu'après de longues distances (Carlson et al. 1972).

D'après Newell et al. (1972) le transport se ferait à une vitesse de 6 m/s. C'est ainsi que Prospero et al. (1972) estiment que 37 x 10^6 tonnes par an passent la longitude des Barbades durant une période de transport de poussières de six mois.

Les aérosols ont une double origine (Schütz 1977): production par déflation éolienne à la surface des continents et des océans pour les particules au diamètre $> 0,1$ μm, formation dans l'atmosphère elle-même pour les particules $< 0,1$ μm.

Selon Jaenicke (1977) et Schütz (1977), la colonne d'air entre 0 et 5 000 m contient surtout des poussières minérales continentales avec, dans la tranche inférieure, au-dessus de l'océan, un peu de sel marin, de particules organiques et de sulfate d'ammonium, mais en quantité négligeable.

En ce qui concerne les variations saisonnières de transport de poussières, le maximum est estival (mai à octobre), le minimum hivernal (Jaenicke 1977), c'est à dire conformes à l'augmentation estivale du nombre de vents et de leur intensité.

Au printemps, de violentes tempêtes de sable soufflent au nord du Sahara; elles sont responsables des pluies de poussières rouges, pluies de 'sang' du moyen-âge, vers l'Europe au-delà de la Méditerranée ou vers l'océan Atlantique.

Nous proposons d'étudier le cas de vents de poussières qui se sont produits en juin 1975. Interprétation effectuée d'après les illustrations de l'article: 'Sable sur l'Atlantique' publié dans le Bulletin d'Information de la Météorologie no. 31, avril 1976, p. 45-48):

Cinq photographies reçues et décodées par le Centre d'Etudes et de Météorologie Spatiale (EERM) de Lannion ont permis de suivre la progression d'une tache laiteuse, probable vent d'aérosols, au dessus de l'océan Atlantique à

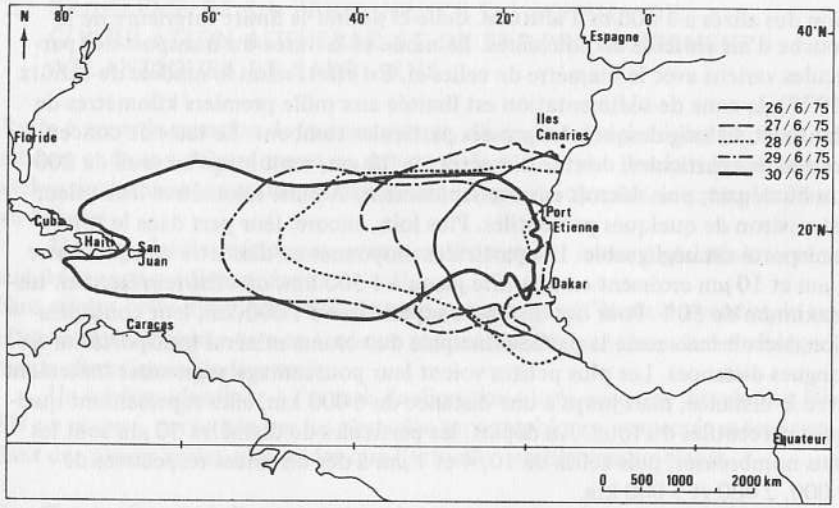


Figure 2.5 Progression d'un vent chargé d'aérosols au dessus de l'Atlantique depuis les côtes africaines vers l'Amérique d'après les images du satellite SMS 1 (visible) reçues par le centre d'études et de météorologie spatiale de Lannion (EERM) en juin 1975.

partir des côtes de l'Afrique jusqu'à la longitude de l'île de Cuba (Figure 2.5).

Sur l'image du 26 juin, la tache s'étend au large des côtes africaines de 10° à 27° N, jusqu'à 30°W. Le 27 juin, la tache s'est agrandie jusqu'à 40°W, le 28 juin l'étalement vers l'ouest s'est encore accru jusqu'à 50°W, enfin, le 29 juin, elle a atteint 78°W. Ce phénomène ne croît pas en latitude. La tache a atteint les côtes de l'île de Cuba le 30 juin; l'article signale que diverses stations météorologiques de la côte ouest de l'Amérique et des îles ont enregistré ce jour-là une brume sèche, prolongée jusqu'au 3 juillet. A partir du 29 juin, l'alimentation saharo-sahélienne de ce transport transatlantique s'est interrompue, la masse des aérosols s'est détachée de la côte africaine. L'article détermine la probabilité d'un transport dans les basses couches vers 1 500-4 000 m à une vitesse de 40 km/h, habituelle à cette saison sur l'Atlantique central. Les portes atlantiques des aérosols africains ont été signalées par de nombreux auteurs (Prospero & Carlson 1972; Rapp 1974).

2.2.2 *Les prolongements sahélo-soudaniens du Sahara*

Les images satellites ont permis aussi de déceler au sud de la limite actuelle erg vif-erg vêtu jusqu'à l'isohyète 800 mm, sous savane au Nigeria et au nord de l'Empire Centrafricain, des structures périodiques tout à fait semblables à celles qui se trouvent dans les ergs sahariens (Mainguet 1976). Ces ensembles sont constitués d'immenses cordons sableux parallèles, actuellement vêtus. Cette observation permet de déceler la limite la plus méridionale du paléo-Sahara et de constater sa position à 5-6° au sud de la limite actuelle (Figure 2.6). Ce qui conduit à admettre que nous sommes actuellement encore dans une phase

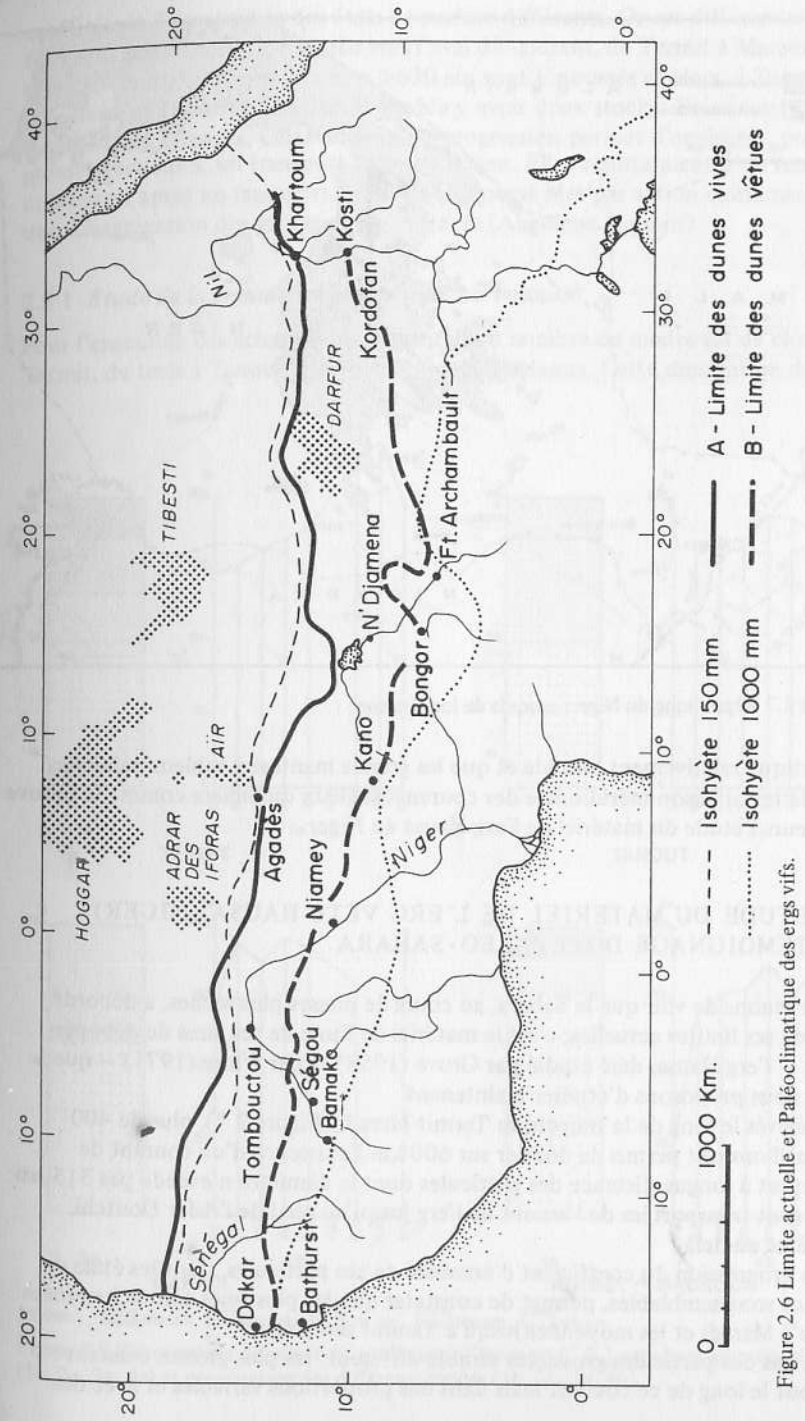


Figure 2.6 Limite actuelle et Paléoclimatique des ergs vifs.

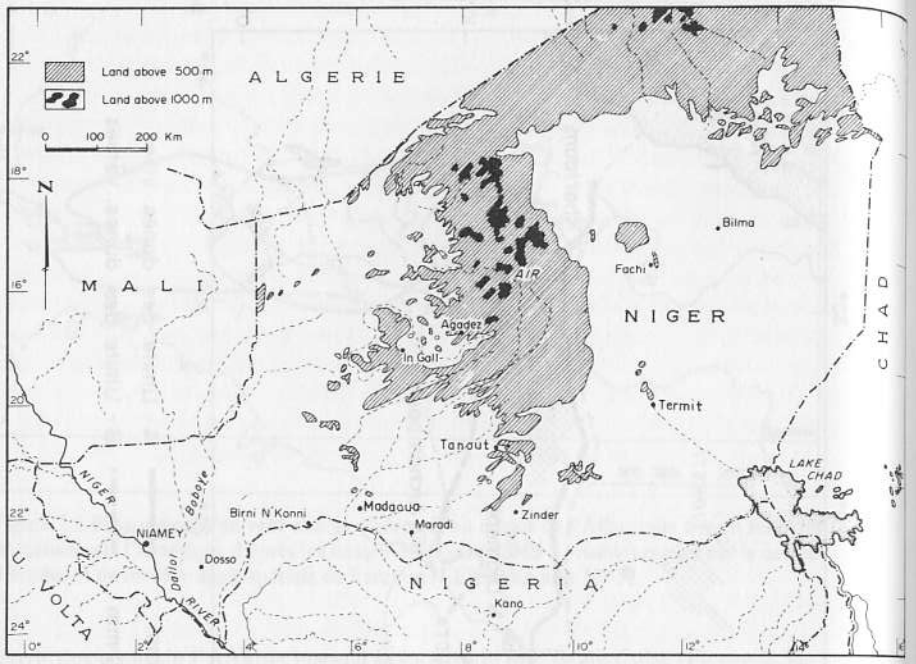


Figure 2.7 République du Niger: croquis de localisation.

climatique relativement humide et que les grands manteaux sableux sahéliens sont la terminaison méridionale des courants sableux du Sahara comme le prouve d'ailleurs l'étude du matériel de l'erg Hausa au Niger.

2.3 ETUDE DU MATERIEL DE L'ERG VETU HAUSA (NIGER): TEMOIGNAGE D'UN PALEO-SAHARA

Nous venons de voir que le Sahara, au cours de phases plus sèches, a débordé hors de ses limites actuelles; c'est le matériel de l'une de ces aires de débordement – l'erg Hausa, déjà étudié par Grove (1958) et par White (1971) – que nous nous proposons d'étudier maintenant.

Prélevés le long de la trajectoire Termit-Maradi (Figure 2.7), plus de 400 échantillons ont permis de déceler sur 600 km l'existence d'un courant de transport à longue distance des particules dont le diamètre n'excède pas 315 μm; elles sont transportées de l'amont de l'erg jusqu'au pied de l'Ader Doutchi, et même au-delà.

La progression du coefficient d'émoussé de ces particules, dont les états de surface sont semblables, permet de constater que les plus fines sont acheminées jusqu'à Maradi et les moyennes jusqu'à Tanout seulement.

Le cas des particules grossières semble différent: les plus grosses existent partout le long de ce courant mais dans des proportions variables et avec des

coefficients d'émoussé et des états de surface différents. Or ces différences se font sans progression de l'amont vers l'aval du courant, de Termit à Maradi. En effet, à Termit les grains grossiers >630 μm sont Emoussés et Mats, à Tanout Anguleux et Luisants, à Maradi il semble y avoir deux stocks: Emoussés et Mats, Anguleux et Luisants. Cette absence de progression permet d'envisager, pour ces grosses particules, un transport autre qu'éolien. Elles résulteraient d'un remaniement local après un transport fluviatile (Emoussé Mat par action chimique) ou une désagrégation des grès grossiers crétacés (Anguleux Luisant).

2.3.1 *Etude de la granularité et de l'indice d'émoussé*

Pour l'ensemble des échantillons, l'éventail du nombre de modes est de cinq à Termit, de trois à Tanout, Maradi et Niamey-Madaoua. Cette diminution du

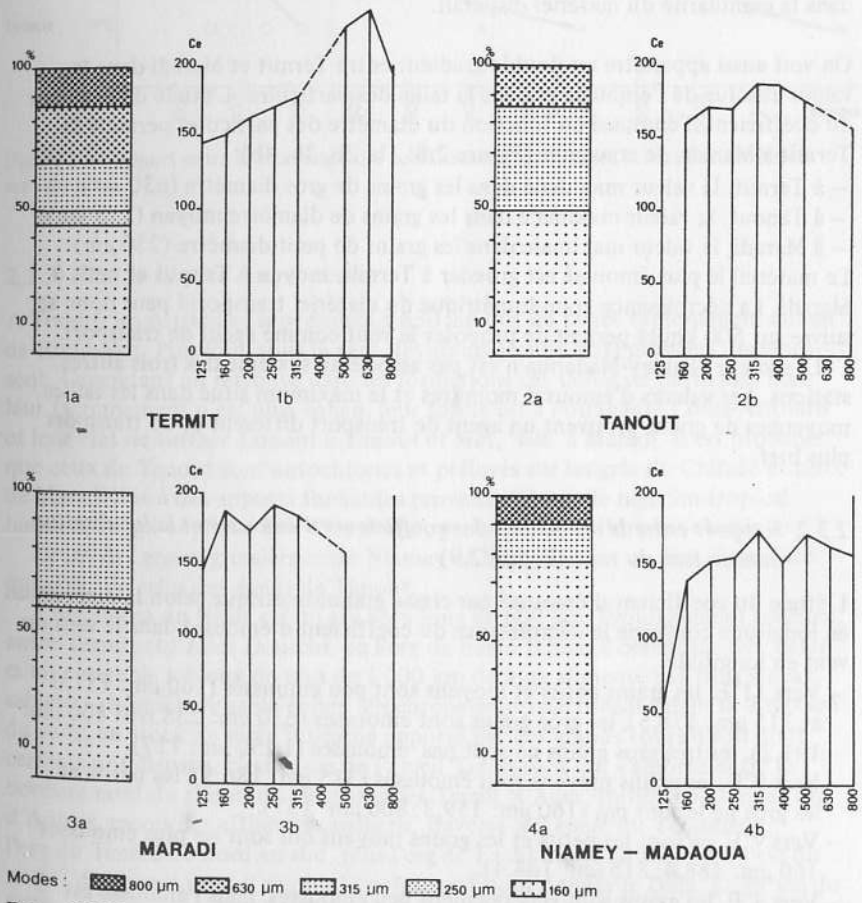


Figure 2.8 Histogramme de valeur du coefficient d'émoussé (C.E.) par classe granulométrique (1a, 2a, 3a, 4a) et pourcentage des différents modes (1b, 2b, 3b, 4b).

nombre de modes dans la direction du vent est le résultat d'une homogénéisation du matériel, donc l'existence d'un tri qui s'effectue le long du courant, et d'un gradient dans la taille des particules de Termit à Maradi (Figure 2.8: 1a, 2a, 3a, 4a).

A Termit, les modes grossiers sont bien représentés puisque les particules de diamètre ϕ>630 μm égalent 33%.

A Tanout, les modes grossiers sont moins nombreux puisque les particules de diamètre ϕ>315 μm ne représentent plus que 14%. L'absence de mode intermédiaire entre 315 et 800 μm semble prouver que le matériel a cessé d'être transporté entre Termit et Tanout.

Au nord de Maradi, les modes grossiers ont disparu. Il ne subsiste plus que des grains moyens à fins. Cependant, les grains de 800 μm existent dans le matériel de terrasses du Goulbi Maradi à Tarna (Niger).

Niamey et Madaoua se différencient encore. Le gradient régulier observé dans la granularité du matériel disparaît.

On voit aussi apparaître un double gradient entre Termit et Maradi dans la valeur absolue de l'émoussé et dans la taille des particules. L'étude de la valeur du coefficient d'émoussé en fonction du diamètre des particules permet, de Termit à Maradi, de constater (Figure 2.8: 1b, 2b, 3b, 4b):

– à Termit, la valeur maximale dans les grains de gros diamètre (630 μm);
– à Tanout, la valeur maximale dans les grains de diamètre moyen (315 μm);
– à Maradi, la valeur maximale dans les grains de petit diamètre (250 μm).

Le matériel le plus émoussé est grossier à Termit, moyen à Tanout et petit à Maradi. La décroissance granulométrique du matériel transporté peut donc se suivre sur 500 km et permet de proposer le vent comme agent de transport.

Le secteur Niamey-Madaoua n'est pas associé au système des trois autres stations. Les valeurs d'émoussé moindres et le maximum situé dans les tailles moyennes de grains prouvent un agent de transport différent et un transport plus bref.

2.3.2 *Rapport entre la croissance des coefficients d'émoussé et la localisation dans le sens du vent* (Figure 2.9)

L'étude du coefficient d'émoussé par classe granulométrique selon la disposition en longitude confirme la décroissance du coefficient d'émoussé dans le sens du vent en longitude.

– Vers 11°E, les grains petits et moyens sont peu émoussés (160 μm: 151,6 et 315 μm: 178,5), les gros grains sont émoussés (630 μm: 238,6 et 800 μm: 191,2), les très gros grains ne sont pas émoussés (1 250 μm: 117).
– Vers 9°E, les grains moyens sont émoussés (315 μm: 186,5), les petits et les gros ne le sont pas (160 μm: 159,3; 800 μm: 157).
– Vers 7°E, ce sont les petits et les grains moyens qui sont les plus émoussés 160 μm: 188,4; 315 μm: 184,4).
– Vers 4°E, les grains sont généralement peu émoussés, mais l'émoussé est supérieur dans les grains moyens et gros (315 μm: 174,5 contre 139,9 pour 160 μm).

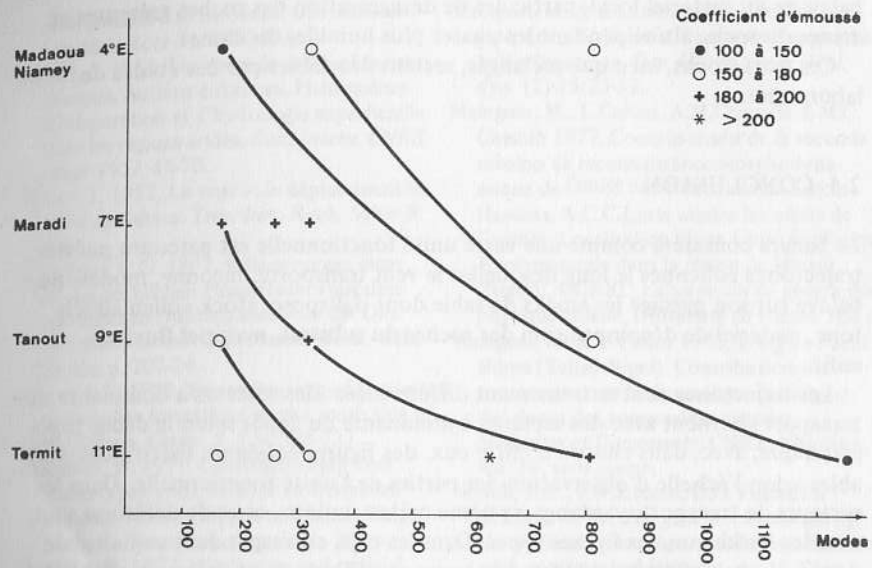


Figure 2.9 Rapport entre la croissance des coefficients d'émoussé et la localisation dans le sens du vent.

2.3.3 *Etat de surface des particules*

A Termit, les particules supérieures à 630 μm ont un faciès typiquement éolien de Rond-Mat. Plus loin, sous le vent, les grains Ronds-Mats grossiers disparaissent. Cependant on retrouve dans les formations ces tailles de particules mais leur façonnement n'est plus éolien, leur forme est à dominante Coins-Arrondis et leur état de surface Luisant à Tanout et Mat, 'sale' à Maradi. Il est probable que ceux de Tanout sont autochtones et prélevés sur les grès du Crétacé et ceux de Maradi dûs à des apports fluviatiles provenant du socle nigérien tropical humide, ce qui explique leur Picoté-Mat, probablement d'origine chimique.

Le lot des grains grossiers entre Niamey et Madaoua ont un état de surface qui rappelle celui des grains de Tanout.

L'erg Hausa du Niger est un erg vêtu long de 600 km. Prolongement sahélien, entre Termit et l'Ader Doutchi, de l'erg de Fachi Bilma, il constitue avec celui-ci un ensemble sableux de plus de 1 200 km de long alimenté par trois stocks sableux: un stock de sable éolien allochtone grano-décroissant dans la direction du vent; un stock de sable fluviatile apporté par des grands cours d'eau dont certains ont disparu, c'est le cas de l'Oued Tafassasset qui s'amorce entre la bordure nord du massif du Hoggar et les Tassili N'Ajjer, traverse ou longe l'erg d'Admer, reçoit des affluents tassiliens, traverse le Ténéré du Tafassasset, l'erg du Ténéré du nord au sud, puis l'erg de Fachi Bilma en passant à l'est du massif de Termit dont il rejoint la pointe sud pour donner le Dilia. Le lit sec du Dilia, entre Termit et N'Guigmi, où ce cours se jetait dans le lac Tchad, reste le tronçon le plus visible de l'Oued Tafassasset; enfin, un troisième stock dû au

balayage du matériel local, particules de désagrégation des roches gréseuses et arènes du socle, altéré pendant les phases plus humides du climat.

Ces trois stocks, bien que mélangés, restent décelables par des études de laboratoire.

2.4 CONCLUSION

Le Sahara considéré comme une vaste unité fonctionnelle est parcouru par des trajectoires éoliennes le long desquelles le vent transporte, façonne, modèle ou balaye sur son passage les stocks de sable dont il dispose: stock éolien allochtone, matériel de décomposition des roches du substrat, matériel fluviatile enfin.

Les trajectoires sont extrêmement différenciées: des secteurs à dominante de transport alternent avec des secteurs à dominante de dépôt selon le décor topographique, avec, dans chacun d'entre eux, des figures éoliennes spécifiques, variables selon l'échelle d'observation des parties de l'unité fonctionnelle. Dans les secteurs de transport, yardangs, système crêtes-couloirs, aires de déflation sont, avec les barkhanes, les figures types. Dans les ergs, correspondant aux aires de dépôt, chaque secteur comporte ses dunes spécifiques dont chaque variété est une réponse à un type de dynamique. Lorsque ces ergs, en milieu sahélien, se couvrent d'un tapis végétal, leur aspect change et de nouvelles dynamiques, avec de nouvelles figures originales, apparaissent.

Pour l'ensemble du Sahara et la zone sahélienne qui le borde au sud, la décroissance du diamètre des particules, du centre du désert vers sa bordure sahélienne, constitue la tendance la plus générale. Ce qui explique que le matériel sableux du Sahel soit si favorable à la céréaliculture.

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3

Environmental responses to climatic change in the West African Sahel over the past 20 000 years

Réaction de l'environnement aux changements climatiques dans le Sahel de l'Afrique de l'ouest depuis les 20 000 dernières années

Les faits géologiques indiquent qu'au cours des 20 000 dernières années le Sahel a dans l'ensemble connu une évolution similaire à celle des zones bioclimatiques correspondantes de l'Afrique centrale et de l'Est. La période 20 000 B.P. - 12 000 B.P. est caractérisée par des conditions plutôt arides, quand des champs de dunes vives recouvraient de grandes parties du Sahel. Le développement de champs de dunes ne paraît pas avoir été le résultat d'un changement majeur dans la circulation atmosphérique. La dominance des processus éoliens à cette époque semble avoir été produite par les effets conjugés de précipitations décroissantes et de vents alizés plus forts en provenance du Nord et de l'Est. A l'évidence, on peut suggérer que l'air humide de la mousson d'été pénétra néanmoins dans le Sahel, apportant une pluie saisonnière en abondance suffisante pour modifier la morphologie des dunes. Après 12 000 B.P. l'humidité augmenta et permit aux dunes de se stabiliser. Les précipitations furent alors suffisamment abondantes pour maintenir de grandes rivières qui traversaient toute la largeur du Sahel, ainsi que de nombreux lacs permanents et des mares. Pendant la fin du Pléistocene et le début de l'Holocène (12 000-8 000 B.P.) les cours d'eau majeurs du Sahel atteignirent probablement leur développement maximum de la fin du Quaternaire, avec de hautes eaux permanentes qui firent les apports les plus importants au débit des fleuves Niger et Sénégal. A cette époque, ces systèmes de rivières dont le bassin d'alimentation s'étendait au Nord jusqu'aux massifs du Sahara méridional, avaient des niveaux de base suffisamment larges pour permettre le développement de grands méandres et d'un régime de charge en suspension dominant. L'écoulement dû aux pluies, apportées sur les massifs par des afflux d'air froid du nord, augmenta probablement les apports de la mousson d'été aux systèmes de drainage majeurs. Et de ce fait aida à maintenir un débit régulier. Les cours d'eau prenant leur source dans le Sahel et alimentés par la seule mousson d'été furent de caractère beaucoup plus saisonnier.

Après une période d'aridité (8 000-7 000 B.P.) l'écoulement depuis les massifs jusqu'au Sahel déclina grandement. Toutes les rivières étaient alors de nature nettement saisonnière étant entièrement alimentées par la mousson. Néanmoins les ressources en eaux de surface étaient relativement abondantes en comparaison de la situation actuelle; des mares permanentes étaient encore largement distribuées et les cours d'eau les plus importants au moins coulaient probablement toute l'année.

La fin de l'Holocène, à partir de 4 000 B.P. vit un déclin progressif de l'humidité vers les conditions semi-arides présentes. Les systèmes fluviaux sont maintenant complètement dégradés, actifs seulement épisodiquement, et encore uniquement dans les bassins de réception des eaux directement affectés par des orages localisés. Les dunes restent généralement immobilisées sous leur carapace de sols, bien que se produise une remobilisation locale, surtout là où les effets anthropiques sont particulièrement sévères. Cependant, les champs de dunes fixées prennent une influence pré-

pondérante pour l'exploitation du Sahel de nos jours. Dans le Sud les sables éoliens sont cultivés de façon intensive, tandis que plus au nord le comblement des dépressions inter-dunaires par l'accumulation de silts et de limons déposés par les eaux permet le développement de mares saisonnières qui constituent une source d'eau importante pour les bergers nomades du Sahel.

3.1 INTRODUCTION

The name Sahel is derived from an Arabic word for shore, thus aptly conveying the impression of a transition zone separating the sand seas of the Sahara from the relatively well-watered regions to the south. Not so many years ago the name was probably unfamiliar to all save those well-acquainted with this part of Africa. Only now, after almost a decade of drought, has there been much generation of scientific interest in the Sahel. Indeed, in terms of Late Quaternary geology and prehistory more is probably known about the Sahara than about the relatively accessible Sahel. Why this should be is not clear, but the reasons are perhaps due less to the low scientific potential of the Sahel, for this is far from being the case, than to the aesthetic and intellectual appeal of the desert. The Sahel offers many of the hardships of desert travel, but few of the scenic compensations, the traveller more often than not being confronted by a rather monotonous rolling landscape, dotted with *Acacia* scrub and vast meadows of 'cram-cram' (*Cenchrus biflorus*), a ubiquitous and painfully spiny grass.

Stimulated by general concern for the human consequences of the present drought, attempts are now being made to understand the origins of this crisis and to find ways in which its adverse environmental effects might best be minimised. Fundamental to discussions of this sort is a thorough understanding of the environmental history of the region. Primary meteorological data is only available in any quantity for the last half-century (Rodier & Roche 1973; Winstanley 1973; Dorize 1974, 1976; Lamb 1976). Indirect data from written sources permit climatic variations in the Sahel to be reconstructed over the past few centuries (see Chapter 8), but for any longer term perspective we are entirely dependent upon environmental information preserved in the sedimentary record of the region.

The purpose of this paper is to review the types of geological evidence used in reconstructing Sahelian environments of the past 20 000 years and critically to assess their palaeoclimatic implications. Attention will also be given to some of the likely effects environmental changes may have had on human exploitation of the region.

3.2 THE SAHEL: DEFINITION AND CLIMATE

Definitions of what actually constitutes the Sahel zone vary, depending upon the particular viewpoint of the author concerned. Criteria such as flora, fauna, stream hydrology, agronomic factors and mean annual rainfall have all been utilised, the last named being the most frequent.

On the basis of mean annual rainfall, there seems to be a consensus that the northern limit of the Sahel coincides with the 100 mm isohyet and the southern limit with the 500 mm isohyet. There are, however, some notable exceptions.

Rodier (1975: 3), using streamflow characteristics, defines the region between the 100 and 300 mm isohyets as sub-desert and places the Sahel between the 300 and 750 mm isohyets. From a vegetational point of view, on the other hand, Maley (1977a, b) limits the Sahel to that region between the 100 and 500 mm isohyets. For the sake of convenience the boundaries of the area covered in the present account are essentially geological, being defined by the southern limit of fixed Pleistocene dunes and the southern limit of modern mobile dunes (Figure 3.1). This region more or less coincides with the broadest possible precipitational definition of the Sahel – that region lying between the 100 and 750 mm isohyets (Figure 3.1). Only the West African Sahel, west of the Chad basin, will be considered in detail. Accounts of the Chad basin and the eastward prolongation of the Sahel, the Qoz of western Sudan, can be found elsewhere in this volume.

Present-day precipitation in the Sahel is almost wholly confined to a distinct rainy season of one to four months duration, between June and September, the bulk of the rain normally falling in July and August. Rain is brought by the influx of moist southern air that follows the northward migrating Inter-Tropical Convergence Zone (ITCZ), which usually reaches its maximum northern extent some time in August. The rainy season ends once the ITCZ has passed the Sahel on its return south, southern air then being replaced by dry continental air. The rains are frequently referred to as 'the monsoon' and although Pédelaborde (1963) has pointed out that strictly speaking this is not correct, we will retain the name as a convenience for referring to any precipitation originating from the warm, humid equatorial air mass.

Potential evapotranspiration rates are extremely high throughout the year, annual totals far exceeding total precipitation. Soil moisture deficits are therefore typical of all but the peak and immediately post-peak periods of the rainy season (Garnier 1961; Ledger 1969).

Apart from an almost total absence of rainfall, the most characteristic feature of the dry season is the 'harmattan' trade wind, blowing from the east or north-east. This wind transports large volumes of suspended sediment from the desert regions as far as the Atlantic and Guinea coasts of Africa and beyond.

3.3 PREVIOUS WORK

Quaternary studies of the Sahel published before 1968 have been ably summarised by Grove & Warren (1968). Since their review a number of valuable works have appeared. Most notable are the studies by Michel (1973) on the Senegal River basin, and those by various members of the ORSTOM team working in the Chad basin (Servant 1973; Maley 1973, 1977a; Maglione 1976). However, although both basins are traversed by the Sahel zone, they should perhaps be regarded, like the Niger bend area, as atypical, since the relatively abundant surface water of these regions is derived from catchments lying well south of the Sahel. Maley (1977a, b), for example, has recently provided a detailed Holocene pollen sequence from a core taken within the Sahel zone of the Chad basin. Unfortunately, although the sequence is undoubtedly of the utmost palaeoclimatic interest, the palaeogeographic setting of the sample site, within the

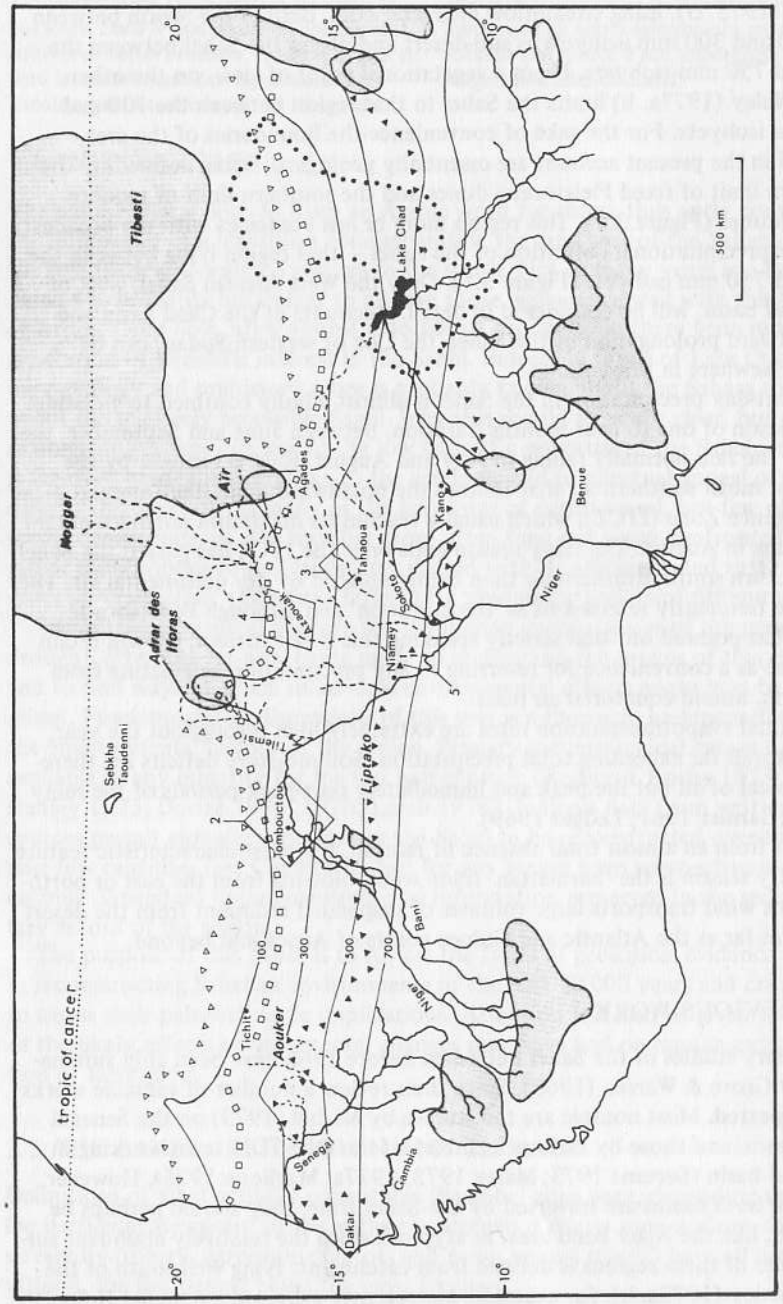


Figure 3.1 The Sahel. Boundaries adopted in this account lie between the open triangles (approximate southern limit of active, modern dunes) and solid triangles (southern limit of fixed, Late Pleistocene dunes). The line of open squares marks the approximate northern limit of *Cenchrus biflorus*, suggested by Capot-Rey (1953) to mark the boundary between the Sahel and Sahara. Solid circles: maximum Holocene extent of Lake Palaeochad. Isohyets (millimetres) from Rodier (1975). Also shown are the positions of the Skylab and Landsat photographs reproduced as Figures 3.2-5. K — Karkarichinkat.

confines of Lake Palaeochad (Maley 1977a, Figure 1), makes it difficult to use the pollen data to locate the position of bioclimatic zones on the surrounding land.

Amongst the most important studies of more 'typical' parts of the Sahel are the accounts of the fixed dunes of northern Upper Volta by Chamard & Courel (1975) and Courel (1977) and the palaeoenvironmental reconstruction based on pedological surveys in northern Nigeria by Pullan (1969) and Sombroek & Zonneveld (1971). A number of other recent works will be referred to in the ensuing text.

3.4 LATE QUATERNARY SEDIMENTS AND LANDFORMS

Most aerial photographs and satellite images of the Sahel bear at least some traces of the two major Quaternary elements of this landscape: stabilised dune fields, some very extensive; and large, mainly sand-filled watercourses (Figures 3.1-5). Both are essentially relict features, produced during Late Pleistocene climatic episodes that differed from the present. There are still locally active accumulations of aeolian sand, although on all but the northernmost margin of the Sahel these occurrences seem to stem directly from the activities of man and his domestic animals. Relict watercourses may briefly be active during the rainy season, but the discharge is usually of limited extent and duration, related to individual storm events, the channel networks no longer operating as integrated drainage systems. Only along the southern edge of the Sahel can the period of discharge extend for any significant length of time after each storm (Rodier 1975).

Relict aeolian and fluviatile sediments are two of the three most important sources of palaeoenvironmental information in the Sahel. The third source is provided by sediments that have accumulated in depressions between fixed dunes. These deposits are predominantly of paludal or lacustrine origin, but accumulations of the coarser-grained products of dune degradation may also yield valuable palaeoclimatic data.

3.5 DUNES

3.5.1 *Types*

Dunes, the most widespread Quaternary features of the Sahel, are present in a variety of forms. Commonest, and certainly the most striking from the air, are longitudinal dunes (sief, silk, sand ridge, etc. of various authors), some of which are very well developed, with crests tens of kilometres long (Figures 3.2, 3.4). Various transverse dune types (aklé, parabolic, barchanoid, mreyye) are also present (Figure 3.3), the aklé and mreyye in particular sometimes forming quite extensive fields (Monod 1958; Grove & Warren 1968; Sombroek & Zonneveld 1971). Large volumes of sand have also accumulated locally in the lee of some topographic obstacles (Pullan 1964; Grove & Warren 1968; Sombroek & Zonneveld 1971).

Reference to more detailed descriptions of dune morphology can be found in

Grove & Warren (1968). Subsequent works include Blanck (1968); Sombroek & Zonneveld (1971); Michel (1973); Chamard & Courel (1975); Courel (1975, 1977); Mainguet (1976); Mainguet & Canon (1976). Although distinct dune forms are recognisable right up to the southern edge of the Sahel, organisation of the dune fields tends to decrease in a southerly direction, the dunes also showing a corresponding decrease in height, distinctly positive features eventually giving way to irregular sand sheets. The fixed dunes of the Sahel are all of desert margin type (Mainguet 1976), giant pyramidal dunes (sand mountain, ghourd), at present confined to major sand seas of the most arid desert cores, being entirely absent.

3.5.2 *Age*

Three main dune generations are recognisable (Grove & Warren 1968; Sombroek & Zonneveld 1971; Michel 1973). The oldest of these is also the least well-preserved, any remaining dune trend frequently being apparent only from the air. However, where dune forms are still recognisable it is clear that the structures were produced in large, well-ordered dune fields. In the Niger bend region, for example, the old dunes were obviously constructed on a more massive scale than any later structures (Figure 3.2).

In terms of the present-day distribution of relict aeolian sands the middle period of dune building was the most important, remnants of the very extensive sand seas produced at this time still covering very large areas of the Sahel (Figures 3.2, 3.3, 3.4). Finally, one, and locally two comparatively recent phases of dune remobilisation are also widely recognised, but the volume of sand deposited at these times was probably very much less than during the two previous periods of dune building and the dunes are correspondingly small and irregular (Figure 3.2). In the main this last phase of dune activity appears to have been confined to small areas of particularly abundant sand supply, such as some of the older aeolian sand accumulations and recently active floodplains (Blanck 1968; Sombroek & Zonneveld 1971; Michel 1973; Servant 1973; Courel 1977).

Some remobilisation of older dunes also seems to be occurring under present-day conditions. Apart from dunes of anthropogenic origin, which appear almost anywhere in the Sahel where human interference has greatly reduced the natural vegetation cover, there are active dunes at places along the transition zone into the Sahara. Daveau (1965) reports reactivated dune crests in the Aouker region of Mauritania and, although there are no published ground observations, the crests of the very large longitudinal dunes of the central Azaouak appear from aerial photographs also to carry some mobile sands (Figure 3.4).

Evidence from coastal Mauritania and Senegal, where relict dunes clearly extend below present sea level, and a limited number of C14 dates from horizons stratigraphically above and below these aeolian sands, indicate that the main (middle) period of dune building now represented in the Sahel occurred between 20 000 B.P. and 12 000 B.P. (Michel 1973; Servant 1973; Beaudet et al. 1976; Rognon 1976a). Courel (1977) prefers the period 28 000 B.P. to 20 000 B.P. for the formation of the Liptako (Upper Volta) dunes, but evidence

for comparatively humid conditions at this time in adjacent regions (Faure 1969; Servant 1973; Rognon 1976a) makes it probable that these dunes were also constructed in the latest Pleistocene.

No radiometric dates have been obtained from the oldest dunes, nor from bounding formations, but a major aeolian sand unit, probably equivalent to the oldest dunes exposed in the Sahel, is present at depth in the Chad basin, where its age is greater than 40 000 years B.P. (Servant 1973). Ages in excess of 100 000 years B.P. have been suggested for the old dunes of Senegal and Mauritania (Grove & Warren 1968; Michel 1973; Beaudet et al. 1976).

The youngest fixed dunes are of mid-Holocene age. A period of dune remobilisation in the Senegal delta area has been dated to between 8 000 B.P. and 6 000 B.P. (Michel 1973; Elouard 1973; Beaudet et al. 1976) and in the Chad basin two episodes of dune reactivation are known, these occurring between 8 000 B.P. and 7 000 B.P. and around 4 000 B.P. (Servant 1973). Sombroek & Zonneveld (1971) correlate the last phase of dune building in northwestern Nigeria with this circa 4 000 B.P. remobilisation, while Blanck (1968) and Courel (1977) suggest that aeolian reworking around the Niger bend area and in northern Upper Volta was contemporaneous with the earlier phase of Holocene remobilisation. In western Sudan a period of Holocene dune formation is also thought to have occurred between 5 000 B.P. and 4 000 B.P. (Wickens 1975).

3.5.3 *Palaeoclimatic implications*

3.5.3.1 *Precipitation.* Modern active aeolian dunes have until recently been considered to be restricted to regions where annual precipitation does not exceed 150 mm (Grove 1958; Wilson 1973). However a recent compilation by Sarnthein & Diester-Haass (1977) indicates that this figure is almost certainly too high. They suggest an upper annual rainfall limit of 25-50 mm for active dunes. The dunes of the Sahel are generally assumed to have formed as a result of a simple southward displacement of the isohyets, bringing dune-forming conditions to what are now more humid regions. This would imply annual precipitation amounts of around 80% (150 mm rainfall limit) or 90% (50 mm rainfall limit) lower than at present along the southernmost margin of Late Pleistocene dune fields. There are a number of reasons for believing precipitation need not have been as low as this.

The distribution of modern Saharan dunes must to some extent reflect the sand-transporting abilities of the trade winds, as well as prevailing rainfall patterns. There is now abundant evidence to indicate that during the Late Pleistocene glacial maximum, the north-east trades, the main sand transporting wind in the southern Sahara, were significantly more vigorous than they are at present (Parkin & Shackleton 1973; Parkin 1974; Diester-Haass 1976; Gardner & Hays 1976). The effectiveness of wind as an agent of sand entrainment and transport varies directly with the cube of its velocity (Bagnold 1941) and thus any increase in wind vigour must greatly enhance the ability of the wind to mobilise sufficient volumes of sand for dune formation. Since the main Sahelian dune fields were produced when trade wind vigour was at a maximum, dune

building could well have occurred under rather more humid conditions than are possible at present.

Although the climate of the Sahel zone during the period 20 000 B.P. to 12 000 B.P. need not have been quite as arid as in modern sand seas, it is not yet possible to give any quantitative estimates of precipitation amounts at that time. However there is some geomorphological evidence to indicate the probability of at least episodic rainfall over some of the Sahelian dune fields.

Courel (1977) has shown that the course of certain of the larger streams cutting the Liptako dune field do not seem to have been much affected by the dune topography, although this has greatly affected the course of smaller streams and, for that matter, the Middle Niger south and east of Tombouctou (Figure 3.2). Courel suggests that even during the period of dune formation, runoff must have been sufficiently frequent for the larger streams to maintain an already-established course. Since the watercourses described by Courel drain neither distant nor highland catchments there must have been periodic, perhaps seasonal rains within the dune field (see below).

3.5.3.2 *Wind directions.* Dune trends indicate that the winds principally responsible for shaping these sand bodies blew in directions similar to the modern harmattan – from an easterly or north-easterly direction (Figures 3.2, 3.3, 3.4). The north-easterly trades are still the major dune-forming winds in the southern Sahara (Wilson 1973; Mainguet 1976; Mainguet & Canon 1976). Interestingly enough the only detailed morphological study of fixed Sahelian dunes (Chamard & Courel 1975; Courel 1977) reveals that in Upper Volta and western Niger the dominant east-west dune crests were modified by a subsidiary wind blowing from a southerly direction. Similarly, Gallais (1967: 27) notes that the younger longitudinal dunes of the Niger bend area (D2 in Figure 3.2) are asymmetrical in cross-section, the north slope being consistently steeper than the south. This again implies that dune development must have been influenced by southerly winds. Such winds would only be possible with the ITCZ lying north of these regions, the modified dune crests thus providing evidence for periodic penetration of monsoonal air into the southern Sahel during the late Pleistocene. Arrival of this relatively moist air would have greatly enhanced the probability of episodic rainfall in the Sahel at that time.

3.5.3.3 *Discussion.* Arrival of monsoonal air in the Sahel with sufficient frequency to produce preservable geological effects implies that the ITCZ regularly penetrated this far north during the Late Pleistocene period of dune building. This suggestion is at variance with previous ideas on the Quaternary palaeoclimatology of West Africa. These generally assume that during full glacials the ITCZ was permanently displaced south of its present position (van Zinderen Bakker 1967; Rognon 1976a). It is therefore of some interest to note that the ideas put forward here are supported by quite different evidence obtained from the tropical eastern Atlantic Ocean. On the basis of microfaunal distribution patterns Gardner & Hays (1976) have suggested that around 18 000 B.P. both the upwelling off northwest Africa and the Benguela – South Equatorial current occupied positions very similar to the present. Since these

current systems are directly related to the trade wind belts Gardner & Hays infer that atmospheric circulation over western tropical Africa during the Late Pleistocene must also have been rather similar to today. They state (p. 231) '. . . that the ITCZ during glacial stages must not have migrated very far outside its present seasonal boundaries'. We can therefore be more certain that dune building in the Sahel was not simply the result of hyperaridity induced by the non-arrival of moist equatorial air. Instead, this region, suffered from the general decrease in tropical rainfall (Williams 1975), which, when combined with significantly more vigorous winds, was sufficient to permit the mobilization of large volumes of surface sediment.

Insofar as they are capable of providing detailed information on the position of the ITCZ, recent attempts at numerical modelling of atmospheric circulation during the last glacial maximum also tend to substantiate the above interpretations of continental and oceanographic data. Three different models suggest that the rising branch of the Hadley circulation, within which the ITCZ is located, was at the same latitudes during glacial times as it is at present (Williams 1978).

Whether the Holocene periods of dune building occurred for the same combination of reasons as those which produced the Late Pleistocene dunes is not clear. As yet there appears to be no unequivocal evidence from the Sahel for episodes of intensified Holocene winds, but my observations in the Guinea coast region are consistent with increased southerly trade wind vigour during the later Holocene.

Precipitation must have been considerably less when the Holocene dunes were formed than during the preceding and succeeding humid phases, and was probably also lower than at present. Maley (1977a) suggests on the basis of the Palaeochad core (see 3.3 above) that the dune-building intervals in the Sahel occurred at times of rather intense aridity. The shape of the late Holocene dunes of northwestern Nigeria does, however, suggest to Sombroek & Zonneveld (1971) that a certain amount of vegetation must have been present when the dunes were formed.

3.5.4 *Human aspects*

Although the region cannot have provided a particularly favourable habitat during the period of dune formation, the likelihood that conditions were not hyperarid means seasonal occupation may at least have been possible.

3.6 MAJOR WATERCOURSES

A number of prominent watercourses, notably the Tilemsi, Azaouak/Dallol Bosso, Dallol Maouri and Tarka run directly into the River Niger, or join seasonally active tributaries of this river (Figures 3.5, 3.6). Under present climatic conditions they are essentially relict features, but it is clear that at times during the Holocene the rivers were active and operated as fully integrated drainage networks, maintained by catchments that stretched far into the present arid zone (Figure 3.6). Similar, now inactive tributaries are also recognisable in the Senegal basin (Michel 1973).

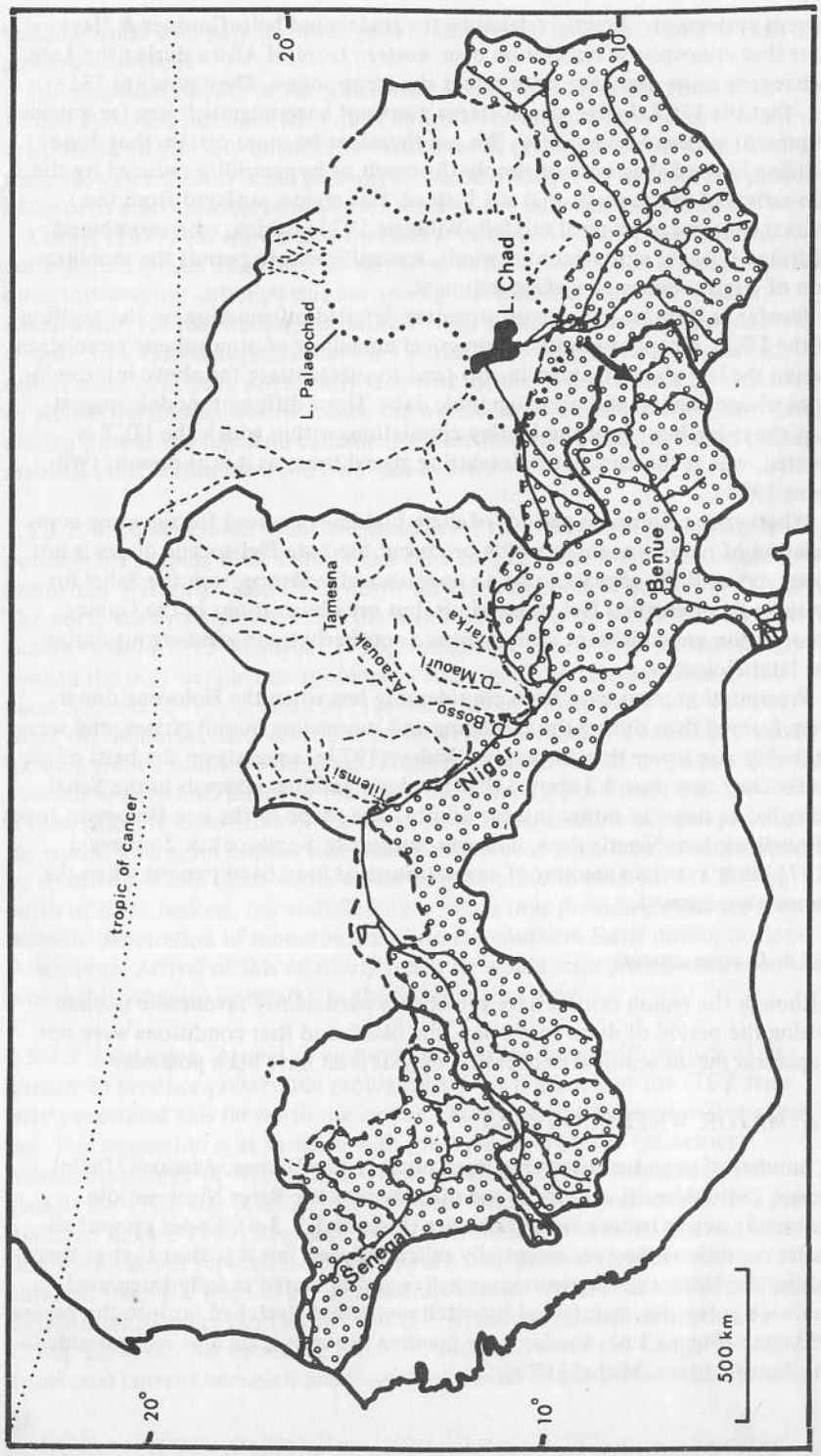


Figure 3.6 Maximum potential catchments of the Senegal and Niger-Benue river systems. Those areas of catchment presently contributing runoff are shaded. During periods of maximum humidity, especially the earlier Holocene, the whole of the catchments were probably active. Overflow from the Chad Basin reached the Benue via the route marked by the arrow. Catchments from Dubief (1965).

3.6.1 *Age*

The main valleys are probably rather old. The southernmost sections of the Dallols Bosso and Maouri, for example, are quite deeply incised into the Continental Terminal tablelands, forming valleys that are more than comparable in scale to the present valley of the middle Niger. Landsat images also reveal that the Dallol Bosso may once have been the dominant stream, the Niger now utilising a large valley that quite clearly originated as a downstream continuation of that Dallol (Figure 3.5).

Traces of ancient channel systems are still abundantly visible along these and other valley floors (Pullan 1965, 1969; Sombroek & Zonneveld 1971). Superimposed upon them are much smaller channels of more recent origin, these carrying any local runoff generated during the brief rainy season (Figure 3.5).

3.6.2 *Late Quaternary fluviatile sediments*

At present it is possible to make only a few general observations on the alluvial history of the relict watercourses, based mainly on information yielded by soil surveys (Bocquier & Gavaud 1964; Boulet 1964; Boulet et al. 1965; Pullan 1964, 1969; Gavaud 1967; Sombroek & Zonneveld 1971). Detailed sedimentological studies have yet to be carried out on any of the fluviatile sediments. These would undoubtedly be of enormous value as it is clear that the alluvial sedimentary record carries a wealth of palaeohydrological information.

The alluvial stratigraphy of the lower Dallols Bosso and Maouri and the Tarka-Rima system is summarised schematically in Figure 3.7. Probably the most striking feature within this sequence of predominantly coarse-grained clastic sediments is the appearance of a clearly-defined phase of argillaceous sediment accumulation. Although not recognisable in all Sahelian fluviatile sequences (see below), a similar phase is reported from widely separated alluvial deposits in the central and southern Sahara (Servant 1974; Rognon 1976a, b; Maley 1977b; Williams 1976). C14 dates from some of these localities show that silt and clay accumulation occurred between 12 000 B.P. and 8 000 B.P. (Servant 1973, 1974; Rognon 1976b). Stratigraphic evidence suggests that the phase of fine grained sediment accumulation recognisable in some of the larger Sahelian watercourses took place during the same interval. This assumption has been used as the basis of the correlation shown in Figure 3.7.

3.6.3 *Palaeohydrology*

3.6.3.1 *Late Pleistocene – early Holocene.* From the form of the palaeochannels and the nature of their associated sediments, Sombroek & Zonneveld (1971) have been able to suggest the probable nature of the fluviatile regime characterising the rivers of northwestern Nigeria at various stages during the Late Pleistocene and Holocene. Figure 3.7 is in part based on some of their interpretations. The Late Pleistocene – early Holocene transition from sand-dominated, shallow, generally low-sinuosity streams to high-sinuosity, suspended load streams is of particular interest. Sombroek & Zonneveld (1971)

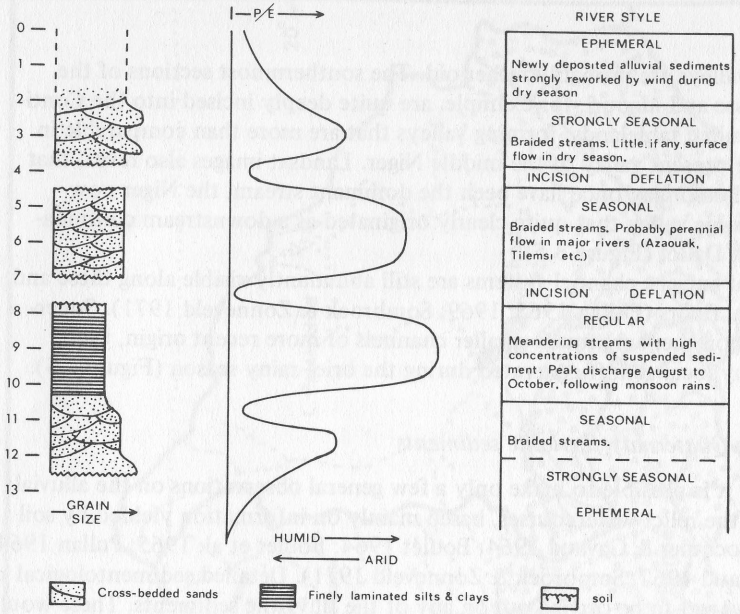


Figure 3.7 Schematic (and provisional) summary of the evolution of the larger rivers of the Sahel during the latest Pleistocene and Holocene. For comparison the precipitation/evaporation (P/E) curve for the Chad basin is reproduced from Servant et al. (1976, Fig. 8). (N.B. the lithological sequence shown in the left hand column is not a conventional sedimentologic log).

suspect that the lower, braided stream deposits, accumulated during a period when precipitation amounts were generally quite high, but rather seasonal in distribution. Certainly some sort of dry season, with consequent reduction in vegetation cover, would be necessary to permit the high sediment yields implied by the development of these braided streams. This phase of alluviation perhaps occurred during the initial transition from the preceeding arid phase, when large volumes of sediment of aeolian and flash-flood origin would have been available for redistribution. A strongly seasonal regime suggests that the rains were of monsoonal origin.

Progressive change from braided to meandering streams evidently resulted from increasing humidity that led also to the very high lake levels of the early Holocene (Figure 3.7). There is general agreement that precipitation at this time was not only relatively abundant but also much more evenly distributed through the year (Sombroek & Zonneveld 1971; Servant 1974; Rognon 1976b; Maley 1977b). A more regular rainfall regime would have encouraged a dense and permanent vegetation cover, thereby greatly reducing the supply of coarse-grained sediment while also promoting humid weathering processes, with consequent increase in the availability of the finer-grained products of rock decomposition. The change in sediment load, together with higher overall discharges, induced the streams to change from relatively straight to high sinuosity courses. Similar stream adjustments during the transition from rather arid to more

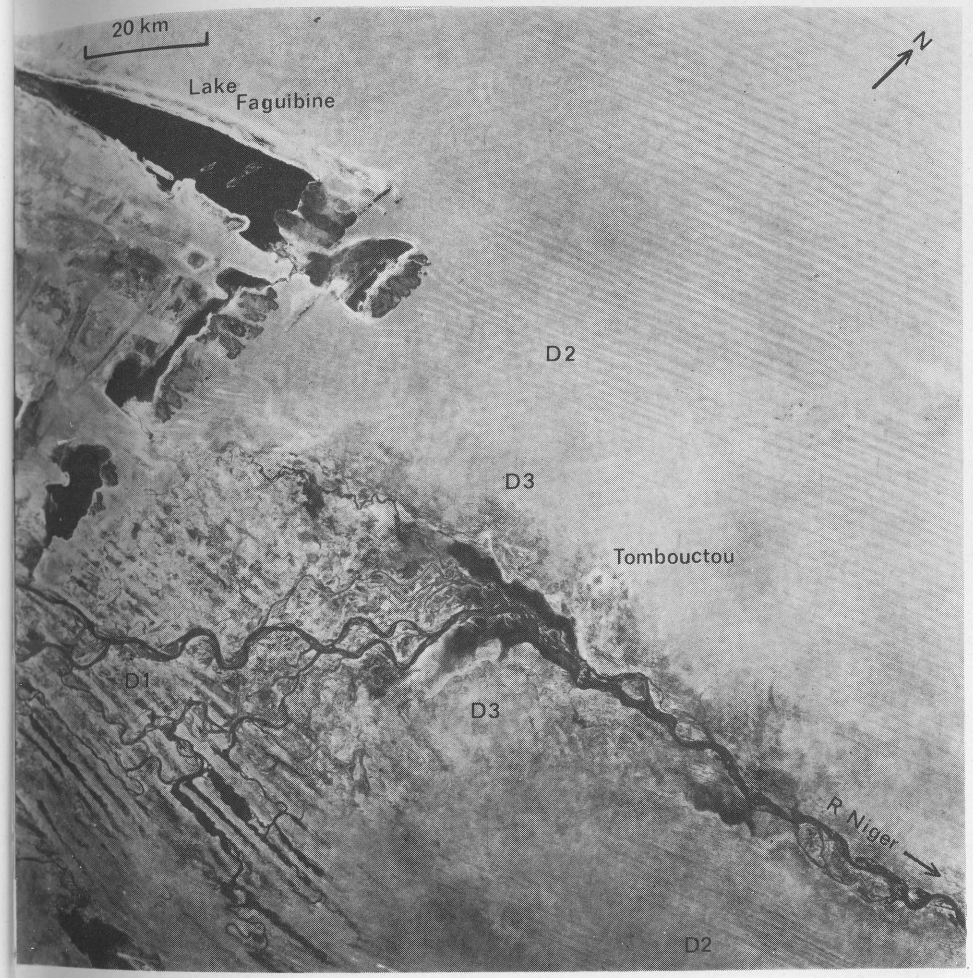


Figure 3.2 Skylab S190A photograph of the Niger bend area. Two generations of fixed linear dunes, differing slightly in trend are clearly visible. The older, and larger dunes (D1) are present only in the southern corner of the photograph. Interdune depressions here hold swamps and lakes, maintained by the Niger. The smaller, but better preserved Late Pleistocene dunes (D2) cover a large area and south of the river they can be seen to partially obliterate the older dunes. Downstream from Tombouctou the course of the Niger was clearly determined by the orientation of these Late Pleistocene dunes. Individual mid-Holocene dunes are not visible at this scale, but occur in areas such as D3. Interpretation based in part on Blanck (1968). NASA photo No. 58-242. Position shown on Figure 3.1.

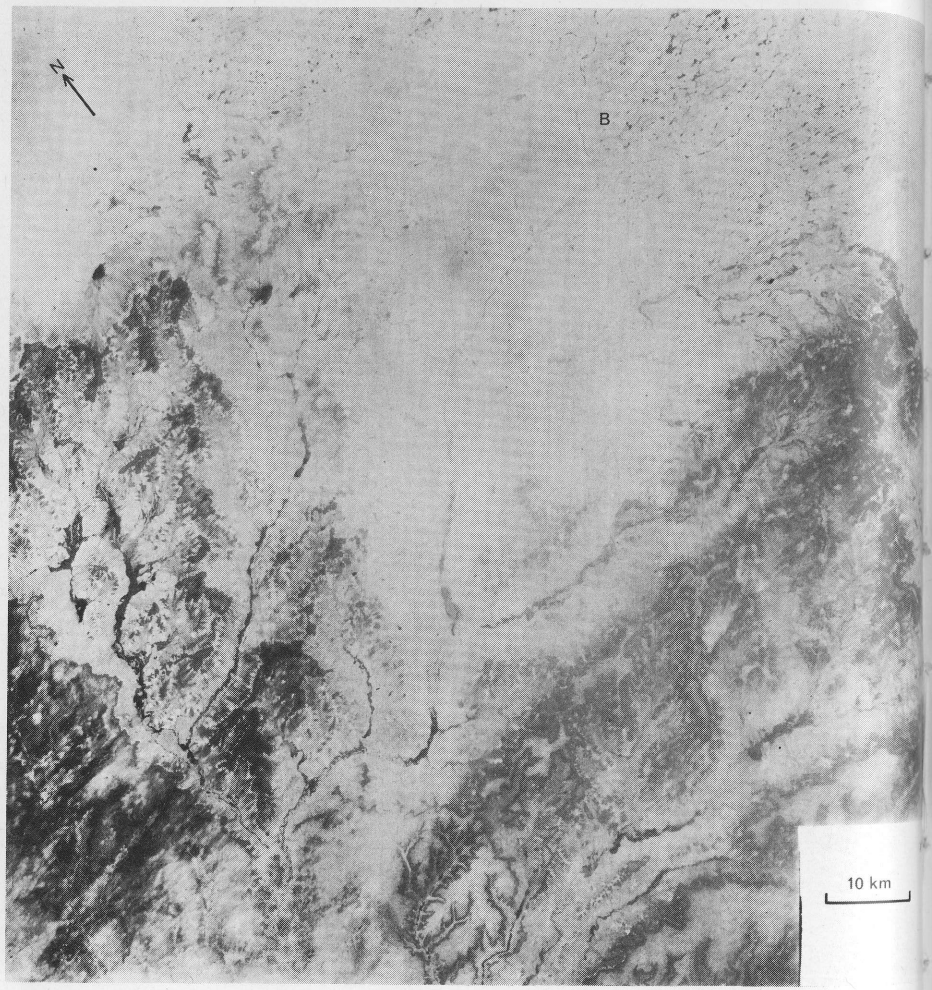


Figure 3.3 Skylab S190B photograph of an area of the south central Sahel, north-east of Tahaoua (see Figure 3.1 for exact location). Lighter tones in north and east are part of an extensive field of fixed dunes. Some traces of barchanoid-like dune forms are still apparent around B, where the seasonally wet inter-dune depressions show up as darker areas. Wind aligned sand streaks across the top of a Continental Terminal-capped plateau can be seen at bottom left. Remnants of formerly well-developed drainage systems are also readily apparent. NASA No. 86-167.



Figure 3.4 Landsat 1 image (Band 7) of the middle Azaouak valley. This very broad, now totally defunct watercourse cuts through a series of large linear dunes. Part of a field of much smaller transverse dunes, apparently of the mreyye type are visible at the bottom (M). NASA No. E-1289093627. See Figure 3.1 for location.

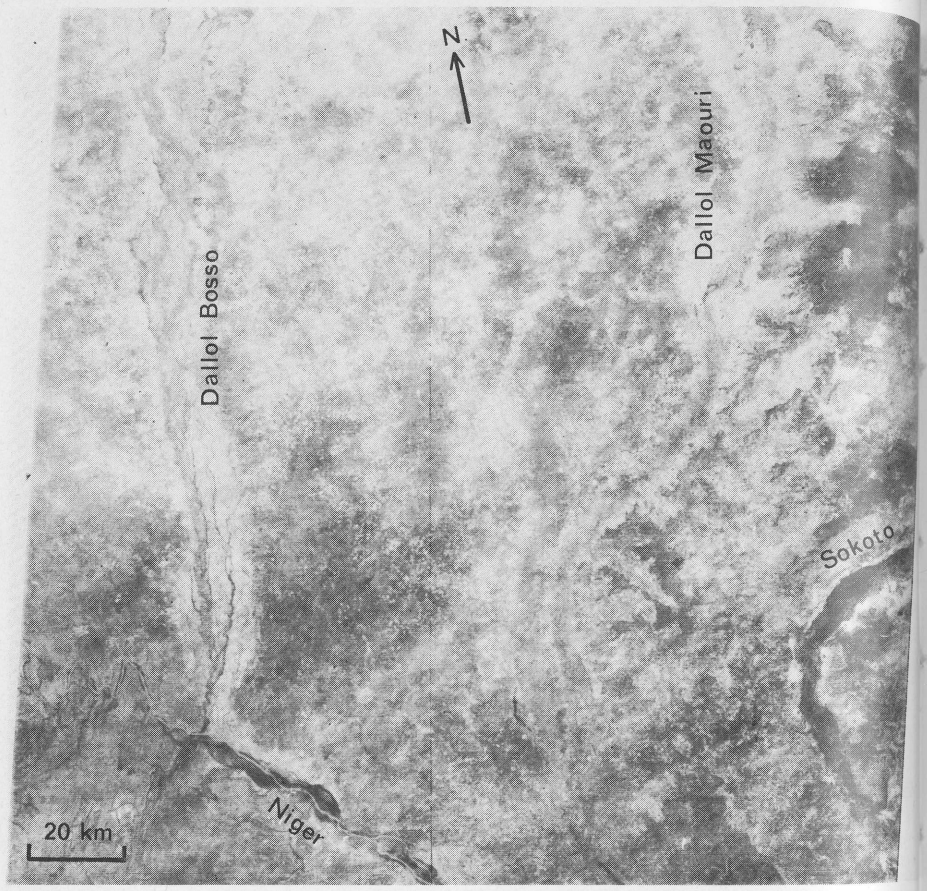


Figure 3.5 Landsat 1 image (Band 5) of part of the present valley of the middle Niger with some of its past and present tributaries. Perennial or seasonally active watercourses are readily distinguished by the darker tones of their floodplains. Thus the still active lower valley of the Sokoto-Tarka system contrasts strongly with the now-defunct Dallols Bosso (Lower Azaouak) and Maouri. The grossly underfit seasonal streams presently occupying the Dallol Bosso are confined to only the lowermost few tens of kilometres of this valley. Note also the distinct change in the character of the Niger valley downstream from its confluence with the Dallol Bosso, the wide floodplain clearly turning into the now inactive valley. NASA No. E-1109093725. See Figure 3.1 for location.

humid conditions have been recorded from other Quaternary fluviatile systems (Schumm 1968; Baker & Penteado-Orellana 1977).

The appearance during the Late Pleistocene and early Holocene of a rainfall regime that apparently differed markedly from the present monsoon is of considerable interest. Rognon (1976a, b) has suggested that less intense and more evenly distributed rainfall could be promoted by a change in the structure of the ITCZ. He postulates that if the warm, moist monsoonal air were to be forced over dry and relatively cool mid-continental air (the reverse happens along the modern ITCZ), then the convergence zone might behave in similar fashion to the typical warm front of higher latitudes. Servant (1974), on the other hand, believes that regular rainfall must in part have been due to rains of northern origin. In support of this hypothesis he cites evidence for significant runoff from the Tibesti Massif between 12 000 B.P. and 8 000 B.P. and notes that this was also the period when cool-water diatoms achieved their greatest abundance in the lakes of the southern Sahara (see also Servant et al. 1976). It is noteworthy that at about the same time runoff from the eastern flank of the Aïr Mountains also reached a maximum (Williams 1976), while along the western flank of the Adrar des Iforas, in the upper Tilemsi valley, surface waters were not only permanent, but also sufficiently cool and well-oxygenated to allow the Nile perch (*Lates niloticus*) to flourish (see also Chapter 18). Recently further evidence favouring the regular penetration of non-monsoonal rain into the central Sahara during the early Holocene has been provided by Maley (1977b), who suggests that tropical depressions were commoner over the mountain massifs than they are at present. Gentle, but rather continuous rains, falling outside the monsoon season, are typically associated with the rare modern tropical depressions that reach this far south (Maley 1977b). However, even if rains of this type reached the central Saharan massifs with some regularity, we do not yet know whether they penetrated as far south as the Sahel with any notable frequency. In fact it seems rather likely that most of the rain falling in the Sahel at this time was of monsoonal origin, the effects of any extra-tropical rain reaching the massifs to the north being felt mainly through its influence on the discharge of rivers whose catchments reach into the mountains.

In northwestern Nigeria and south-central Niger the phase of predominantly silt and clay accumulation from high sinuosity streams was apparently confined to just those watercourses with tributaries extending far north into the southern Sahara – e.g. the Dallol Bosso and Tarka (Boulet et al. 1965; Sombroek & Zonneveld 1971). These catchments were presumably large enough to gather both monsoonal and northern rains, the main rivers thereby receiving runoff from one area or another throughout much of the year. Under these conditions the major north-south river systems must inevitably have possessed a high baseflow with a correspondingly high incidence of channel-forming discharges leading to the development of strongly meandering stream courses. In contrast, smaller streams, originating in the Sahel and maintained only by monsoonal precipitation, must still have had a much more seasonal regime. It is interesting to note, therefore, that at around the time the streams from the north were at their most regular, smaller watercourses rising in the uplands of northwestern

Nigeria do appear to have been seasonal in character. From similarities in channel form and sediment load, Sombroek & Zonneveld (1971: 82) infer that these streams developed in a climate of comparable or slightly greater humidity than that prevailing in this part of Nigeria at present. Independent evidence strongly suggests that an abundance of monsoonal rainfall did penetrate far into West Africa during the early Holocene. Tropical lakes were everywhere high (Rognon 1976a; Street & Grove 1976; Talbot & Delibrias 1977); discharge of the Senegal was probably at a maximum (Michel 1973); a tropical flora may have inhabited the Jebel Marra massif (Wickens 1975) and watertables were high in the fixed dune fields of the Sudan Qoz (Williams et al 1975) and probably also in the Sahel. From palynological evidence Michel & Assémien (1969) conclude that a vegetation of Sudan savanna type occupied the lower Senegal valley at this time. Assuming that the bioclimatic zones were more or less parallel to present zones, this would imply similar conditions throughout the length of the Sahel.

3.6.3.2 *Mid – Late Holocene.* Maximum fluviatile activity in the Sahel was terminated by the onset of a brief period of aridity (Figure 3.7), when at least some of the previously deposited alluvial sediments were reworked by the wind (section 3.5.2 above). Eventually relatively humid conditions returned, but now the monsoon seems to have been the only important source of water, the river valleys everywhere being characterised by sand-dominated, low-sinuosity braided streams of seasonal character.

Some fluviatile activity still occurred in the massifs during the mid-Holocene, but here, too, the sediments that accumulated were now much coarser. Sands and gravels predominate, deposited from episodic flood events that incised channels into the early Holocene argillaceous deposits (Jäkel & Schulz 1972; Geyh & Jäkel 1974; Rognon 1976b; Williams 1976). Whether the southward flowing streams made any significant contribution to the rivers of the Sahel is not known. Servant (1973, 1974) suspects that runoff from Tibesti during the mid-Holocene was negligible, but this was clearly not the case along the north-eastern flanks of the Aïr, where runoff was sufficient to maintain a permanent, albeit slightly brackish lake (Williams 1976). Episodic, possibly seasonal flow in the mountain wadis probably persisted from around 7 000 B.P. to 5 000 B.P. (Rognon 1976b; Maley 1977b; Williams 1976), so during this time they may well have acted as occasional tributaries to the lowland streams of the Sahel.

Evidence from lowland southern Saharan lakes (Munson 1974; Servant 1974; Servant et al. 1976) suggests generally elevated monsoonal precipitation during the mid-Holocene. At this time the Saharan coast of Mauritania and similar latitudes of inland Mauritania are thought to have had a climate of southern Sahel – northern Sudan savanna type (Elouard 1973; Munson 1974), a flora and fauna dated to around 5 000 B.P. to 4 000 B.P. from the Dhar Tichitt region of south-central Mauritania indicating annual rainfall to have been twice as great as at present (Munson 1974). These data imply that the Sahel itself might have been subjected to a Sudan climate, and in the south even a Guinea savanna-like climate at this time (c.f. Maley 1977b). Under these conditions the drainage networks of the Sahel may still have functioned seasonally as fully integrated systems, the larger rivers probably flowing throughout the year.

Subsequent evolution of Sahelian river systems towards their present highly degraded state followed the late Holocene decline in monsoonal precipitation which between 4 000 B.P. and 3 500 B.P. was low enough to permit local aeolian dune formation (Servant 1973, 1974; Maley 1977a). Thereafter, although the reappearance of permanent water in some of the lake basins indicates periods of moderate precipitation (Servant 1973, 1974; Elouard 1973; Munson 1974), rivers in the Sahel are likely to have been at best highly seasonal in character. Faunal and floral analyses of material excavated from archaeological sites at Karkarichinkat, in the Lower Tilemsi valley (Figure 3.1), imply that between 3 950 B.P. and 3 300 B.P. this watercourse was probably reduced to a series of muddy pools during the dry season. At the time of occupation the sites were surrounded by savanna woodland, indicative of annual rainfall amounts somewhat in excess of 300 mm (Smith 1975). From about 2 000 B.P. to the present the fluviatile regime has probably alternated between highly seasonal and its prevailing ephemeral state.

3.6.4 *Changes in effective catchment area*

Late Pleistocene and Holocene changes to rivers originating in, or north of the Sahel, must have profoundly affected the two major river systems of West Africa; the Niger-Benue and the Senegal. At present those areas of catchment which occupy the Sahel zone and northwards make insignificant contributions to the discharge of these rivers, but the situation must have been very different during more humid periods, when effective catchment areas were very much greater (Figure 3.6). This is especially true of the Niger-Benue system, which at the height of the humid phases received water from the overflowing Chad basin as well as the greatly enlarged effective catchment of the Niger itself. The resulting variations in discharge, hydrological regime and sediment load must have profoundly influenced the development of both the Niger and Senegal deltas. Unfortunately very little is known in detail about the Late Quaternary history of either delta, so it is not yet possible to see just what sedimentological effects these climatically-induced variations had on delta growth.

3.6.5 *Significance of the fluviatile systems to human exploitation of the Sahel*

In the southern Sahel, where rainfall is sufficiently abundant and regular to permit sedentary agriculture, sediments lining the relict alluvial valleys provide zones of relatively fertile land between the laterite-capped Continental Terminal plateaux. Since the unconsolidated sands can also yield abundant good water at no great depth, the valleys tend to be relatively densely populated.

Further north, where human populations are nomadic, favourable edaphic conditions provided by some alluvial accumulations can encourage the growth of valuable seasonal pasture. In Niger, for example, extensive spreads of fluviatile sands occur where the various streams draining upland areas formerly converged at the head of the Azaouak (Figure 3.6). This region, known as the Tamesna, is an important winter grazing ground for Tuareg stock. The water-storing capacity of the sands encourages the growth of the shrub *Schouwia*

schimperi, which provides excellent browsing for camels, the leaves containing sufficient moisture to allow these animals to go without drinking (Gérard 1974). Sections of some relict watercourses may also form part of seasonal transhumance routes (see Chapter 19).

The little that is known about the prehistory of the major relict watercourses is summarised in Chapter 18 of this volume. Undoubtedly both the rivers and their associated floodplains must have presented obvious economic attractions to former populations of the Sahel, these resources presumably being of paramount importance to the water-based economies that were so widely distributed in the Sahel and southern Sahara during early and mid-Holocene times (Sutton 1977; Chapter 18). Exploitation of the riverine resources may have been most intensive during times of environmental stress (seasonal or longer term), when surface water supplies became limited. In this respect it would be of particular interest to know what role the major north-south watercourses may have played in the development and dissemination of plant and animal domestication in West Africa. The arid phases of the Holocene, as well as the eventual decline towards present-day conditions, must inevitably have induced movements in the human populations of the Sahel. While they still carried water, the main river valleys would have provided obvious refuges and migration routes for man, his livestock and his cultivated food plants, as discussed in Chapter 18.

3.7 FIXED DUNE ENVIRONMENTS

Conservation of the dunes in bioclimatic conditions markedly different from those under which they were produced has been achieved largely by stabilization of the upper ten or so centimetres (rarely more than 20 cm) of previously unconsolidated sand. Below this stabilized surface layer the sands are still incoherent. A number of different binding agents are involved which in combination are remarkably effective at protecting the dunes from rapid degradation.

3.7.1 *Dune stabilization*

With increasing humidity the first step towards dune stabilization is probably colonisation of the unstable sand surface by vegetation. Although often low in nutrients, dunes may nevertheless be preferentially colonised, mainly because the great porosity and permeability of well-sorted aeolian sands permits large volumes of water to be stored within the body of the dune (Bagnold 1954; Worrall 1969; Cooke & Warren 1973). Colonisation commences on the lower slopes, presumably because moisture percolates downward through the dune, the exposed crest remaining mobile longest (Bagnold 1954; Cooke & Warren 1973). Although the binding effect of some plant roots must contribute towards stabilization, the vegetation cover is probably of equal importance in aiding the subsequent development of the most characteristic feature of the fixed dunes of the Sahel: a hard-setting, coherent crust, at most a few centimetres thick and relatively rich in fines (Tricart & Brochu 1955; Daveau 1965; Sombroek & Zonneveld 1971; Barbey & Carbonnel 1972; Talbot & Williams 1978). The source of these fines is slightly problematic. Some must come from the breakdown of unstable sand grains, but such minerals often make up only a very small proportion of the unaltered sediment (e.g. Worrall 1969; Courel 1977; Talbot & Williams 1978), so a significant proportion of the fines are probably of airborne origin. Winds blowing out of the Sahara are notable for the large volumes of sediment they carry (Chester et al 1972; Prospero & Carlson 1972; Emery et al 1974). Situated immediately downwind from the desert cores, the Sahel is particularly well-placed to receive windblown dust and it is probably material of this origin that has been incorporated into the dune surface. Deposition of airborne particles would be greatly enhanced by the baffling effect of vegetation (Olson 1958) and once deposited the fines can then be bound into place by other processes. Packing of silt and clay particles between surface sand grains as a result of raindrop impact (Williams 1969) is possibly the most important means of incorporating newly deposited fines into the dune surface. However, the particularly durable and coherent nature of the fixed dune surface also seems to owe much to the binding effect of filamentous fungi and algae, which have been reported from some Sahelian dunes (Daveau 1965; Barbey & Couté 1976; Talbot & Williams 1978).

3.7.2 *Dune degradation*

The easily identifiable relict dune forms present in the Sahel provide ready testimony to the effectiveness of the stabilisation processes. Nevertheless the dunes have been, and still are being degraded, as the varying preservation of the different dune generations shows, the oldest now commonly being represented by no more than low strips and mounds of sand.

Where fixed dunes are, or were cut by active rivers, or reach the littoral zone (marine and lacustrine), they are obviously prone to the normal processes of fluvial and wave erosion (e.g. Tricart & Brochu 1955). Dune degradation due to these processes occurs in only a very small proportion of the total area of fixed Sahelian dunes, however, and in general any erosion that takes place is the result of runoff generated on the dunes themselves.

The humid phases of the latest Pleistocene and Holocene inherited a landscape shaped mainly by aeolian processes. As such the landscape lacked an integrated drainage system and to a large extent this is still the case, the dune fields containing countless small drainage basins, the position and form of which has been determined largely by the nature of the original inter-dune depressions (Figures 3.2, 3.3). Any runoff thus tends to be confined to small, local streams, and ultimately to accumulate in shallow pools and marshes. Development of watercourses with sufficient discharge to breach the dune barriers has been relatively infrequent. Even during the most humid intervals, when the potential for fluvial activity should in theory be at a maximum, the very low runoff from fixed dunes, particularly when heavily vegetated (see below), greatly reduces the possibility of high magnitude flood events. Furthermore, during these periods, the immense storage capacity of unconsolidated aeolian sands would have maintained a high watertable and so a dense vegeta-

tion cover, thereby imparting considerable stability to any stream bank and the lower slopes of the dunes. Even today the favourable soil moisture conditions provided by the inter-dune depressions is still apparent, these areas carrying significantly more permanent vegetation than the upper dune slopes. For these reasons fluviatile modification of the fixed dune fields has been of a generally low order.

3.7.2.1 *Present-day dune degradation.* Data on the hydrology of fixed dune areas is scanty, but the small number of field measurements confirm a rather larger body of qualitative observations which show that despite the presence of a surface crust, the great bulk of any precipitation falling on fixed dunes is absorbed into the dune, surface runoff being rare. From a small catchment (9.1 hectare) near Tahaoua, Niger (median annual precipitation c. 400 mm), entirely given over to millet cultivation, Vuillaume (1969) obtained annual runoff coefficients of between 7.9 and 12.5%. However, Rodier (1975) suggests these values may be rather high and as a general rule feels that the coefficieint of around 0.5%, obtained from a catchment near Niamey (20 km^2; median annual precipitation c. 600 mm), may be more realistic. For the small catchment near Tahaoua, Vuillaume (1969) states that assuming no rainfall during the previous 24 hours then at least 14.5 mm of rain must fall in any storm before runoff can occur. Storms of this intensity are not frequent, but at least one would be expected during most years. The figure is of course a minimum and for any notable geomorphic changes to take place storms of much greater intensity are certainly required (see below).

Despite the obvious limitations of the data, it will be clear from the above that the development of significant runoff on stabilised dune sands is likely to be a rather rare event. Nevertheless, away from areas influenced by human activities, the most widely reported degradation of these dunes is that due to gully erosion, so overland flow of sufficient intensity to cut through the hard-setting surface crust must be generated from time to time. In a recent study of dune degradation, Talbot & Williams (1978) have suggested that gullying of Sahelian stabilised dunes is confined to a rather restricted bioclimatic zone and occurs most readily where annual rainfall is in the range 200-400 mm. In regions of higher rainfall vegetation is sufficiently dense and permanent to impede the development of overland flow, so that gullying does not often occur. In the Liptako dune field, for example, where annual rainfall is 400-600 mm, Courel (1977) reports that gullying is effective only where human interference has degraded the natural vegetation cover. At the other extreme, along the drier northern margin of the Sahel, in the Aouker erg of Mauritania, Daveau (1965) notes that the zone of dunes with active gullies is succeeded northwards by dunes upon which gullies are now being obliterated by windblown sand. A phase of recent aridification is presumed to be responsible for the present inactivity of the more northerly gullies, allowing a return to conditions under which aeolian processes can dominate.

Even within the bioclimatic zone favourable to gully erosion a number of factors must be satisfied before significant runoff can occur. The surface crust

is of primary importance in reducing the infiltration capacity of the dune sands and yet, as shown above, the crust is clearly incapable of completely sealing the surface on all but the oldest dunes. For runoff to occur storms must therefore be of sufficient intensity to overcome losses due to infiltration. In central Niger, at least, storms of a magnitude necessary to cause significant reworking of the dune sands are at present rather uncommon, gully activity being highly episodic (Talbot & Williams 1978). To be effective it also seems probable that even the intense storms must occur early in the rainy season, before much of the seasonal vegetation has appeared. There is unlikely to be much surface erosion once the dunes have acquired the dense covering of grasses which spring up when the rains are under way.

Although it is the stabilising effect of vegetation that is usually emphasized, Barbey & Carbonnel (1972) have pointed out that some perennial plant species may actually aid the development of gullies by helping concentrate overland flow. However the presence of suitable plants is clearly not essential for the initiation of gully erosion. In parts of central Niger, at least, there is no evidence that the channeling effect of vegetation has played any part in determining the position of gully heads (Talbot & Williams 1978).

In now rather humid regions like south-eastern Brazil, where annual rainfall at present exceeds 1 200 mm, gully erosion of fixed dunes is insignificant, but very extensive degradation can occur after heavy rain through mass-movement of water-saturated sands (Bigarella 1975). There are no reports of dune degradation of this sort occurring in the Sahel, although it could conceivably take place in some of the southernmost fixed dunes and might, perhaps, have been rather widespread during the humid phases of the Holocene.

Aeolian remobilisation of the dune sands is possible only where the surface crust has been removed. Destruction of the crust and natural vegetation through tillage or browsing and trampling by livestock render the sands particularly prone to deflation, aeolian reworking occuring throughout the Sahel wherever there has been extensive man-induced surface damage (e.g. Daveau 1965; Courel 1977).

3.7.3 *Sediment accumulation in inter-dune depressions*

Sediments liberated during erosion of the fixed dunes have been reworked and redeposited, much of it in inter-dune depressions, the dune fields now displaying a complexly juxtaposed suite of sediments that accumulated under contrasting bioclimatic regimes. As yet unexplored in any detail, it is likely that these depressions contain some of the best records of Late Pleistocene and Holocene environmental change in the Sahel.

3.7.3.1 *Pools and marshes.* Sediments accumulating here are predominantly sandy silts and muds, often containing wood fragments and other finely divided plant debris. Modern deposits are usually strongly disrupted by desiccation cracks that develop as the surface water disappears. Seasonal evaporation also tends to make the sediments strongly alkaline, locally resulting in the growth of calcrete nodules (Pullan 1969). During more humid periods, when water tables

were higher, the depressions carried larger and more permanent bodies of water. Remnants of the sediments that accumulated in these lakes occur throughout the Sahel. The commonest deposits are silts and clays, sometimes rather calcareous, but diatomites are also known, the latter apparently accumulating more particularly during the early Holocene (Beaudet et al. 1976). Some of the diatomites are extremely pure, the absence of any clastic influx suggesting that these accumulated in lakes fed entirely by groundwater (Faure 1969).

3.7.3.2 *Alluvial fan and sheetflood deposits.* Sand transported during gully erosion of fixed dunes may be deposited on small alluvial fans spreading out from the lower dune slopes. Talbot & Williams (1978) have described fans of this type that are episodically active along the flanks of fixed dunes in the region of Janjari, Niger. The fans are composed almost entirely of redeposited, well-sorted aeolian sands that have accumulated in cyclic fashion. Episodes of fan aggradation alternate with periods of degradation and also with intervals when dunes and fans were stabilised under a dense cover of vegetation. It is probable that the cycles are climatically controlled, recording alternations between relatively dry conditions (like the present), periods of more intense rainfall and periods of significantly greater rainfall.

On very low slopes gullying is impersistent and irregular. Sediment mobilised as a result of flow down these slopes tends to accumulate as thin (commonly ⟨30 cm), laterally extensive sheets rather than in distinct fans. These deposits have a very low preservation potential, being particularly prone to dry season deflation, but the sheet floods are responsible for introducing thin beds of sand into the pond and marsh silts.

3.7.4 *Human aspects of fixed dune environments.* Deposition of fine-grained sediments in inter-dune depressions has been of extreme importance to the exploitation of fixed dune regions, especially in the northern half of the Sahel. The muds and silts provide an effective seal to underlying formations, be they dune sands or bedrock, and therefore encourage the accumulation of surface water. The pools, which develop during the rainy season, can provide water for up to several months and the periphery of such pools are thus particularly favourable occupation sites. Furthermore, since they are widely distributed throughout the fixed dune fields, the pools permit much more extensive exploitation of these regions than might otherwise be possible.

The particular value of surface water resources to those nomads wishing to maintain large herds of livestock is emphasised when it is realised just how far groundwater may lie below the surface of the depressions. Depths to water table of 10 m are common and at In Waggeur, Niger, for example, a well immediately adjacent to a large seasonal pool had to reach 88 m before permanent groundwater was encountered. Seasonal availability of surface water makes fixed dune areas particularly attractive to the pastoral nomads of the Sahel, especially as the grasses of the surrounding dunes provide good grazing. Occupation usually occurs during the winter months following the rainy season, once ephemeral water supplies in more northerly regions have become exhausted (Bernus 1974; Gérard 1974).

Some of the obvious advantages of the stabilised dune environment must also have been appreciated by prehistoric inhabitants of the Sahel. Neolithic artefacts are notably abundant in the fixed dune fields and it is clear that during this period these areas were extensively occupied. The Neolithic of north-eastern Niger has been dated to between 7 000 B.P. and 4 000 B.P. (Clark 1971; Maley et al. 1971; Clark et al. 1973; Roset 1974). In the Sahel at this time surface water is likely to have been more abundant than at present and probably permitted rather longer occupation of fixed dune areas, although the likelihood of a markedly seasonal climatic regime (section 3.6.3.2) may still have necessitated some dry season movement towards the larger waterbodies. In view of their attractiveness to modern pastoralists it would be of considerable interest to know whether fixed dune fields were of similar importance to their Neolithic counterparts. These areas, like the main watercourses, would have assumed particular importance as increasing aridity forced pastoralists to retreat from more northerly areas. Evidence for domesticated cattle in the southern Sahara dates back to at least 5 760 ± 500 B.P. (Clark et al. 1973; Chapter 20), so it is probable that the fixed dune fields of the Sahel have played an important part in the transhumance cycle of nomadic pastoralists for a very long time indeed.

It is also clear that the earlier Holocene cultures subsisting on fishing and other water-based resources were by no means confined to major river valleys. Lakes were extensively exploited (Sutton 1977; Chapter 18 of this volume), the numerous flooded inter-dune depressions and dune-blocked valleys that existed during early and mid-Holocene times probably providing one of the main reasons why these cultures became so widespread in sub-Sahara Africa.

Fixed dunes are also important to the sedentary agriculturalists of the southern Sahel. Cultivation of the dunes can be extremely intensive, in stark contrast to the often completely untilled dune depressions (see for example photos in Grove 1970: 131), the sandy soils of the former providing some of the best land for the cash-crop ground-nut economy so important to the Sahel countries (Tricart & Brochu 1955; Worrall 1969).

3.8 SUMMARY AND FINAL COMMENTS

Palaeoenvironmental interpretations based on evidence from the sedimentary record of the Sahel show that over the past 20 000 years the region has evolved in broadly similar fashion to adjacent areas of West Africa. It will be apparent from this review, however, that detailed studies, securely based on a framework of radiometric dates are sadly lacking. Clearly a great deal more work remains to be done. Two environments in particular, the defunct fluviatile systems and the fixed dunes, would undoubtedly repay further investigation. A necessarily generalized discussion of the palaeohydrology of the watercourses has been attempted above. Detailed study of the alluvial sequences preserved in the major south-flowing dry valleys should provide much more precise information on Late Pleistocene and Holocene changes in fluviatile regime and possibly rainfall sources as well. The greatest potential of the inter-dune depression sequences

probably lies in their palynological record of variations in the vegetation clothing the immediately adjacent dune slopes.

This survey has also shown that the issue of atmospheric circulation over tropical West Africa during the Late Pleistocene arid phase remains open. Field evidence suggests that seasonal movement of the ITCZ was probably little different from today, aridity resulting from a concurrent decrease in precipitation and increase in wind vigour. Although the interpretation presented here is substantiated by palaeoceanographic data (section 3.5.5.3), it is clearly desirable that a search be made for further evidence from terrestrial West Africa.

3.8.1 Evidence has been presented herein which suggests that the Late Pleistocene arid phase may not have been a result of the ITCZ being displaced permanently to the south. If so, it is important to establish whether or not any significantly greater northward penetration of the ITCZ was involved in the development of the subsequent humid phase.

Penetration of the modern ITCZ into continental West Africa is in most years sufficient to bring small amounts of monsoonal precipitation at least as far as 20°N. Increased rainfall from a humid air mass reaching northern limits comparable to those achieved at present could thus have produced the latest Pleistocene and Holocene humid phases. That the ITCZ cannot have penetrated much further north than it does today is shown by the evidence for hyperaridity persisting throughout the Holocene in the Sebkha de Taoudenni (20°30'N) (Cour & Duzer 1976).

3.8.2 A brief but notably arid interval separated the early and mid-Holocene humid phases and similar arid intervals also occurred at other times. As yet we have very little information on the effects these arid spells may have had on the hydrology of the Sahel. Surface water supplies must have been greatly reduced, with obvious human implications. It is possible that the observed aeolian reworking of floodplain sediments at these times was in part a consequence of human over-exploitation of dwindling resources, especially once man had acquired large numbers of domesticated livestock. In this respect it is interesting to note that anthropogenically-induced changes in the flora of the Sahel are detectable in the pollen rain reaching the Sebkha de Taoudenni from mid-Holocene times onwards (Cour & Duzer 1976).

3.8.3 I have speculated on those aspects of increased surface water resources that might have been particularly favourable to past human exploitation of the Sahel. At the same time it is, however, advisable to sound a note of caution. During more humid periods the Sahel obviously had a savanna-like climate. Surface waters of the modern West African savanna carry with them some highly undesirable effects. Besides the ubiquitous mosquito-borne infections, the two most notable endemic diseases here are river blindness (*Onchocerciasis*) and sleeping sickness (*Trypanosomiasis*). The fly vector of the former requires running water during its larval stage, while the vector of the latter depends upon riverine woodland for its dry season refuge. Both diseases strongly influence exploitation of the modern savanna (Morgan & Pugh 1969; Grove 1970), river

blindness, for example, being one of the main reasons why the floodplains of many savanna rivers are very thinly populated. Such hazards to human populations were presumably present during the Late Pleistocene and Holocene when the Sahel may also have come under their influence. Perhaps during the periods of maximum fluviatile activity, the association of river-blindness with running water would have made fixed dune areas all the more desirable habitats, although even these would presumably not have been free from the risk of sleeping sickness (which infects cattle as well as man).

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4

Les changements climatiques de la fin du Tertiaire en Afrique: leur conséquence sur l'apparition du Sahara et de sa végétation

End-Tertiary climatic changes in Africa: their effect on the origin of the Sahara and its vegetation

The present vegetation of the Sahara is not uniform: the northern part is inhabited mainly by taxa of holarctic origin and the southern part by taxa of tropical origin. Diverse data show that desert conditions appeared during lower Pliocene time. Earlier, during the first part of the Tertiary, equatorial conditions prevailed over the southern part of what is now the Sahara. An important climatic change occurred near the Eocene-Oligocene transition. From Oligocene time to the Miocene, the area of the Sahara was occupied by a tropical vegetation of Sudano-Guinean or Sudanian type. By contrast, southern Africa including Zaire was dominated before the Miocene by conditions that were dry and at times even totally arid. This difference between northern and southern Africa was only partly due, especially in the early Tertiary, to the more southern position of Africa, because since the Eocene the equator has been close to its modern position. It seems likely that the principal cause of the extension of tropical savanna over the Sahara lay in the general circulation of the atmosphere. From the Eocene, the appearance of the first glaciers in Antarctica introduced a global thermal disequilibrium which brought moisture to the Sahara, but not to southern Africa. The Intertropical Convergence Zone must have reached the northern Sahara regularly; the Tethys Sea was also a source of humidity.

The first northern hemisphere glaciations appeared during late Miocene time. This involved a decrease in the global disequilibrium and at the same time aridification of the Sahara. The cooling of the northern hemisphere was accentuated during the early Pliocene, coincident with the appearance of desert conditions in the Sahara. On the other hand, during the Pliocene, various data indicate an increase in moisture to the south of the Sahara. One can believe that this cooling, by increasing the thermal gradient between equator and pole in the northern hemisphere, was the prime cause of the expansion of the subtropical anticyclones, which produce desert conditions, and at the same time of an important retreat of the ITCZ to the south of the Sahara with consequent increase of rainfall over what are now the Sudanian and Sudano-Guinean zones. This same phenomenon has re-occurred several times during the Holocene but on a much smaller scale.

Pollen analysis of Pliocene samples shows that the modern xerophytic vegetation was already in place in the Sahara. The heterogeneity of the modern vegetation of the Saharan mountains is the result of ancient influences, tropical or holarctic, which have affected the Saharan flora. In this regard, the tropical origin of *Olea laperrini* is evaluated. The xerophytic taxa of tropical origin may have come from the 'Rand Flora', which would have developed since the beginning of the Tertiary from the flora of the Cape or its precursors. The xerophytic taxa of holarctic origin (saharo-sind taxa) would have become differentiated during the course of the Tertiary in the dry regions of Asia.

4.1 INTRODUCTION

Les données paléobotaniques (pollens, bois, empreintes de feuilles) concernant le Plio-Quaternaire du Sahara sont relativement réduites. Elles concernent essentiellement le Pliocène et la fin du Quaternaire et ont déjà fait l'objet d'une synthèse (Rossignol & Maley 1968) qui a été reprise récemment par Schnell (1976 v. 4: 29-34). A partir des données sur le Pliocène et d'autres concernant des périodes plus anciennes, cet article essayera de rechercher quand et comment sont apparues les conditions désertiques au Sahara et comment s'est effectué son peuplement végétal.

La plupart des botanistes admettent que certains taxons vivant actuellement au Sahara et sur ses montagnes ont pu y parvenir dès le Tertiaire. Il sera donc nécessaire de prendre un certain recul et de voir quels étaient la végétation et le climat du Sahara au Tertiaire.

4.2 LE PEUPLEMENT VEGETAL ACTUEL

L'étude du peuplement végétal actuel du Sahara montre que 'le Sahara est double: il n'y a pas le Sahara, mais deux Saharas, l'un (N) plutôt paléarctique, l'autre (S) plus ou moins paléotropical' (Monod 1957: 76). Cette dualité résulte des conditions climatiques. Les deux facteurs essentiels sont le rythme des pluies, quand il en tombe, et la température. Le Sahara septentrional a un rythme méditerranéen assez bien marqué, c'est-à-dire que les pluies peuvent se produire de l'automne au printemps. L'hiver les gelées ne sont pas rares. Le Sahara méridional a un rythme nettement tropical, c'est-à-dire que les pluies se produisent essentiellement en été, au moment où la température est la plus élevée: on peut ainsi parler du Sahara tropical. Sa limite septentrionale est difficile à situer (Barry et al. 1976); en plaine, l'isohyète 100 mm pourrait grossièrement servir de limite. Le Sahara central, suivant les années, est affecté tantôt par les conditions climatiques du Sahara septentrional avec ici des pluies liées essentiellement aux dépressions soudano-sahariennes, tantôt par celles du Sahara méridional, avec des pluies estivales liées à la remontée du Front Intertropical. Ainsi l'hétérogénéité de la végétation du Sahara central (Barry et al. 1972) pourrait résulter de l'alternance ou de l'interpénétration de ces deux influences climatiques. De plus les changements climatiques qui affectèrent le Sahara depuis la fin du Tertiaire et au cours du Quaternaire, firent varier ces deux influences, favorisant l'une au détriment de l'autre, en faisant déferler vers le Nord ou vers le Sud des vagues de taxons nouveaux. A chaque fois les montagnes du Sahara servirent de refuges à un certain nombre de taxons inadaptés aux conditions nouvelles, soit parce qu'ils y trouvèrent l'humidité nécessaire à leur survie, soit du fait des températures plus basses des sommets. Ainsi les montagnes du Sahara, oasis au milieu du désert, sont des lieux privilégiés pour l'étude de l'histoire des flores sahariennes, particulièrement par l'analyse pollinique de sédiments anciens.

4.2.1 *Origine des taxons vivant actuellement au Sahara* (d'après Quézel 1965: 41; Monod 1957: 76)

Origine holarctique: Les *taxons eurasiatiques* peuvent être subdivisés en trois groupes. Les *taxons de type tempéré* sont très peu nombreux et réfugiés sur les plus hautes montagnes. Les *taxons méditerranéens (s. stricto)* sont relativement bien représentés sur la bordure nord-occidentale et sur les montagnes. Les *taxons saharo-sindiens* constituent plus de 70% de la flore du Sahara septentrional et sont encore très abondants au Sahara central. Le rythme climatique tropical les élimine, c'est pourquoi ils font presque complètement défaut au Sahara méridional. Ils proviendraient en majorité de la région 'mésogéenne' mais une origine australe est aussi possible pour certains (Zohary 1962).

Origine africaine: Les taxons proprement africains peuvent avoir soit une origine tropicale, soit une origine africaine-australe (Flore du Cap) où règne le pendant austral du climat méditerranéen. Les *taxons sahéliens,* adaptés à des conditions arides, se rencontrent partout au Sahara méridional et central dans les paysages de savane désertique. Les *taxons soudaniens et soudano-guinéens* sont très rares au Sahara; on les rencontre seulement dans les oasis du Sud (Borkou) et surtout réfugiés sur le sommet de quelques montagnes (Aïr, Tibesti, Ennedi). Les *taxons montagnards* originaires des flores africaines de moyenne altitude (Djebel Marra, Ethiopie, Afrique orientale) se rencontrent presque uniquement au Tibesti et en Aïr. Les *taxons oro-africains* originaires des flores des hautes montagnes africaines (Djebel Marra, Ethiopie, Afrique orientale) existent essentiellement au Tibesti. Les *taxons érémitiques* très adaptés aux conditions sahariennes représentent les vestiges d'une flore xérophile archaïque répandue à travers toute l'Afrique et appelée 'Rand Flora' (Monod 1957: 14).

Cette Rand Flora apparaît très importante pour l'histoire des flores xérophiles africaines. Elle correspondrait à l'extension à travers l'Afrique, au moins dès le début du Tertiaire, de la Flore du Cap, ou de ses précurseurs (Wild 1963: 132; Schnell 1976 v. 3: 198), qui vit actuellement dans l'extrême sud de l'Afrique sous un climat à rythme méditerranéen. De nombreux taxons montagnards et oro-africains trouveraient ainsi leur origine dans la Rand Flora (Wild, ibid). Cependant, dans leur expansion à travers l'Afrique, un certain nombre de taxons de la Rand Flora se seraient adaptés à des conditions plus chaudes et plus tropicales (Schnell, ibid.). Comme le fait remarquer Monod (1957: 16), il devient ainsi 'difficile, ou impossible, de distinguer les vraies africaines de la Rand Flora, des paléotropicales ordinaires, à distribution de type congo-indien voire congo-malais'. Ainsi les taxons hypothétiquement issus de la Rand Flora appartiendraient à deux lignées: l'une formée de taxons ayant conservé leur adaptation à une rythme méditerranéen, se marquant surtout par leur faculté de vivre sous des températures peu élevées, l'autre au contraire formée par ceux qui se sont adaptés à des températures plus chaudes et à un rythme tropical. Différentes listes de taxons pouvant appartenir à la Rand Flora ont été publiées (Monod 1957: 16). Parmi ceux-ci on peut citer *Podocarpus, Erica,* les Euphorbes cactiformes, des Crassulaceae.

4.3 LE SAHARA AVANT LE DESERT

Les travaux des géologues et des géochimistes ont montré que du Paléocène à l'Eocène des conditions équatoriales ont régné sur le Sahara méridional, en particulier au Mali et au Niger (Millot 1963: 315) où la sédimentation dans un golfe marin était purement chimique, dominée par l'attapulgite. Aucun apport terrigène ne venait des zones continentales. Ces données impliquent une altération intense sous couvert forestier dense. Vers la limite Eocène-Oligocène (Radier 1959; Busson & Grambast 1965) des changements de faciès sont intervenus, traduisant un important changement climatique. Un climat tropical avec une saison sèche de type soudanien à soudano-guinéen a fait son apparition. Sur tout le Sahara se dépose un vaste complexe détritique appelé 'Continental Terminal'. Faure (1966: 492) a montré qu'au Niger des dépôts importants d'oolithes ferrugineuses se formaient et que la kaolinite – minéral typique des conditions tropicales – était pratiquement la seule argile de ces dépôts. D'autre part, des dépôts lacustres largement silicifiés se rencontrent à travers tout le Sahara: Tanezrouft (Karpoff 1958: 228), Algérie (Conrad 1968: 438), Soudan (Whiteman 1971: 90). Durant la première partie du Tertiaire, particulièrement à l'Eocène inférieur, des mers épicontinentales se sont étendues sur le nord du Sahara et dans le secteur de la boucle du Niger (Furon 1960; Louvet et al. 1971). A partir de l'Oligocène, ces mers se retirent progressivement.

Les données paléobotaniques convergent avec les données précédentes. Des couches paléocènes du Niger, vers 17°N, ont livré des bois appartenant à des taxons forestiers (*Macaranga, Ricinodendron, Sapium, Guarea, Trichlia*) (Koenigeur 1971). A partir de l'Eocène, ce sont les espèces de savane qui dominent (Louvet et al 1971). Les principales familles suivantes ont été recensées au Sahara: Euphorbiaceae, Combretaceae, Caesalpiniaceae, Papilionaceae, Palmae, Sapindaceae, Rutaceae, Moraceae, Myrtaceae, Guttiferae, Annonaceae, etc. (d'après les traveaux de Boureau et ses élèves, in Aubréville 1970). Des analyses polliniques ont été effectuées par Kedves (1971) sur des sédiments carottés provenant du nord de l'Egypte, dans la région du Caire (Eocène et Oligocène) et du Wadi Natrun (Miocène et Pliocène). Malgré la difficulté de rattacher un certain nombre de formes polliniques à des taxons botaniques, ces analyses apportent des informations sur la partie nord orientale du Sahara. Ainsi, un échantillon de la fin de l'Eocène, présentant une grande abondance de pollens de Gramineae et la première apparition d'un type pollinique de Compositae, pourrait être corrélé avec l'important changement climatique marquant le début du 'Continental Terminal'. Des types polliniques apparentés aux Sapotaceae et aux Bombacaceae étaient présents à l'Eocène et d'autres apparentés à *Ilex* à l'Oligocène. Il faut aussi noter la présence de pollens apparentés aux Cycadales, en quantité relativement importante, à travers presque tout le Tertiaire et qui disparaissent après le Pliocène inférieur. Les Cycadales sont des vestiges des anciennes flores mésozoïques et possèdent des structures xéromorphes particulières (Schnell 1976 v. 3: 63). Actuellement, en Afrique, on trouve les genres *Cycas* et *Encephalartos.* Ce dernier genre, endémique de l'Afrique, se rencontre dans les savanes boisées, particulièrement sur les plateaux gréseux et les sols rocailleux (Schnell, ibid.); d'après Monod (1971) ce genre serait à rattacher à la Rand Flora. Bonnefille

(1975: 33) a trouvé aussi des pollens de Cycadales dans des couches pléistocènes d'Ethiopie. A partir du Pliocène, Kedves (ibid.) a trouvé pour la première fois des pollens d'*Alnus* et de Caryophyllaceae. Ces derniers résultats sont identiques aux analyses de Kourkour (Pliocène supérieur) discutées plus loin.

Pour l'Afrique au sud de l'équateur, les données paléoécologiques concernant le Tertiaire, particulièrement avant le Miocène, sont plus rares. Au Kenya et en Ouganda, c'est seulement à partir de la base du Miocène datée radiométriquement qu'on rencontre des biotopes forestiers et de savane, riches en espèces animales et végétales (Hamilton 1973: 190). Par contre, antérieurement sur l'Afrique australe jusqu'au Zaïre (De Ploey et al. 1968; Van Zinderen Bakker 1975; Gill 1961: 347) et même jusqu'en Centre-Afrique (RCA) (Gérard 1958: 31) les conditions étaient arides et à certaines périodes franchement désertiques (dépôt du 'Système du Kalahari'; cf. de Ploey et al. 1968; Furon 1960: 80).

Cette différence assez nette entre le nord et le sud de l'Afrique n'était due qu'en partie, surtout pour la première partie du Tertiaire, à la position plus méridionale de l'Afrique. Au début du Tertiaire, l'équateur devait se situer vers le nord du Nigéria (Robinson 1973: Figure 3). Mais dès l'Eocène il occupe une place très proche de sa position actuelle (Girdler 1968: Figure 4). Il semble bien que la cause principale de l'extension des savanes tropicales sur le Sahara soit due avant tout à la circulation atmosphérique générale. Au début du Tertiaire, le gradient thermique Pôle-Equateur (P-E) devait être nettement plus faible qu'actuellement sur les deux hémisphères (Frakes & Kemp 1973: 555). Une évaporation élevée sur les océans et une circulation atmosphérique plus méridionale devait faciliter les transports d'humidité jusque dans les zones polaires (ibid.). Mais l'apparition des premières glaciations sur l'Antarctique dès l'Eocène (Kennett 1972; Le Masurier 1972) a introduit un déséquilibre des échanges thermiques qui était favorable au Sahara mais défavorable à l'Afrique australe. En effet, ce refroidissement précoce a augmenté le gradient thermique P-E sur l'Hémisphère Sud et, par là-même, a provoqué l'extension et la descente en latitude des anticyclones subtropicaux qui sont toujours une cause d'aridité (De Planhol & Rognon 1970: 41).

Etant donné la relation directe existant entre le gradient thermique P-E et la position de la ZCIT (Flohn 1965; Pédelaborde 1970: 63; Newell 1973), il apparaît qu'un gradient thermique estival très réduit sur l'Hémisphère Nord et en même temps élevé sur l'Hémisphère Sud était favorable à l'envahissement du Sahara par la mousson. Le refroidissement de l'Hémisphère Sud se fit par à-coups, car des phases de réchauffement y ont été détectées au cours de l'Oligocène et du Miocène (Denton et al. 1969). Elles eurent pour effet de diminuer le déséquilibre thermique global favorable au Sahara. Ces différents phénomènes sur les deux Hémisphères eurent comme corollaire une augmentation de la saison sèche sur le Sahara et aussi une extension plus limitée de la mousson vers le Nord. Il faut remarquer à ce propos que les pluies de l'extrême nord de l'Afrique, sur le Maghreb en particulier, n'étaient pas forcément liées à la mousson. La Téthys devait être une source importante d'humidité pouvant être à l'origine de pluies sur le Nord de l'Afrique.

Différents indices (bois, Rongeurs) montrent qu'au cours du Miocène le climat tropical semi-humide était en déclin sur le Sahara et que des oscillations

plus ou moins arides y apparurent. L'étude des faunes de Rongeurs (Jaeger 1975: 137) a montré que des phases arides se sont produites au Maghreb au cours du Miocène moyen et supérieur. Le net endémisme des Rongeurs du Maghreb à cette époque semblerait pouvoir s'expliquer par un Sahara déjà plus sec. Cet endémisme 'implique un isolement déterminé au Nord par la Téthys, mais qui au Sud ne peut être imputé qu'à une barrière climatique' (Jaeger 1975: 131). Cela rejoint en partie l'observation de Louvet et al. (1971: 182) selon laquelle des bois datés du Miocène supérieur du nord de la Libye présentent des zones poreuses nettes, indiquant un climat à saison sèche prononcée.

La fermeture de la Téthys vers l'Est s'est effectuée au début du Miocène (Dewey et al. 1973), permettant d'importants échanges fauniques entre l'Eurasie et l'Afrique du Nord, surtout au Miocène inférieur; quelques immigrants asiatiques sont aussi notés au Miocène moyen et supérieur (Jaeger, ibid.). On peut penser qu'en même temps des échanges floristiques se sont produits. Il faut noter que les représentants actuels des Rongeurs qui sont arrivés au Maghreb au cours du Miocène sont caractéristiques pour la plupart des zones arides et semi-arides.

4.4 L'APPARITION DU DESERT AU PLIOCENE

4.4.1 *Les faits*

Les données actuellement disponibles montrent que les conditions désertiques font leur apparition au Sahara central et méridional dès le début du Pliocène (étage situé classiquement entre 5 et 1,8 MA; Berggren et al. 1974). Les premiers dépôts éoliens sont signalés au Sahara par Butzer & Hansen (1968: 362) dans le Pliocène inférieur de Kourkour (oasis du sud de l'Egypte à environ 50 km à l'ouest du Nil). Cet âge a été obtenu par des données géomorphologiques en relation avec le Nil. D'autre part, vers le nord du Tchad, dans la région de Koro-Toro, le gisement de Kolinga 1 (altitude env. 280 m) a pu être situé entre 4 et 5 MA (Pliocène inférieur) grâce à sa faune, par référence aux faunes bien datées de l'Afrique orientale (Coppens 1972: 184). Ce gisement a aussi fourni des bois rapportés à *Tamarix* et à *Retama* cf. *raetam* (Coppens & Koenigeur 1976). C'est à cette latitude la première apparition de taxons d'origine holarctique probable (Zohary 1973: 385 et 393) et bien représentés actuellement au Sahara dans l'élément Saharo-sindien. Avec ces deux bois se trouvait aussi une liane (Caesalpiniaceae ou Papilionaceae) suggèrant un biotope de ripisylve (ibid.). Ces diverses données pourraient s'interpréter par des conditions désertiques sur le Sahara central, allant en s'atténuant sur le nord du Tchad.

Des dépôts rapportés au Pliocène ont été étudiés dans le bassin du Tchad par Servant (1973: 13). Ils proviennent d'affleurements situés dans la région de Koro-Toro et de plusieurs sondages profonds effectués dans la zone du lac Tchad. Près de Koro-Toro, des dépôts fluvio-lacustres épais de 70 m au minimum ont pu être datés grâce aux faunes de mammifères (Coppens, ibid.): vers

la base, du Pliocène inférieur (zone de Kolinga 1) et plus haut dans la série, du Pliocène supérieur (zone de l'Ouadi Derdemi, comparée à Omo 2, datée de 2 à 3 MA). Les couches lacustres contiennent des diatomées qui ont été étudiées par Servant-Vildary (1973). Un certain nombre de ces diatomées sont archaïques ou éteintes et connues du Pliocène d'Europe et d'Amérique du Nord. Certaines, particulièrement les *Centrales,* peuvent être utilisées comme marqueurs stratigraphiques (ibid.: 212). De cette manière, Servant-Vildary a prouvé que le Pliocène existait dans les sondages effectués près du lac Tchad. Ici les couches pliocènes sont épaisses de 200 à 250 m et correspondent essentiellement à des formations lacustres argileuses riches en diatomées (analyses polliniques en projet). Les couches sous-jacentes antépliocènes sont des sables fluviatiles mal classés (Servant 1973: 19). Les dépôts susjacents, épais en moyenne de 60 à 80 m, sont des sables éoliens avec des lentilles d'argile ou de calcaires lacustres (série des Soulias) correspondant approximativement au Pléistocène (Servant, ibid.). Dans la région de Koro-Toro, la fin du Pliocène ou le début du Pléistocène (Servant, ibid.: 15) se marque par l'apparition de calcaire et de sable éolien (Formation de Morouo) et en même temps par l'apparition de diatomées à cachet moderne (Servant-Vildary 1973:213). Près du lac Tchad, de la même manière, des sables éoliens sont parfois interstratifiés vers le sommet des couches lacustres et, fait important, en même temps que les diatomées *Centrales* archaïques disparaissent au profit d'une flore diversifiée de *Pennales,* il y a apparition dans un niveau, d'espèces nord-alpines et tempérées (ibid.: 205). Il faut donc concevoir en plaine des conditions de température relativement basse. Cette brève période de refroidissement est intéressante car elle semble pouvoir se corréler au moins en partie avec des changements climatiques importants détectés vers l'équateur (cf. infra) et avec une période de refroidissement en Méditerranée, caractérisée par la biozone à *Globorotalia inflata* qui vit actuellement en hiver dans des eaux fraîches (de 13° à 15°C) (Cita 1975: 540). Le paléomagnétisme a permis de situer cette biozone entre 2,2 et 1,8 MA (Chamley 1975: Figure 8), c'est-à-dire à la fin du Pliocène.

L'accumulation de l'épaisse série lacustre pliocène semble avoir été favorisée par la subsidence de la partie orientale tchadienne du bassin à cette époque (Servant 1973: 22), mais elle semble due surtout à un climat tropical nettement plus humide qu'antérieurement sur les régions méridionales du bassin. Cette interprétation est confirmée par des données provenant du Nigéria et du Sénégal. Dans la partie méridionale du bassin du Tchad, sur le Plateau de Jos, une cuirasse ferrugineuse épaisse de 5 à 10 m s'est développée sur une série fluvio-volcanique d'âge finiTertiaire (Boulangé et al. 1971). La cuirasse a été ensuite recouverte par des basaltes dont les âges K-Ar sont compris entre 0,5 en 2 MA (Burke et al. 1970: 75). Cette cuirasse se situe donc assez bien au Pliocène. D'autre part au Sénégal, une importante phase d'altération fini-Tertiaire a été aussi responsable de la formation d'une cuirasse ferrugineuse très épaisse (Tessier 1965; Nahon et al. 1970; Tessier et al. 1975) qui repose par endroits sur des couches volcaniques miocènes datées par le K-Ar (six dates situées entre 13,2 $\pm$ 0,4 et 6,9 $\pm$ 0,2 MA; Cantagrel et al. 1976). Toutes ces données concourent à situer au Pliocène une importante période humide sur ces régions.

4.4.2 *Essai d'explication*

A l'échelle des datations disponibles, l'apparition du désert sur le Sahara et le renforcement de la pluviosité plus au Sud semblent synchrones. Ces deux phénomènes qui paraissent ainsi liés pourraient résulter de l'accentuation du refroidissement de l'hémisphère Nord à partir du début du Pliocène.

Le refroidissement de l'hémisphère Nord vers la fin du Tertiaire s'est d'abord manifesté par l'apparition de glaciers de montagne aux hautes latitudes en particulier dans les montagnes de l'Alaska où des tillites interstratifiées avec des coulées volcaniques ont été datées par le K-Ar de 9 à 10 MA (Miocène supérieur) (Denton et al. 1969). La présence de glaces permanentes jusqu'au niveau de la mer a nécessité un refroidissement plus accentué. Ainsi les premiers icebergs ne sont apparus dans la Mer du Labrador que vers 3 MA (Pliocène moyen) (Berggren 1972 in Mercer 1976: Figure 6). Une forte augmentation passagère des icebergs se situe ensuite vers 2,5 MA (ibid.) puis une autre vers 1,9 MA (Pliocène supérieur) (Kent et al. 1971 Figure 8; Berggren et al. 1974: 151). Ce dernier refroidissement peut se paralléliser en partie avec celui observé au Pliocène supérieur en Méditerranée (cf. supra). Auparavant, vers la base du Pliocène, entre 5,5 et 4,5 MA, un abaissement de la température des eaux de la Méditerranée nord-occidentale (région de Nice) a été aussi décelé par l'étude des isotopes de l'Oxygène (De Lumley 1976: 312). Ces baisses de température jusqu'en Méditerranée sont une preuve de l'accentuation du refroidissement de l'hémisphère Nord dès le début du Pliocène.

Ce refroidissement, en augmentant le gradient thermique P-E, aurait été la cause première de l'extension des anticyclones subtropicaux et d'un important recul de la ZCIT au sud du Sahara. Chaque année la ZCIT demeurait plus longtemps sur ce qui est approximativement les zones soudanienne et soudano-guinéenne actuelles et, par voie de conséquence, il y avait augmentation des pluies. Au cours de l'Holocène, à plus petite échelle, le même phénomène s'est reproduit plusieurs fois pour la zone soudano-guinéenne du sud du bassin du Tchad (Maley 1977). Plus au nord, l'apparition des conditions désertiques au début du Pliocène a résidé dans l'extension concomitante des anticyclones subtropicaux. Si les diverses datations données ci-dessus se confirment, il apparaît que les conséquences du refroidissement de l'hémisphère Nord se sont rapidement manifestées aux basses latitudes. En effet, les changements climatiques aux basses latitudes sont dus avant tout à des changements dans la circulation atmosphérique générale, provoqués eux-mêmes par des variations de la température (Lamb 1966: 210).

En Afrique, les conséquences du refroidissement de la fin du Pliocène se sont faites sentir jusque vers l'équateur. Dans le Nigéria méridional, des données polliniques (Germeraad et al. 1968) indiquent la persistance de taxons forestiers depuis le début du Tertiaire jusqu'au Pléistocène. Cependant, des changements importants semblent être apparus au Pliocène sur la chaîne de l'Adamaoua et son prolongement vers la mer. En effet, des analyses polliniques effectuées sur des sondages provenant du delta du Niger ont montré la brutale apparition vers la fin du Pliocène de grandes quantités du pollen très typique de *Podocarpus milanjianus*, gymnosperme montagnard (Knapp 1971). Une datation assez

précise a pu être obtenue car dans un des sondages, ce phénomène intervient juste au-dessus d'un niveau contenant *Globigerinoides obliqua* et *Globorotalia miocenica*. D'après Berggren et al. (1974: Figure 4), la présence simultanée de ces deux foraminifères marins se situerait entre 2,2 et 2,3 MA et plus approximativement au cours du Pliocène supérieur.

Podocarpus milanjianus est un arbre qui se rencontre actuellement sur plusieurs sommets de l'Adamaoua. Il appartient à l'étage forestier montagnard de moyenne altitude, situé approximativement entre 1 600-1 800 m et 2 200-2 500 m (Letouzey 1968: 333). La cause de l'expansion brutale de *Podocarpus* pourrait résider dans l'apparition en altitude d'une saison sèche relativement longue. Richards (1952: 152) a montré que sur les montagnes tropicales, la limite supérieure de la forêt dense dépendait de la longueur de la saison sèche. On peut donc imaginer que cette expansion aurait été causée par la diminution de l'épaisseur du flux de mousson, permettant à l'harmattan d'exercer son influence désséchante et détruisant ainsi la végétation qui ne supporte pas de saison sèche, au profit de taxons déjà adaptés à une certaine sécheresse. Ces taxons, dont *Podocarpus*, devaient végéter dans quelques stations isolées. Le refroidissement bien marqué sur l'hémisphère Nord à la fin du Pliocène permet probablement d'établir une relation de cause à effet entre le renforcement de l'anticyclone subtropical saharien et le renforcement de l'alizé boréal sur les basses latitudes. A ce propos, il est aussi intéressant de remarquer qu'en Afrique orientale, dans le bassin de l'Omo, entre 2,3 et 2 MA s'est produit un important changement de végétation correspondant à une sécheresse plus marquée en plaine et en altitude (Bonnefille 1976).

4.5 LA MISE EN PLACE DE LA VEGETATION XEROPHILE AU SAHARA

Les analyses polliniques sont un instrument important pour les reconstitutions paléobotaniques car elles donnent une image de l'environnement végétal, non seulement local mais aussi à plus grande distance comme l'ont montré des études effectuées sur la pluie pollinique actuelle au Sahara ou sur ses bordures (Maley 1972; Van Campo 1973; Cour & Duzer 1976). Ainsi, en reprenant quelques analyses polliniques d'échantillons pliocènes du Sahara, il est possible de savoir si dès cette époque les grandes unités floristiques énumérées dans l'introduction se trouvaient déjà au Sahara.

4.5.1 *Le Hoggar*

Deux échantillons des sommets du Hoggar (Rognon 1967) ont déjà fait l'objet d'analyses polliniques; l'un venant de l'Illamane vers 2 100 m d'altitude (Van Campo et al. 1964), l'autre de Tahag vers 1 800 m (Van Campo et al. 1965). L'étude des restes de mammifères contenus dans ces deux gisements (Arambourg in Rognon 1967: 461 et 474) avait fait conclure à un âge villafranchien inférieur ou mio-pliocène. Les données géomorphologiques montrent que le gisement de Tahag appartient à un cycle sédimentaire un peu plus ancien que celui de

l'Ilamane (Rognon, ibid.). L'échantillon de l'Ilamane est une diatomite dont l'étude de diatomées a été effectuée par Manguin (in Rognon 1967: 461). Comme l'ont montré les recherches de S. Servant-Vildary (1973), certaines diatomées fossiles peuvent servir de marqueur stratigraphique. Dans la diatomite de l'Ilamane, l'abondance de *Stephanodiscus carconensis* et d'autres diatomées archaïques permet de ranger cet échantillon dans la partie supérieure du Pliocène. Le second échantillon est un coprolithe de crocodile provenant des formations lacustres de Tahag, voisines et sédimentologiquement comparables à celles de l'oued Temorte (Rognon 1967: 473). Les diatomées y ont été aussi étudiées par Manguin (ibid.: 470) et la présence de diatomées archaïques comme à l'Ilamane, en particulier de *Stephanodiscus carconensis* conduit à ranger aussi cet échantillon dans la partie supérieure du Pliocène. Les deux échantillons étant ainsi placés dans le Pliocène supérieur, leurs spectres polliniques ont été regroupés afin d'obtenir un spectre moyen pour cette époque.

La comparaison de spectres polliniques fossiles et actuels a déjà permis au Sahara des interprétations intéressantes (Van Campo 1973; Maley 1972, 1973, 1977; Cour & Duzer 1976). Pour les sommets du Hoggar, plusieurs spectres actuels ont déjà été obtenus par l'analyse pollinique de poussière (méthode Cour 1974; prélèvements et analyses inédites de Cour & Duzer, communication personnelle). Le spectre actuel présenté ici (Table 4.1) provient du Plateau d'Irafizène (2 050 m d'altitude); il est bien représentatif car il est très comparable à d'autres analyses effectuées pour des localités voisines. Actuellement, les sommets du Hoggar abritent entre 1 800 et 2 500 m une végétation à caractère méditerranéen assez marqué. Entre 1 300 et 1 800 m l'élément saharo-sindien est prédominant. Au pied du massif, entre 900 et 1 300 m, les espèces tropicales sahéliennes sont relativement abondantes (Quézel 1954).

Sur le tableau donnant la liste des pollens, classés d'après la répartition actuelle des taxons dont ils proviennent, on observe tout d'abord un premier groupe de pollens appartenant à des taxons tempérés et méditerranéens (taxons holarctiques). Dans ce groupe, pour l'actuel, les taxons absents du massif représentent 0,8%. Deux taxons marqués par (H), *Artemisia* et Cupressaceae, actuellement bien représentés en zone méditerranéenne, mais présents aussi au Hoggar ou au Tassili, représentent 5,46% dont 5,3% pour *Artemisia.* Au Pliocène supérieur, pour ce premier groupe, on constate que les taxons actuellement absents du massif représentaient 21% et pour ceux actuellement présents 2,7%. Pour l'ensemble de ce groupe, les taxons les mieux représentés sont *Pinus*, 3,5%, *Platanus,* 2,7%, *Artemisia,* 2,5%, et *Quercus,* 2,1%. Sur la base de leurs seuls pourcentages il est actuellement assez difficile de savoir si ces taxons étaient présents ou non au Hoggar. Cependant, la présence d'*Artemisia* est écologiquement très probable et de plus les analyses polliniques effectuées par Beucher (1971) sur des sédiments néogènes de la vallée de la Saoura au sud de Beni-Abbès, ont montré que ce taxon y était déjà très bien représenté. On peut sans doute éliminer *Pinus* car son pollen est bien connu pour voyager facilement loin de sa zone d'émission. Pour les deux autres taxons, la présence de *Quercus* serait plus probable que celle de *Platanus* car certains *Quercus* à feuilles persistantes, tel *Q. coccifera,* supportent une certaine aridité. Par contre *Platanus,* taxon à feuilles caduques, a des besoins hydriques beaucoup plus importants.

Tableau 4.1 Pourcentages relatifs des pollens

	Actuel Hoggar (Irafizène) %	Pliocène sup. Hoggar %	Pliocène sup. Kourkour U8 %	Pliocène sup. Kourkour U4 %
GROUPE 1. TAXONS HOLARCTIQUES (tempérés et méditerranéens)				
a. Arbres:				
Cedrus	0.07			
Pinus	0.25	3.5	8.3	1.4
Picea cf. *orientalis*		0.4		
Cupressaceae (H)	0.14	0.2		1.0
Taxus baccata		0.4		
Callitris			0.8	
Platanus		2.7	0.4	
Quercus	0.28	2.1	cf. 0.4	cf. 0.5
Alnus		1.5	3.7	0.3
Ulmus		0.6		
Pterocarya		0.4		
Betulaceae	0.04	0.6	1.2	
Corylus		1.9	3.3	
Carpinus			1.2	
Tilia		0.4	0.8	
Ostrya		0.7	1.2	
Juglans		0.4		
Salix				0.2
Castanea		0.2		
Aesculus		0.7	0.4	
Ericaceae		1.1		
Pistacia			1.2	
Rhamnaceae (non *Ziziphus)*		0.6	1.2	0.1
Syringa		0.2		
Carya			0.8	0.1
Celtis cf. *australis*			2.0	0.1
Argania	0.11			
Phyllirea		0.7		
Fraxinus		0.2		
Total (nombre de grains)	(25) 0.90	(102) 19.5	(66) 26.9	(33) 3.7
b. Herbes:				
Artemisia (H)	5.32	2.5	2.5	3.3
Aethusa		0.2		
Paeonia		0.2		
Mercurialis	0.04			
Ranunculaceae		0.8		0.3
Rosaceae (non *Neurada*)		0.4	0.4	0.1
Valerianaceae		0.2		
Total (nombre de grains)	(150) 5.36	(22) 4.3	(7) 2.9	(33) 3.7
Total a + b	(175) 6.26	(124) 23.8	(73) 29.8	(66) 7.4

(H) taxons présents actuellement au Hoggar ou au Tassili –

Tableau 4.1 (suite)

	Actuel Hoggar %	Pliocène sup. Hoggar %	Pliocène sup. Kourkour U8 %	Pliocène sup. Kourkour U4 %
GROUPE II. TAXONS SAHARO-SINDIENS				
Chenopodiaceae-Caryophyllaceae	26.04	34.4	7.1	14.8
Cruciferae	12.21	2.2	0.8	0.7
Zygophyllaceae	0.11			11.7
Plantago	0.75	2.2		0.1
Ephedra	0.96	0.2		0.4
Umbelliferae	1.61		0.8	1.0
Resedaceae	0.04		0.4	1.3
Phoenix	0.04		3.7	9.0
Echium	0.21	0.4		
Tamarix	0.28			0.8
Fagonia	0.14			0.1
Trichodesma	0.44			0.1
Cleome arabica	0.43			
Hyoscyamus	0.04			
Asphodelus	0.04			
Rhus	0.11	0.2		
Rumex	0.04	0.6	0.8	0.1
Helianthemum		0.2	cf. 0.4	cf. 0.1
Moltkia ciliata	0.21			
Plumbaginaceae		0.2		
Total (nombre de grains)	(1 212) 43.30	(208) 40.6	(34) 14.0	(355) 40.2
GROUPE III. TAXONS TROPICAUX				
1. Sahariens (pro parte):				
Acacia sp.	0.32			
Acacia tortilis ssp. *raddiana*				6.8
Acacia etbaica				3.1
Maerua crassifolia	0.14			
Capparidaceae	0.04		0.4	0.9
Cassia	0.07			
Chrozophora	0.04			
Blepharis	0.14			
Tribulus	0.50			
Ficus			0.4	
Celastrales (cf. *Gymnosporia)*				1.6
Balanites aegyptiaca	0.14			
Olea[1]	1.07	0.4	cf. 0.4	0.35
Oleaceae		1.0		1.25

Tableau 4.1 (suite)

	Actuel Hoggar %	Pliocène sup. Hoggar %	Pliocène sup. Kourkour U8 %	Pliocène sup. Kourkour U4 %
2. Non Sahariens:				
Combretaceae	0.85			0.2
Tapinanthus			cf. 0.4	
Antidesma		0.6		
Sapotaceae (non *Argania*)		0.2		0.2
Myrtaceae (non *Myrtus*)		0.4		
Myrica		0.2		
Ericaceae (non Médit.)			0.9	0.1
Ilex				0.1
Sapindaceae		0.2	0.4	
Hymenocardia				0.3
Podocarpus			0.4	
Lannea	0.04	0.4		
Phyllanthus			0.9	
Securinega virosa	0.07			
Hyphaene	0.07		cf. 0.4	5.1
Gynandropsis	0.07			
Boscia	0.04			
Mitracarpus scaber	0.11			
Monechma	0.08			
Total (nombre de grains)	(106) 3.80	(17) 3,4	(11) 4.6	(117) 20.0
(1) Les pollens actuels d'Olea peuvent être en partie d'origine méditerranéenne.				
GROUPE IV. UBIQUISTES				
Cramineae	22.97	17.3	34.3	15.1
Cyperaceae	15.71	5.0	0.4	0.7
Urticaceae	0.64	1.4	2.5	0.4
Compositae (non *Artemisia*)	6.14	2.7	9.9	5.3
Euphorbia	0.92	0.6		0.1
Papilionaceae	0.07	0.6		
Liliaceae		0.4		
Leguminoseae			0.8	1.0
Campanulaceae				0.1
Rubiaceae				0.1
Eucalyptus	0.04			
Total (nombre de grains)	(1 302) 46.51	(144) 28.0	(116) 47.9	(202) 22.8
Indéterminés	(4) 0.14	(21) 4.1	(9) 3.7	(84) 9.5
Somme de base	2 799	514	242	884
GROUPE V. HYGROPHILES				
Typha	11	1	4	5
Potamogeton		2		
Filicales		8	2	7
Total (nombre de grains)	11	11	6	12
Total des pollens comptes	2 810	525	248	896

Cependant les pourcentages plus élevés que ceux de l'échantillon actuel pourraient aussi s'interpréter comme résultant d'apports lointains d'origine septentrionale en provenance de régions recouvertes de végétation beaucoup plus dense qu'actuellement, n'ayant pas subi de dégradations anthropiques.

Le groupe II rassemble des taxons appartenant à l'élément saharo-sindien. Dans le Sahara actuel ces taxons sont très abondants ou typiques de cet élément bien qu'un certain nombre existe aussi, au niveau de la famille ou du genre, dans les régions méditerranéenne ou tempérée. Le pourcentage total assez élevé de ce groupe, 40%, très proche du pourcentage actuel, 43%, montre qu'au Pliocène cet élément était déjà très bien représenté au Sahara. Bien que le spectre pliocène présente une variété moins grande de taxons, les masses principales se retrouvent telles les Chenopodiaceae-Caryophyllaceae (pollens de type périporé), les Cruciferae et *Plantago*. Ces données permettent de penser que sur le Hoggar l'élément saharo-sindien devait occuper une place assez voisine de celle qu'il occupe actuellement. De plus, au Néogène, cet élément était déjà très fortement représenté sur le Sahara septentrional (Beucher 1971). Ce fait, lié au pourcentage très faible de l'élément tropical, conduit à placer les sédiments néogènes de Beucher dans le Pliocène.

L'*Olea* du Hoggar (*O. laperrini*) est considéré dans cet article comme d'origine tropicale (cf. 4.9, fin du chapitre). Cependant il est très probable qu'une partie des pollens d'*Olea* de l'échantillon actuel provient de la zone méditerranéenne où *O. europaea* est cultivé. Ceci tend à diminuer légèrement le pourcentage de l'élément tropical du spectre actuel. L'élément tropical a été rassemblé dans un troisième groupe dont le pourcentage actuel est de 3,8% et pour le Pliocène de 3,4%. Bien que ces pourcentages soient assez proches, on constate que la plupart des taxons n'ont pas la même origine. Pour ceux-ci, les taxons actuels sont soit d'origine sahélienne, 1,35% et présents au pied du Hoggar, soit présents au Sud du Sahara en zone sahélienne ou soudanienne, 1,25%, dont 0,85% de Combretaceae. Par contre, au Pliocène, les taxons sahéliens sont totalement absents du spectre au profit de taxons tropicaux plus humides. Seul le genre *Lannea* 0,4% est assez typiquement soudanien, les autres sont plutôt soudano-guinéen ou de type montagnard (*Myrica* et Myrtaceae non *Myrtus*: 0,6%). Il semble bien que, comme pour le spectre actuel et vu la faiblesse de leur pourcentage, ces pollens soient d'origine plus ou moins lointaine. Des sédiments pliocènes ont été analysés pour le Tibesti (Maley et al. 1970) mais le grand nombre de pollens indéterminés, plus de 15%, rend l'interprétation difficile.

4.5.2 *L'oasis de Kourkour (Egypte)*

Dans cette oasis située dans le sud du désert occidental de l'Egypte, une formation de travertins calcaires, appelée 'tufs des Plateaux', a été datée du Pliocène (cf. *supra*) (Butzer & Hansen 1968: 363). Cette formation, située entre 370 et 340 m, a été subdivisée en une unité inférieure et une unité supérieure, séparées par une phase érosive. Deux échantillons (U4 et U8) de deux localités différentes et rangés dans l'unité supérieure, qu'on peut raisonnablement placer dans le Pliocène supérieur, ont fourni des pollens (Van Campo et al. 1968). Butzer & Hansen (ibid.: 515) considèrent que U8 est plus ancien que U4.

Il n'y a pas de données disponibles concernant la pluie pollinique actuelle dans le sud de l'Egypte. En ce qui concerne les taxons d'origine tempérée ou méditerranéenne (groupe I), une comparaison peut être faite avec le Hoggar car ces deux régions sont à des distances comparables des zones méditerranéenne et tempérée. Cependant, on doit noter que Kourkour n'est pas très éloigné des collines de la Mer Rouge qui possèdent une végétation particulière avec des taxons d'origine méditerranéenne (cf. infra).

Pour l'échantillon le plus ancien, U8, le pourcentage total du premier groupe, environ 30%, est supérieure de 6% à celui du Hoggar au Pliocène. Cependant, les 8% de *Pinus*, pollen connu pour son aptitude à voyager loin de sa zone d'émission, doivent être considérés comme des apports lointains. Les autres taxons dominants sont différents de ceux du Hoggar: *Alnus* 3,7%, *Corylus* 3,3%, *Celtis australis* 2%, *Artemisia* 2,5%. Ces pourcentages d'*Alnus*, de *Corylus* et *Celtis australis* peuvent s'interpréter soit comme correspondant à une végétation autochtone, soit comme des apports lointains en provenance d'une zone méditerranéenne à la végétation plus dense et plus étendue qu'actuellement sur le littoral et en Palestine. On peut signaler ici que *Pinus* et *Alnus* vivent actuellement en Cyrénaïque et au Maghreb (Maire 1952: 141; 1961: 83), *Celtis australis* au Maghreb et que des empreintes foliaires de *Carpinus* (taxon tempéré) ont été trouvées dans des dépôts lacustres du Pléistocène moyen de la région d'Alger (Arambourg et al. 1943: 28). L'hypothèse de l'autochtonie semble assez difficile à soutenir, car vu la basse altitude du site de Kourkour et des collines environnantes (350 à 450 m), il n'est pas possible de concilier la cohabitation de ces trois taxons avec un élément saharo-sindien de 14% dont 7% de Chenopodiaceae-Caryophyllaceae et surtout 3,7% de *Phoenix*. Un tel pourcentage du pollen de *Phoenix* implique obligatoirement que ce taxon vivait sur le site. En effet, les données sur la pluie pollinique actuelle au Sahara montrent que les pollens de *Phoenix* voyagent très mal dans l'atmosphère. A environ 7 km de la palmeraie de Béni-Abbès, le contenu pollinique de l'atmosphère présente un pourcentage moyen annuel de 0,35% (Cour et al. 1971). Près du lac Tchad, dans une zone où *Phoenix* est relativement abondant, un pourcentage de 0,8% a été obtenu dans la mare de Latir (Maley 1972). De plus un pourcentage de 34% de Gramineae implique un paysage relativement ouvert. Toutes ces données font considérer les pollens du premier groupe comme probablement allochtones, *Artemisia* sans doute mis à part.

Le second échantillon pliocène supérieur de Kourkour, U4, n'a pas été regroupé avec U8 car son spectre est très nettement différent. En effet, tout d'abord, le groupe 1 (taxons tempérés et méditerranéens) présente un pourcentage relativement faible, par rapport aux autres échantillons, de 7,4%. Les taxons dominants y sont *Artemisia* 3,3%, *Pinus* 1,4%, Cupressaceae 1%. Ensuite le groupe II (taxons saharo-sindiens) présente un fort pourcentage, 40%, avec en particulier 9% de *Phoenix*. Ce dernier pourcentage rapproche U4 de U8, car il implique aussi une grande abondance de ce taxon sur le site même. Enfin l'aspect le plus original du spectre apparaît dans le groupe III (taxons tropicaux) avec, par rapport aux autres spectres, un pourcentage relativement important de 20%. Les taxons dominants sont *Acacia tortilis* spp. *raddiana* et spp. *spirocarpa* 6,8% (ces deux espèces ont des pollens très proches), *Acacia etbaica* 3,1%, *Hyphaene*

5,1%, Celastrales (proche de *Gymnosporia*) 1,6%, *Olea* et Oleaceae 1,6% et Capparidaceae 0,9%. Il est classique au Sahara de ranger le genre *Olea* dans le groupe holarctique car l'espèce connue au Hoggar, Aïr et Darfur, *O. laperrini,* est considérée par la plupart des botanistes comme d'origine méditerranéenne. Cependant Bruneau de Miré & Quézel (1961: 119) ont estimé qu'une origine tropicale est aussi possible pour cette espèce qui 'paraît être bien voisine sinon identique à la description donnée d'*O. somalensis*' qui, d'après Turrill (1952: 9), est synonyme d'*O. chrysophylla.* Or cette dernière espèce est actuellement présente non loin de Kourkour sur la portion méridionale des collines bordant la Mer Rouge, en particulier au Djebel Elba (angle SE de l'Egypte), au Djebel Erkwit (Soudan) et en Erythrée. Son aire s'étend aussi en Ethiopie, à l'Afrique orientale, jusqu'en Afrique australe et plus à l'Est, en Arabie, aux Indes et en Chine occidentale. Du fait de son aire si étendue, cette espèce présente des variations considérables (Turrill, ibid.). (Voir le paragraphe 4.9 concernant l'origine tropicale d'*Olea laperrini*). Ces considérations et celles exposées en 4.9 permettent de penser que les pollens déterminés pour Kourkour comme *Olea* ainsi qu'une partie de ceux déterminés comme Oleaceae pourraient appartenir au complexe formé par *O. chrysophylla* (Chevalier 1948).

Parmi les taxons du groupe I, *Pinus* et Cupressaceae sont probablement d'origine lointaine. Pour *Artemisia,* comme pour les autres échantillons, son autochtonie est assez probable.

L'image fournie par ce spectre, en particulier par les taxons dominants du groupe tropical et par la forte représentation des taxons saharo-sindiens, a de nombreux points communs avec la végétation très spéciale des collines de la Mer Rouge entre l'Erythrée et le Djebel Elba, en particulier avec celle connue au Djebel Erkwit (18°50′ N) (Kassas 1956) ou au Djebel Elba (22°N) (Drar 1936). Cette chaîne côtière bénéficie de pluies assez bien réparties tout au long de l'année, compensant la faiblesse relative du total (200 à 300 mm/an). De plus, au cours de l'hiver, ces sommets sont très souvent entourés de brouillard venant de la Mer Rouge. Cet ensemble de conditions favorables font que ces collines, entre 800 et 1 500 m d'altitude, servent actuellement de refuge à une flore particulière, caractérisée par la cohabitation de taxons tropicaux, saharo-sindiens, méditerranéens et même tempérés dans les zones les plus humides. La quasi totalité des arbres et arbustes sont d'origine tropicale et un grand nombre appartient à l'élément montagnard africain avec des aires s'étendant souvent jusqu'en Afrique australe. De nombreux taxons, tels les Euphorbes cactiformes, des Crassulaceae, etc., présentent des structures xéromorphes remarquables qui sont une des caractéristiques principales des flores d'Afrique australe. Ces particularités des taxons tropicaux permettent de penser qu'un certain nombre sont issus de la Rand Flora.

La végétation du Djebel Erkwit est actuellement la mieux connue. Kassas (1956) y distingue cinq zones en allant de la plus humide sur les sommets orientaux vers 1 500 m, qui font face à la Mer Rouge et au brouillard, à la plus sèche vers l'ouest qui fait la transition avec le désert. La plupart des arbres se rencontrent en plus ou moins grande abondance dans les différentes zones. Les plus caractéristiques sont: *Maytenus senegalensis,* plusieurs Euphorbes cactiformes,

Euclea schimperi, Dodonaea viscosa, Diospyros mespiliformis, Rhus, Phoenix, Acacia etbaica, Olea chrysophylla, etc. Les zones les plus sèches se caractérisent en plus par *Dracaena ombet* et des taxons fréquents en zone sahélienne ou sur le Sahara tropical: *Acacia tortilis, Balanites, Ziziphus, Maerua, Boscia.* Les arbrisseaux et les herbes de la zone la plus humide sont d'origine très variée: tempérée, méditerranéenne, montagnarde africaine, africaine australe, saharo-sindienne, sahélienne. Des fougères et des hépatiques y sont aussi présentes, telles *Cheilanthes farinosa* et *Actiniopteris radiata,* qui peuvent appartenir à la Rand Flora, en particulier la seconde d'après Jaeger (1964).

4.6 HYPOTHESES SUR LES LIGNEES AFRICAINES

Ainsi, il est vraisemblable qu'une partie de la végétation résiduelle des collines de la Mer Rouge s'étendait au Pliocène supérieur sur le Sahara oriental, au moins jusqu'à Kourkour. On peut penser qu'au Pliocène ou même avant (?), elle était présente sur le rebord oriental du bassin du Tchad car actuellement de nombreux taxons typiques de cette flore subsistent encore sur les montagnes du Nord du Darfur, à la limite méridionale du Sahara, en particulier sur les flancs du Djebel Gourgeil (Quézel 1969: 89) (Euphorbes cactiformes, *Aloe, Andrachne aspera, Gymnosporia senegalensis, Actiniopteris radiata,* etc.). La présence de peuplements parfaitement développés d'*Olea laperrini* un peu plus haut sur le massif du Gourgeil (Quézel, ibid.: 90), peuplements séparés de la zone méditerranéenne par la largeur du Sahara, semble être une donnée supplémentaire à l'origine africaine de cet olivier.

La présence actuelle d'autres taxons africains (éléments montagnard et oro-africain; cf. Bruneau de Miré & Quézel 1961) d'origine orientale ou australe sur les massifs de l'arc montagneux qui limite le nord du bassin du Tchad, serait peut-être une preuve de l'extension ancienne des lignées de la Rand Flora sur le Sahara. Parmi les taxons remarquables, on peut noter *Olea laperrini* en Aïr et au Hoggar (Bruneau de Miré & Quézel 1961), *Gymnosporia senegalensis* assez fréquent sur le Sahara central (Tibesti, Hoggar, Tassili) et septentrional ainsi que dans le sud marocain (Ozenda 1958: 337). Le genre *Erica,* considéré comme d'origine australe (Schnell 1976, 3:122) est représenté par *E. arborea* sur le plus haut sommet du Tibesti (Quézel 1965) ce qui permet de penser que cette espèce peut être une relique de la Rand Flora, d'autant plus que son pollen y a été trouvé dans un sédiment pliocène (Cohen in Maley et al. 1970: 148). Cependant, le fait que certains des spectres pliocènes présentés ici (Hoggar, Kourkour U8) soient très pauvres en taxons pouvant appartenir aux lignées de la Rand Flora, semble montrer que les conditions climatiques nouvelles apparues au début du Pliocène les ont éliminés presque totalement du Sahara, sauf quelques reliques isolées. Ainsi leur présence au Sahara serait plus ancienne que le Pliocène. Dans cette optique, le spectre U4 de Kourkour, plus récent que U8, correspondrait à une pulsation moins aride ayant favorisé un retour jusqu'à Kourkour de la végétation des collines de la Mer Rouge, riche en taxons issus de la Rand Flora.

Bien que les bois fossiles connus pour le Sahara au Tertiaire n'appartiennent pas à des genres considérés comme typiques de la Rand Flora, les facteurs favorables à sa pénétration sur le Sahara ont existé puisque des péjorations climatiques s'y sont produites avant le Pliocène (cf. supra). De plus, l'étude de la végétation actuelle des Iles Canaries apporte quelques arguments en faveur d'une extension anté-pliocène de la Rand Flora sur le nord de l'Afrique. En effet, la formation puis la séparation du continent africain des Iles Canaries sont intervenues entre le Miocène inférieur et moyen (cf. Axelrod 1975); c'est pourquoi une grande partie de la flore actuelle est considérée comme issue directement de la flore miocène nord-africaine (Axelrod, ibid.). Or une grande partie des taxons relictes des Canaries, tels ceux de la Laurisylve, a des affinités, souvent très étroites avec des taxons africains d'origine orientale ou australe (Axelrod, ibid.): elle peut donc être issue de la Rand Flora.

La vaste répartition actuelle à travers l'Afrique tropicale humide de flores sèches est un fait notable (Aubréville 1949). Les montagnes situées dans la zone tropicale sèche juste au sud du Sahara, abritent souvent des Euphorbes cactiformes, parfois des *Olea* et de nombreux autres taxons d'origine orientale ou australe (Monts Mandara, Cameroun: Letouzey 1968; Plateau de Jos, Nigéria: Monod 1952; etc.). Ainsi, si on admet qu'au Tertiaire le Sahara était colonisé par une végégation de type soudanien ou soudano-guinéen, on peut envisager l'hypothèse que ses montagnes abritaient aussi une végétation comparable à celle des Monts Mandara ou du Plateau de Jos.

4.7 HYPOTHESES SUR LES LIGNEES SEPTENTRIONALES MESOGEENNES

L'importance prise par les taxons saharo-sindiens dans les différents spectres polliniques du Pliocène supérieur montre que l'installation au Sahara de cet élément est très précoce. L'origine principale de ces taxons xérophiles est septentrionale, 'mésogéenne' (Quézel 1965: 32). Comme on l'a vu, les premières traces de cet élément (*Retama* cf. *raetam* et *Tamarix*) apparaissent sur le nord du Tchad dès le Pliocène inférieur, en même temps, semble-t-il, que les premières manifestations véritables du désert (sables éoliens à Kourkour). Or au cours du Miocène des phases arides se sont produites au Maghreb et sur le nord de la Libye (cf. supra), en même temps qu'y pénétraient des faunes asiatiques adaptées pour certaines à des conditions arides (Jaeger 1975). Des flores sèches se sont probablement introduites à la même époque sur la bordure nord du Sahara. Puis, lorsque le désert s'installa au début du Pliocène, elles se répandirent sur le Sahara, car ces taxons d'origine septentrionale semblent avoir été mieux adaptés aux conditions désertiques nouvelles. Il apparaît que seuls les taxons les plus xérophiles de la Rand Flora, essentiellement des herbacées, purent se maintenir sur le Sahara et se répandre au moins en partie, dans ce qui est actuellement la région Saharo-sindienne. En effet, Zohary (1962) indique que certains taxons saharo-sindiens de la Palestine ont des affinités avec l'Afrique australe. Au Sahara, ces taxons d'origine australe sont plutôt classés à part dans un groupe érémitique (Quézel 1965; cf. supra). Parmi ces taxons, on peut citer:

Neurada, Caylusea, Ifloga, Aristida, des Zygophyllaceae, Aïzoaceae, Cucurbitaceae, etc. De la même manière, des taxons saharo-sindiens d'origine septentrionale purent s'étendre vers le sud par le couloir de l'Afrique orientale et gagner les déserts de l'Afrique australe (Monod 1971).

4.8 CONCLUSION

Une grande partie de la végétation du Sahara semble avoir une origine très ancienne, aussi bien en ce qui concerne les lignées africaines que les lignées septentrionales. Lorsque ces taxons sont arrivés au Sahara, sans doute au début du Pliocène pour les lignées septentrionales, et peut-être au cours de la seconde partie du Tertiaire pour un certain nombre de taxons de la Rand Flora, il semble qu'ils étaient déjà adaptés aux conditions qu'ils y trouvèrent. Dès le Pliocène, les conditions désertiques très rudes semblent avoir éliminé du Sahara un certain nombre de taxons de la Rand Flora non adaptés à ces conditions extrêmes, ceux, par exemple, qu'on trouve sur les collines de la Mer Rouge ou sur le Djebel Gourgeil. L'évolution de tous ces taxons d'origine septentrionale et africaine semble s'être faite au cours du Tertiaire, d'une part dans des régions arides septentrionales (cf. Zohary 1973: 325) et d'autre part dans les régions arides de l'Afrique australe (Wild 1963-64: 132; Gill 1961: 347). Après leur installation ou leur maintien au Sahara, on peut penser que ces taxons se diversifièrent pour donner les espèces actuelles. Parallèlement aux lignées septentrionales, l'étude des Mammifères miocènes de l'Afrique du Nord a abouti aussi à la conclusion qu'un grand nombre étaient de nouveaux immigrants qui se différencièrent antérieurement 'en Asie au Nord de l'Himalaya' (Jaeger 1975: 131). L'aridité des régions nord-asiatiques au cours d'une partie du Tertiaire a pu être due à leur continentalité, mais on peut aussi penser qu'elle était due à la persistance d'un régime anticyclonique de type subtropical, liée au décalage vers le nord des zones climatiques, comme Flohn (1965) en a montré la possibilité.

Toutes les conclusions sur les flores sont encore assez conjecturales et de nombreuses données supplémentaires sur le Pliocène et le Quaternaire seront nécessaires pour les confirmer ou les modifier. Il apparaît aussi que des données paléobotaniques antérieures au Pliocène devraient être recherchées concernant les montagnes du Sahara.

4.9 NOTE CONCERNANT L'ORIGINE TROPICALE D'*OLEA LAPERRINI*

Le pollen d'*Olea laperrini* est beaucoup plus variable dans son ornementation (diamètre du reticulum et diamètre des columelles) et dans une moindre mesure dans sa taille, qu'on l'a décrit (Bénichou 1962: 49). Des données inédites, confirmées par Ferguson (in Wickens 1976, table 7) montrent en particulier qu'il n'est pas possible de séparer le pollen d'*O. europaea* de celui de certains échantillons d'*O. laperrini* qui présentent, d'une manière assez homogène, des pollens

avec un reticulum relativement large et des columelles épaisses (échantillon Leredde, ss. no., Tassili, Tamrit, d'après Maley inédit, in collection Montpellier; échantillon Wickens, no. 1461, Djebel Marra in Wickens, ibid.). Cette variabilité oblige à réviser la détermination des pollens fossiles (deux grains observés) attribués à *O. europaea* qui proviennent du Borkou (Kaortchi), dans le nord du Tchad, d'une diatomite paraissant 'extrêmement récente' (Quézel & Martinez 1958). Or des études récentes ont montré que cette diatomite est anté-holocène: soit de l'extrême fin du Pléistocène supérieur (M. et S. Servant, communication personnelle), soit d'après des critères palynologiques (Maley 1976), elle pourrait être plus ancienne et se situer avant 20 000 B.P. du fait de la présence de nombreux pollens de Cupressaceae, car ces pollens sont absents des sédiments du Tchad et du Tibesti postérieurs à 20 000 B.P. environ. De plus, dans d'autres sédiments du nord du Tchad (région de Beurkia), situés entre environ 20 000 et 22 000 B.P. (Servant 1973), l'auteur a trouvé des pollens d'*Olea* (inédit) comparables aux pollens d'*O. laperrini* actuels. Parmi les pollens fossiles observés (sept grains), certains ont une exine avec un reticulum relativement large, jusqu'à 2 microns, pour un diamètre équatorial du grain de 21 microns. Ces différentes données et l'ancienneté très probable de la diatomite de Kaortchi conduisent à attribuer les pollens à *O. laperrini.*

Il est aussi possible d'établir des comparaisons entre le pollen actuel d'*O. laperrini* et celui de certains échantillons d'*O. chrysophylla.* L'étude des pollens de différents échantillons nord-africains et arabiques de cette dernière espèce (collection de Montpellier) montre que son pollen est aussi très variable, en particulier lorsqu'on considère le reticulum. Sur six échantillons, les pollens de trois (Dj. Elba, Erythrée, Yémen) ressemblent à ceux d'*O. laperrini* ayant un reticulum étroit, deux venant d'Ethiopie (Shoa et ss. loc., in Bonnefille 1971: pl 3) se distinguent de ces derniers par un reticulum plus large, et un d'Arabie (Abha, près de la Mer Rouge, environ 17°30′ N) a des grains très polymorphes (hybride?) rendant la comparaison impossible. Cette étude pollinique préliminaire devra être approfondie.

Le rapprochement d'*O. laperrini* et d'*O. chrysophylla* avait déjà été proposé par Chevalier (1948: 4). Cette opinion est renforcée par la découverte au Djebel Marra d'un bois carbonisé, daté de 3 520 ± 100 B.P. 'whose structure agrees very well with that of *O. indica* Kleindorf ex Burm. (syn. *O. africana* Miller, *O. chrysophylla* Lam., *O. ferruginea* Royle)' (Wickens 1975: 113). De plus, l'étude anatomique comparée de bois et de feuilles d'*O. europaea* d'Algérie et d'*O. laperrini* provenant du Hoggar, de l'Aïr et du Djebel Marra, a montré que ces deux oliviers sont deux entités taxonomiques distinctes (Bénichou 1962: 53). A ce propos, il serait nécessaire de revoir un échantillon du sud marocain attribué à *O. laperrini* (Jahandiez & Maire 1934: 575) et cité parfois comme tel (Chevalier 1948: 4; Wickens 1975: 118). En effet, Jahandiez & Maire écrivent (ibid.), à propos du polymorphisme des formes cultivées et spontanées d'*O. europaea*, 'qu'une forme spontanée trouvée dans les Callitraies du versant Sud du Grand Atlas, dans la vallée des Mentaga, a les feuilles semblables à celles d' *O. laperrini* Batt. et Trab. du Hoggar; nous n'avons pu malheureusement en voir les fruits'. Cet échantillon n'a donc pas été formellement déterminé et ne peut donc pas être cité comme *O. laperrini.*

Toutes ces données montrent qu'*O. laperrini* devrait être rattaché au complexe formé par *O. chrysophylla* et appartenir ainsi sans doute à la Rand Flora.

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5

The Saharan and East African uplands during the Quaternary

Les montagnes du Sahara et de l'Afrique de l'Est pendant le Quaternaire

Les régions de haute montagne entre la Mediterranée et l'Equateur sont des 'îles' climatiques et écologiques qui diffèrent des régions basses environnantes par la diminution des températures, la fréquence du gel et généralement une augmentation des précipitations et des modifications de la couverture végétale.

Dans ce chapitre, la répartition latitudinale des températures et des pluies et l'influence qu'elle exerce sur les plantes et sur les mécanismes morphodynamiques sont analysées. Dans les montagnes sahariennes (Hoggar, Tibesti, Sinaï), la végétation est limitée par la sécheresse aux fonds des oueds qui ont des ressources en eau souterraine suffisante ou aux régions les plus élevées où la température et l'évaporation sont réduites et où les pluies 'saisonnières' ne sont pas inconnues. Les orages et les pluies de forte intensité (ordinairement provoquées par la convergence d'air humide équatorial et de masses d'air plus froides extra tropicales) peuvent engendrer des sheet floods et des crues dans les oueds. Les processus de gélifraction sont négligeables à cause de l'absence d'humidité. Des différences thermiques notables sont caractéristiques entre le Hoggar et le Tibesti. Le rythme saisonnier est beaucoup plus sensible au Hoggar, tandis que le Tibesti est plus fortement influencé par un rythme tropical diurne et par conséquent, les variations saisonnières y sont moins prononcées.

Dans le massif du Semien, en Ethiopie, les étages écologiques atteignent leurs positions les plus élevées en parallèle avec les températures, tandis que dans le massif du Bale, le climat et la flore ressemblent beaucoup aux montagnes de l'Afrique de l'Est (Mt Kenya). Dans la zone équatoriale, le rythme diurne aboutit à un étagement écologique et géomorphologique bien défini. Par exemple, la limite des arbres coïncide avec les isothermes de température du sol de 6-8°C, ce qui s'accorde bien avec les mesures dans d'autres régions équatoriales.

Les glaciers et les processus glaciaires sont encore actifs dans quelques massifs méditerranéens, et sont en évidence au-dessus de 4 500 m dans l'Afrique de l'Est. Les processus périglaciaires sont actifs au-dessus de 2 000-2 500 m dans les montagnes de la bordure sud méditerranéenne; en Ethiopie et en Afrique de l'Est, ils se manifestent par des niveaux de blocs détritiques à partir de 4 200 m.

Dans les montagnes du Sahara les étages périglaciaires actuelles sont toujours à de très hautes élévations à cause de la faible teneur d'humidité, et peuvent disparaître totalement dans les localités très arides.

Pendant la dernière glaciation würmienne les montagnes de la lisière sud de la Mediterranée, de l'Ethiopie, et de l'Afrique de l'Est étaient recouvertes de glaciers. Dans les montagnes du Sahara on ne retrouve que des niches nivales, à des élévations supérieures à 2 400 m dans le Hoggar et à partir de 3 000 m au Tibesti. Les processus périglaciaires étaient en évidence au-dessous de 1 000 m dans les massifs méditerranéens, entre 1 100 et 1 800 m dans les massifs sahariens, et au dessus de 3 000 m en Ethiopie et en Afrique de l'Est. L'état actuel de nos connaissances ne permet pas une mise au point complète des glaciations antérieures au Würm dans cette région. Toutes

les montagnes de la bordure méditerranéenne jusqu'en Afrique de l'Est ont connu un abaissement de température d'environ 6-8°C pendant le Würm, et d'encore plus pendant une glaciation plus ancienne. En conclusion, nous retenons la similarité climatique entre l'Ethiopie méridionale et l'Afrique de l'Est, la différence entre les massifs sahariens et ceux d'Ethiopie, la différence climatique entre le Hoggar et le Tibesti.

Les accumulations fluviatiles en bordure des montagnes

Dans les vallées inférieures et sur le pourtour des trois massifs montagneux, il existe de grandes terrasses alluviales deposées au cours du Pléistocène supérieur et de l'Holocène. Ces terrasses sont en relation directe avec les variations climatiques du Sahara central au cours des dernières dizaines de milliers d'années. Malgré des differences lithologiques entre les trois massifs, les caractéristiques de ces terrasses sont assez voisines. La plus ancienne, l'Oberterrasse du Tibesti, s'est mise en place dans un contexte d'aridification du climat qui rappelle les conditions actuelles. Cette terrasse, d'origine rhexistasique, est très bien représentée au NW du Tibesti et prend une grande extension sur le pourtour de l'Atakor, où elle est formée de sables et de graviers rougeâtres, surtout à l'aval des régions granitiques. D'après des arguments préhistoriques (outils de l'Acheuléen supérieur au sommet de cette terrasse), une corrélation est proposée avec la terrasse de sables rougeâtres, correspondant à une crise climatique, qui a affecté le Plateau somalien.

Après l'entaille de cette terrasse, une nouvelle terrasse emboîtée est constituée par des limons argileux gris ou bruns souvent riches en matière organique, déposés en phase de biostasie (couvert végétal assez dense, pluies bien réparties sur l'année). Cette Mittelterrasse est datée au Tibesti entre 15 000 et 8 000 ans B.P. Ses relations avec un climat de type méditerranéen humide ont été démontrées aussi bien dans l'Atakor qu'au Tibesti, par l'étude des pollens, des paléosols et des Diatomées. Elle prend une grande extension en Ethiopie, surtout à l'Ouest du Plateau éthiopien.

Enfin une terrasse récente (Niederterrasse) s'est développée au Tibesti lors de l'assèchement du climat vers 5 000-4 000 ans B.P. Formée surtout de sables (phase rhexistatique), elle s'est mise en place sous des conditions d'écoulement assez voisines de l'Actuel. Dans l'Atakor, sa granulométrie est plus fine (limons) et elle se confond souvent avec la terrasse moyenne. Il semble, en effet, que le passage du Pluvial à l'aridité actuelle ait été plus progressif dans l'Atakor et à l'Ouest du plateau éthiopien qu'au Tibesti.

INTRODUCTION

The central Sahara is dominated by two high mountain systems: the Hoggar and Tibesti. The Hoggar (23°N-24°N; 5°E-7°E) covers an area of 12 000 to 13 000 km², with its highest point (Le Tahat) at 2 918 m. In comparison Tibesti (19°N-22°N; 16°E-19°E) covers about 100 000 km². Its highest points form a triangle with Emi Koussi (3 415 m) in the south, Mouskorbé (3 376 m) in the northeast and Toussidé (3 265 m) in the northwest.

We will also consider the two highest massifs in Ethiopia. In the north, the Simen Mountains (13°N) reach 4 543 m on Ras Dashan, while the Bale Mountains (7°N) in the south reach 4 450 m on Tullu Dimtu. Important features of both massifs are extensive high plateaux above 4 000 m which preserve evidence of environmental changes since the last glaciation to the present time, and show the climatic differences between northern and southern Ethiopia at comparable elevations.

Finally, we will also review data from the uplands on the southern and northern margins of the Sahara and Ethiopia, paying special attention to the equatorial uplands of the upper White Nile, and to the Mediterranean uplands of Sinai, Lebanon and the Atlas.

5.1 THE PRESENT CLIMATE OF THE HIGH MOUNTAINS FROM THE MEDITERRANEAN TO EAST AFRICA

Dubief (1959/1963, 1971) has summarized much of the meteorological information available from the scattered network of Saharan weather stations. Since then, and especially as a by-product of the recent Sahel drought, many new studies have begun (Dhonneur 1974). Many monographs and short papers exist for the different mountain areas of the Sahara and East Africa: Hoggar (Dubief 1959/1963; Yacono 1968), Tibesti (Heckendorff 1972, 1977; Gavrilovic 1969; Indermühle 1972), Sinai (Gvirtzman 1976), Simen (Stähli 1977), Bale (Buer 1971), Mt Kenya (Brinkman et al. 1968, Coe 1967). For all mountain regions the rudimentary data (particularly for the higher localities) can be used only as a very general indication. Nevertheless, for individual mountain ranges such as the Hoggar there are long sequences of data, and in some cases the network of weather stations was temporarily increased, as on Mt Kenya during the Geophysical Year. A comparative study of the mountain regions is still lacking, despite the fact that they may be considered as key localities for climatic, ecological and geomorphic studies, as well as favourable areas for future development of their water and timber resources.

A source of indirect climatic information includes the evidence from ecology and geomorphology. Studies of mountain and desert vegetation and landforms may also furnish important climatic information (Lauer & Frankenberg 1977), just as the distribution and orientation of major desert dunefields may throw light on prevailing patterns of atmospheric circulation (Wilson 1971; Mainguet & Canon 1976; Chapter 2 of this volume).

An evaluation of individual events is equally critical to our understanding of air mass circulation and of the processes of atmospheric heat exchange. Case studies include analyses of exceptionally heavy precipitation (Jalu & Damotte 1966; Winstanley 1970) as well as of droughts (Plote 1974).

In recent years the disadvantage of a very sparse network of weather stations has been in part offset by the availability of weather-satellite data for single climatic elements. Raschke et al. (1973) have described net radiation, Winiger (1975) cloud conditions, and Flohn (1975) has summarized information from satellite meteorology relating to tropical atmospheric circulation.

5.1.1 *A survey of the present climate of the high mountains from the Mediterranean to East Africa*

Most attempts to arrange Africa into climatic zones come to the conclusion that the different zones are arranged in an almost ideal meridional sequence. The 'backbone' of Africa (Troll 1974) comprising the eastern highlands is an exception to this general rule, and this difference between the Sahara and the eastern uplands is fundamental. The Saharan uplands occur within a huge area of more or less uniform climate, but the eastern massifs act as climatic boundaries in their own right. The consequences are obvious. The climate of the Saharan mountains varies primarily with elevation, but the climate of the East African uplands (and of the Atlas, another climatic divide) varies with aspect as well as elevation.

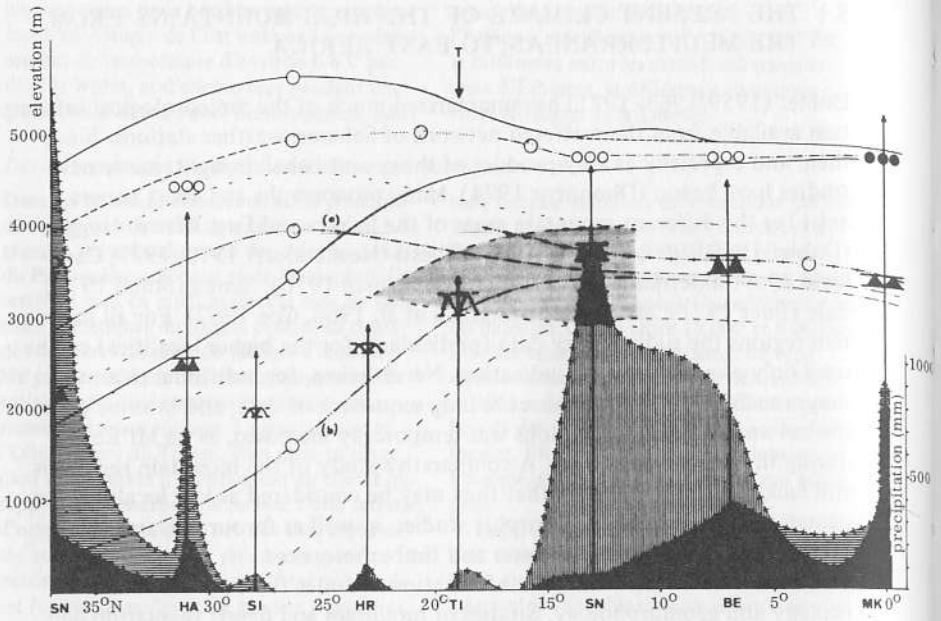


Figure 5.1 Meridional cross-section of climatological parameters from the Mediterranean to the equator.

SN Sierra Nevada (Mulhacen)
HA High Atlas (Toubkal)
SI Sinai (Mt Catharina)
HR Hoggar (Assekrem)
TI Tibesti (Emi Koussi)
SN Simen Mts (Ras Dashan)
BE Bale Mts (Tullu Dimtu)
MK Mt Kenya

Mountain elevation

0°C – isotherm warmest month (free atmosphere) (WMO 1965)

0°C – isotherm coldest month (free atmosphere) (WMO 1965)

10°C – isotherm warmest month (free atmosphere)

10°C – isotherm coldest month (free atmosphere)

4.5°C – isotherm for the warmest month (free atmosphere) = approximate position of the snow line

hypothetical position of the snow line over the arid zone if sufficient humidity available

mean annual position of the 0°C isotherm (free atmosphere) = approximate position of the snow line

mean annual position of the 7°C isotherm (free atmosphere) = approximate position of the tropical timber-line

hypothetical daily altitudinal variation of the 10°C – isotherm (terrestrial values transposed to free atmosphere) for (a) the warmest and (b) the coldest month.

observable snow line

hypothetical snow line

timber-line

tree line

total amount of precipitation May-October

total amount of precipitation November-April

T transitional zone between the tropical diurnal climate and the subtropical seasonal climate

References: Dubief 1959/63; Gavrilovic 1969; Lebedev 1970; Messerli 1967a; Stähli 1977; WMO 1965.

The obvious outcome of very low, erratic precipitation, high mean temperatures and high potential evapotranspiration is an absence of soil and vegetation cover in the arid parts of North Africa. The geomorphic consequences are predictable: the unprotected land surface is exposed to extreme temperature fluctuations and to the erosional impact of wind as well as episodic and sometimes heavy rainfall.

Increased precipitation, lower temperatures, and reduced potential evaporation mark the transition to adjacent climatic zones. The decisive characteristic is the seasonal distribution of precipitation, with winter rains along the Mediterranean, summer/autumn rains in the Sahel, summer rains in the Simen highlands of Ethiopia, and two wet seasons on Mt Kenya.

The mountains of the central Sahara are somewhat unique. As orographic activation centres for atmospheric disturbances, they form islands of higher precipitation. Both temperature and potential evaporation are reduced in the higher areas, so that vegetation is no longer confined to localities with shallow groundwater, as in wadi beds out on the plains. Wind action is less active than in the flat lowlands, so that in the uplands water is almost exclusively responsible for the removal and transport of material.

The mountains in the less arid zones show remarkable asymmetries in vegetation belts that reflect the climatic conditions. The climatic, geomorphic and vegetational altitudinal belts of the Atlas and Bale mountains correspond closely to those of neighbouring regions. For example, the altitudinal change in plant associations in the Bale mountains is very comparable to that on Mt Kenya.

5.1.2 *Temperature*

The presentation of meridional climatic profiles (Figure 5.1) enables us to evaluate how far a regional climate follows the continental trend. The marked climatic differences between Tibesti and the Hoggar seem to stem more from the meridional trend than from any east-west differentiation. Figure 5.1 shows the free-atmosphere 0°C isotherm (Messerli 1973), supplemented by the 10°C isotherms for the locally warmest and coldest season (data from WMO 1965; Thompson 1965). The mean daily altitudinal fluctuations of the 10°C isotherm were also calculated. The following facts show clearly:

In the equatorial tropics (0°N-10°N) the climate is strictly diurnal, for the isotherms for the warmest and coldest months are no more than 300 m apart, which is in the range of the diurnal variation at any time of the year.

A seasonal temperature difference is more evident in the Simen Mts, in contrast to the Bale Mts, with the 0°C isotherm for the warmest month at a higher elevation in the drier northern massif.

The high mountains of the central Sahara, the Hoggar and Tibesti, differ widely in their thermal regime. Although separated by only 2-4° of latitude, they display the greatest meridional temperature gradient, with an intriguing seasonal reversal of trend. In winter the 0°C and 10°C isotherms in Tibesti are 600-800 m higher, and in summer are 200-400 m lower than in the Hoggar. Tibesti is transitional with respect to the dominance of diurnal and seasonal climate, and is thermally less continental than the Hoggar.

Mountains north of the Sahara, including Mt Sinai, have a seasonal temperature regime similar to that of the Mediterranean region.

The calculated elevation of the lowest daily position of the 0°C isotherm for the coldest season is somewhat hypothetical (see also Figure 5.7). The greater tendency to frost in the Hoggar as compared with Tibesti is shown, even though areas of temperature inversions are not included. In the Simen Mts of Ethiopia the number of potential frost occurrences is likewise high, following the general trend.

Free atmospheric temperature values in high mountain areas are only to a limited extent comparable to those of meteorological stations. In particular, daily fluctuations in surface temperature are more pronounced, and valleys experience nocturnal inversions of temperature, which exert a prime control over frost occurrence and over plant limits. Table 5.1 shows how the incidence of frost varies between the different mountain regions. Discrepancies between Table 5.1 and Figure 5.1 reveal how locally-influenced weather-station observations differ from those in the free atmosphere.

A good example of the influence of microclimate is the altitudinal distribution of temperature minima in Tibesti. Mean temperatures follow the usual trend, with Bardai warmer than Trou au Natron, but the mean minimum temperature in Bardai is far lower than at Trou au Natron, although the latter station is nearly 1 500 m higher. One consequence of these temperature inversions is the occurrence of frosts along the foot of the mountains, although they are geomorphically ineffective as they do not penetrate to any great depth. Equally critical is whether the frosts occur during the dry or wet season. In the Mediterranean areas cold and wet periods occur simultaneously, and in the Hoggar there may be scanty rains during the cold season, in 10 per cent of all cases according to Yacono (1968:34). In Tibesti, on the other hand, it is rare for frosts to coincide with wet conditions. In the high mountains of Ethiopia, which experience marked diurnal temperature changes, frost is common and effective above 4 000-4 200 m in the Simen and Bale Mts, and frost-patterned ground is very evident (Hastenrath 1974; Messerli 1975).

The differences between air and surface temperatures can be considerable. Stähli (1977) registered differences of 5-8°C between minima during the dry season, but only of 1-2°C under clouded skies during the wet season throughout several field seasons at Geech (3 600 m) in the Simen Mts. The same holds good for Tibesti (Jannsen 1969; Indermühle 1972:134ff.) and the Hoggar (Dubief 1959:69; Yacono 1968:38; Exkursionsbericht 1974:29). This means that the number of frost days at a given altitude may be far greater than specified on the station report, although the ground frost not recorded by station instruments may not be very effective. Of greater concern are observations of needle ice, which is virtually unknown in the central Sahara, occurs above 4 000 m in the Simen Mts during the wet season, and above 3 300-3 800 m at all seasons on Mt Kenya (personal observation, and Hastenrath 1976:235).

5.1.3 *Precipitation*

The central Saharan lowlands receive less than 50-100 mm of precipitation during an average year, but the uplands have a higher rainfall with a more

Table 5.1 Temperature data

Area	Station	Altitude (m)	Mean temp. of warmest month (at 2 m, °C)	Mean temp. of coldest month (at 2 m, °C)	Mean daily amplitude (°C)	Mean daily minimum coldest month (°C)	Absolute minimum (°C)	No. of days with frost change (at 2 m)	No. of days with frost change (surface)	Temp. gradient ΔT/100 m (°C) Warmest month	Coldest month	Period of records	References
Sinai	Mt. Catharina	2621	18.2(IX)	1.0(I)	9.5	− 2.7	?	?	?	0.55	?	1934-37	Gvirtzman 1976 Smithsonian Institute
Hoggar	Tamanrasset	1376	28.9(VII)	11.7(I)	13.5	+ 4.0	− 6.6	9.8	39.9	0.65-	0.22-	1926-50	Dubief 1959, 1971 (completed)
	Assekrem	2706	18,8(VII)	6.3(I)	10.0	+ 2.3	− 11.4	41	106/114	0.92	0.85	1955-60	Yacono 1968
Tibesti	Bardai	1020	30.9(VII)	13.3(I)	20.1	+ 0.6	− 4.5	22	40	0.8	0.5	1965-68	Heckendorff 1972, 1977
	Trou au Natron	2450	18.0(VI)	8.0(I)	10.0	+ 3.5	− 6.8	5	ca. 100			1965-68	Gavrilovic 1969 Jannsen 1969
Simen	Debarek	2860	15.5(IV)	10.3(IV)	10.3	+ 6.4	+ 3.0	0	0	0.45	0.88	1973-74	Stähli 1977
	Geech-Camp	3600	9.5(IV)	6.2(XII)	9.1	+ 1.0	− 2.0	11	?			1973-74	
Bale	Dinshu	3200	14.8(II)	10.6(IX)	18.7	+ 4.3	− 3.5	?	?	?	?	1971	Buer 1971
Mt Kenya	I	3048	11.6(II)	8.9(VII)	14.4	+ 2.2	− 1.7	?	?	0.47	0.57	1957-58	Griffiths 1972;
	II	4770	−2.2(III)	−3.9(VIII)	5.1	− 3.7	− 8.3	>300	>300			(short periods)	Knapp 1973; Coe 1967; Brinkman et al. 1968; Mitchell 1971

Table 5.2 Rainfall data (same references as in Table 5.1)

Area	Station	Altitude (m)	Yearly no. of days with >0.1 mm	Mean annual precipitation (in mm)	Min. annual precipitation (in mm)	Max. annual precipitation (in mm)	Max. amount of rain in 1 day (in mm)	Yearly no. of months with <5 mm prec.	Period of records
Sinai	Mt Catharina	2 621	10	61.8	10.7(?)	81.0(?) (without Nov.)	76.2	7	1934-37
Hoggar	Tamanrasset	1 376	14	46.1	5.2(1961)	159.0(1933)	48.8	7-9	1925-62
	Assekrem	2 706	40-45	144.9	37.2(1961)	267.8(1957)	130.8	1-3	1955-62
	Assekrem	2 706	?	118,7	7.6(1973)	267.8(1957)	?	?	1956-74*
Tibesti	Bardai	1 020	22(1966) 67)	11.9	0.0(1962)	60.7(1966)	9.9	11	1957-68
	Trou au Natron	2 450	20	126.8	9.0(1967)	192.4(1966)	45.6	6	1966-68
Simen	Debarek	2 860	?	993	863 (1972)	1 086 (1973)	100(?)	3	1971-74
	Geech-Camp	3 600	154	1 529	1 467 (1973)	1 590 (1974)	68	2-3	1973-74
Bale	Dinshu	3 200	171(1969-71)	1 162	1 158? (1970)	1 217 (1975)	?	0	1970-75
Mt Kenya	I	3 048	?	1 535	1 113 (1965)	1 930 (1963)	?	0(?)	1960-63/65-71**
	II	4 770	?	858	630 (1971)	1 060 (1968)	?	0(?)	1959-60/64-72**

* personal communication, J.Dubief.
** original records, NWD, Nairobi.

definite seasonal distribution. The Atlas Mts are far wetter, reflecting their proximity to the Atlantic and Mediterranean. Rainfall in the Sinai Mts is comparable in amount to that in the Hoggar and Tibesti, but is highly seasonal. Rainfall in the Ethiopian mountains varies according to elevation and latitude, with the precipitation regime in the Bale Mts resembling that of equatorial East Africa.

5.1.3.1 *Vertical distribution of precipitation.*

Accurate data on the change in rainfall with elevation are available only for the Hoggar (Dubief 1963:122ff.)and Mt Kenya (Thompson 1966). For the other mountains we need to integrate the scanty information available (Table 5.2) with the model of altitudinal distribution developed by Lauer (1975:84ff.), giving the results shown on Figure 5.2.

Precipitation in the Atlas Mountains increases progressively with elevation (500 to over 1 000 mm) on both the humid and the arid side of the mountains until the summit region (3 000-4 000 m). Even though measurements on Toubkal (4 165 m) in the High Atlas suggest a decrease in precipitation, it is difficult to obtain reliable rainfall measurements on mountain summits, and the geomorphic evidence argues against a general decrease (Messerli 1967:182). Aspect is important in the Atlas Mts, as shown by rainfall values of 100-300 mm in the Saharan piedmont, 300-1 000 mm in the Mediterranean piedmont, and 300-600 mm in the lowlands facing the Atlantic.

Precipitation is low in the Sinai Mts, probably ranging somewhere between 200 mm (Dubief 1963) and somewhat less than 100 mm (Atlas of Israel IV/2; 61.8 mm: Smithsonian station 1934-1937). These precipitation values are very little higher than those of the central Saharan uplands. This is even more remarkable as Mt Hermon, located only a few hundred kilometres further north, can count on more than 1 500 mm as a yearly average. Even though it is not protected by any other mountain against advancing cyclonic disturbances, the position of Mt Sinai relative to the Mediterranean coastline and to the path of the rain-bearing Mediterranean depressions is responsible for its aridity.

The Hoggar and Tibesti receive an annual precipitation of the same order of magnitude, with the rainfall at Tibesti concentrated in the south-west of the massif. The results presented by Dubief (1963) for the Hoggar are based on an unusually long set of observations, and show a greater tendency for rainfall to increase with elevation during wet than during dry years. In both cases, the zone of maximum rainfall lies between 2 300 and 2 700 m. Summer rainstorms are especially common at higher elevations in the Hoggar, and a similar situation may also obtain in Tibesti, although it has not been verified by measurements.

Rainfall distribution in the Ethiopian highlands is complex and interesting. Two maxima are to be observed at c. 1 800 m and c. 3 600 m (Stähli 1977). Despite the fact that this information, which applies to the Simen Mts, is somewhat at variance with that of Lauer (1975b:88), it supports his general altitudinal sequence. The lower maximum is attributable to the shallow monsoon air whose condensation level is soon attained. Orographic effects may be dominant in the case of the upper maximum.

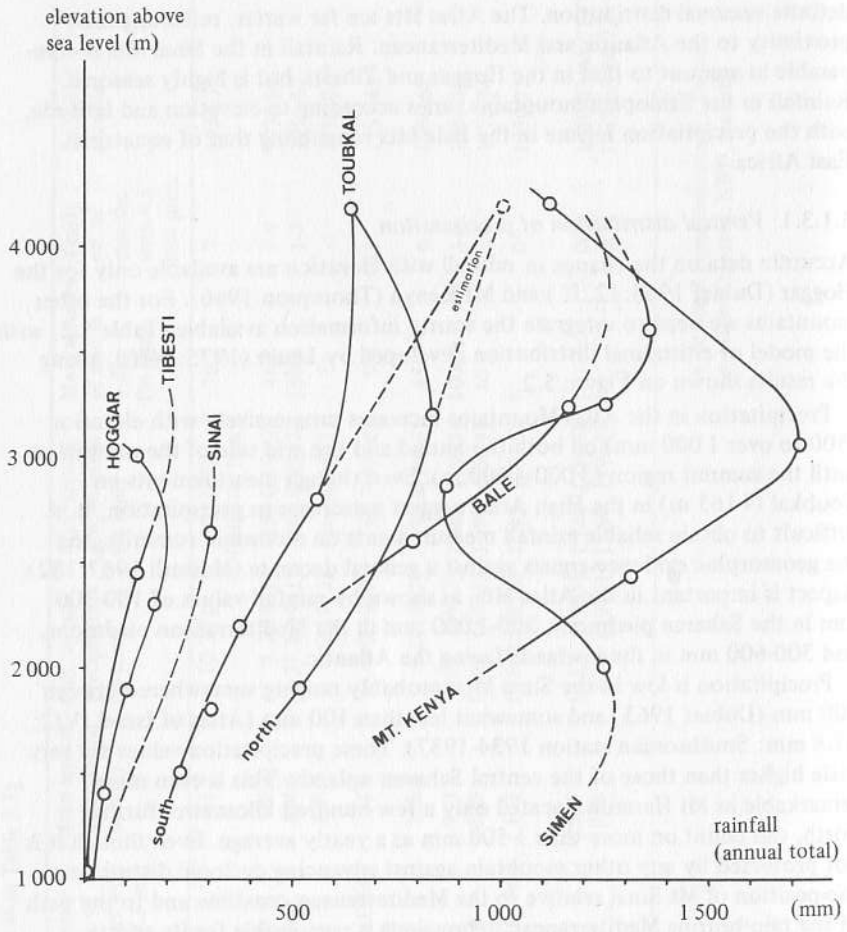


Figure 5.2 Vertical rainfall distribution (annual totals) of African mountains north of the equator. (O) = measured values.

Precipitation in the Bale Mts is probably comparable to that in the Simen Mts although more evenly distributed throughout the year, with two rainy seasons. Vegetation cover seems denser on the slopes facing southwest, although we possess precise data from only the northern slopes. Meteorological observations at Goba and Dinshu point to an increase in rainfall with elevation in the central part of the massif, but whether there are two maxima is not known.

Mt Kenya receives its maximum precipitation at an elevation of c. 3 000 m, the amount varying greatly according to aspect, with maxima on the western and southeastern flanks.

5.1.3.2 *Annual rainfall distribution.* It is possible to distinguish between permanently humid and intermittently humid mountain ranges. Even the central

Saharan uplands show a distinctly seasonal rainfall distribution in the long term, in contrast to the adjacent lowlands.

The ectropical or Mediterranean rainfall type is dominant in the Atlas, is less pronounced in the Sinai and occurs only episodically in the Hoggar and Tibesti. Precipitation falls mainly in winter, in response to the passage of westerly depressions which reach the Atlas from the Atlantic, and weaken rapidly inland. Depressions occasionally reach the Hoggar and more rarely Tibesti, producing rain which is not very heavy but may be quite long-lasting. Heavier rainfall occurs when cold ectropical air masses meet warm humid air flows originating from equatorial regions. Southwesterly depressions occasionally reach the southeastern flanks of the Atlas, thereby lessening the rain-shadow effect. Summer rainfall in the northern Sahara occurs mostly during thunderstorms, and is increased by orographic factors. In the Sinai summer precipitation has only rarely been registered.

The equatorial zone of East Africa (Mt Kenya) has a rainfall pattern related to the position of the convergence zone between the southeast and the northeast trades. This results in two rainfall peaks in April and November, although rainfall is registered on Mt Kenya every month, in contrast to the surrounding semi-arid plains. The rainfall has a typical daily pattern, especially in the transitional months before and after the rainy season, with clear skies in the morning, cloud build-up before noon, followed by rain until late afternoon. During the most humid months, precipitation may occur at any hour of the day. This daily pattern of cloud formation allows greater insolation of the northern and eastern slopes of the mountain. In addition, the bulk of the precipitation on Mt Kenya comes from the southeast and the west, which, together with insolation, leads to a distinct asymmetry of the vegetation belts.

In the Bale Mts, a pattern similar in many respects to that of Mt Kenya can be observed. There are two wet seasons, with maxima in April and August, again reflecting the position of the intertropical convergence zone (ITCZ), although not as well separated as in the equatorial case of Mt Kenya. Seasonal influxes of air from the Zaïre basin supplement the trade winds of both hemispheres.

The Simen Mts at the northern end of the Ethiopian plateau are exposed to the influence of the anticyclonic cells dominant over Arabia and the Sahara. The northern ITCZ just reaches the areas north of the Simen Mts and produces one rainy season in summer, sometimes with a secondary peak in March-May associated with southeasterly winds (Stähli 1977). Peak summer rainfall is on the higher eastern slopes of the Simen Mts, for the unstable southwesterly air masses flow around and not over the ridges, to become absorbed on the lee side of the massif by the dominant upper east winds, in a manner still not fully explained (Suzuki 1967:30; Flohn 1965:183). A westerly air stream is dominant during the dry winter months and the transitional months, and high-level troughs may collide with more humid air masses from the Indian Ocean to produce rain.

The Saharan uplands receive precipitation almost exclusively from outside the desert, usually by reactivating disturbances which originate either from the northern westerlies or from equatorial monsoonal sources, depending on the season. In the long run, and despite the lack of a well-defined rainy season, it is possible to distinguish three types of rainfall regime in the Hoggar. 40 per cent

of the annual precipitation is associated with the July-October 'monsoon', 32 per cent with the pre-monsoonal 'Sudano-Saharan perturbations' (April-July), 15 per cent with 'Mediterranean depressions' (November-January), and the rest originates as local Saharan depressions or else cannot be clearly identified (Dubief 1971; Rognon 1970:47). In Tibesti, 90 per cent of the rain falls in summer (Gavrilovic 1969:47), and only the northern slopes receive ectropical depressions. Although the above proportions are valid today, they may well have varied during the past.

Mayençon (1961) has defined a 'heavy rainfall' as one of 30 mm or more in 24 hours. In areas of sparse plant cover and high relief, heavy downpours are potent geomorphic agents, as well as being of prime value in replenishing ground water in the oueds (Rognon 1970:196). Dubief (1963:97, 102) describes several such very heavy rainstorms in the Hoggar, such as 104.6 mm/24 hrs on Assekrem (26/11/1958) and 48.8 mm/24 hrs at Tamanrasset (25/5/1933). They are more unusual in Tibesti, where there is a record of 370 mm of rain within three days (Heckendorff 1972:136, citing Hervouet 1958).

Far less intense rainfall may produce sheetfloods and flowing water in the oueds. Messerli & Indermühle (1969:89) observed runoff from a 10 mm summer thunderstorm on Emi Koussi (Tibesti), and Gavrilovic (1969) reported sheetfloods at Bardai after rain with an intensity of 6.5 mm/hr. Precipitation of this magnitude may fall almost every year, at least in the higher parts of the central Saharan uplands. Such falls are usually related to local thunderstorms and depend on the presence of relatively humid 'monsoonal' air masses. On the other hand, heavy rainfall may occur over large areas when cold ectropical air masses coincide with influxes of equatorial air, as described by Vanney (1960). Jalu & Damotte (1967:231ff.) mention the relationship between heavy rainfall and a belt of low pressure between the Mediterranean and the Niger, which may allow ectropical air to enter the Sahara and to underride humid tropical air. These conditions are optimally present in winter, and are sometimes associated also with Sudano-Saharan depressions (Dubief 1971:304).

The geomorphic effect of oued floods is visible on air photos and satellite images (Dubief 1973). Rognon (1970:113) has estimated the likely recurrence interval of oued floods at Tamanrasset on the basis of known monthly rainfall. The probable number of floods per 100 years is as follows:

J	F	M	A	M	J	J	A	S	O	N	D
8	2	0	6	8	10	18	24	28	8	2	6

The expected frequency of severe floods is similar in winter and summer, and the oued Tamanrasset flows for a distance of 300-400 km about once every six or seven years.

Exact figures are not available for the other mountain areas of the Sahara and the Sinai. Flood frequency in Tibesti is probably less than in the Hoggar, and probably about similar in the Sinai. Big floods are well known in the Atlas, fed by melting snow as well as by thunderstorms.

In Ethiopia the vegetation cover reduces the erosive impact of floods. Nevertheless, erosion is becoming an increasingly serious problem following excessive clearing of the remaining forests of the Simen Mts (Hurni 1975).

Table 5.3 Frequency of snow fall (adapted from Messerli 1972:63)

Area	Latitude	Altitude of snow fall area	Frequency	Season
High Atlas	31°N	Above 1 000 m	Annual	Winter
Anti-Atlas	30°N	Above 1 500 m	Annual	Winter
Sinai	28°N	Above 2 000 m	Annual (?)	Winter
Hoggar	23°N	Above 2 500 m	Every 3rd year (?)	Winter
Tibesti	21°N	Above 3 000 m	Every 7th year (?)	Winter
Simen Mts.	13°N	Above 4 000 m	Annual	Rain period
Bale Mts.	7°N	Above 4 000 m	Annual	Rain period
Mt Kenya	0°N	Above 4 000 m	Annual	In all seasons

5.1.3.3 *Snow.* Although the hypothetical present-day snow line would be discontinuous owing to insufficient moisture in the arid zone (Messerli 1966a: 131), snow is not unknown in the central Saharan uplands, nor in the mountains of Sinai and Ethiopia (Table 5.3). The likelihood of snowfall is of course far greater in regions where precipitation occurs in the cold season, which accounts for the difference between the Hoggar and Tibesti. In Ethiopia, especially in Bale, where the wettest months are in summer, hail and sleet are more common than snow.

5.1.3.4 *Rainfall fluctuations.* Towards the centre of the desert, the seasonal and annual incidence of rainfall becomes so erratic as to be almost random, except in the desert uplands. Figure 5.3 shows the frequency distribution of rainfall at the Hoggar stations Tamanrasset and Assekrem for the period 1955-1973/74. The two curves are almost parallel, but, if we took the relative values, the curve for Tamanrasset would be slightly steeper, indicating greater variability.

Figure 5.4 shows the annual rainfall for Tamanrasset during the period 1925-1974 (omitting 1973). Once again, we do not have a purely random distribution, but for several periods a grouping of drier or wetter years. Dorize (1976:226) shows that, within this annual fluctuation, winter and summer precipitation are of variable importance. Some of the rainfall fluctuations are of purely local importance but, since the Saharan uplands are located at the limit of influence of tropical and ectropical disturbances, they offer a guide to slight changes in the atmospheric circulation. The well-known influence of the position of high-pressure centres (Azores, St Helena) upon the advance of the summer monsoon into the southern Sahara is a case in point.

Dubief (1947:18) analysed annual rainfall distribution in the Hoggar back to 1860. He found that summer rainfall was more important during 1900-1939 than during 1860-1900, when winter and spring rainfall contributed 60 per cent of the annual total. We have seen that freeze-thaw activity and a dense plant cover depend primarily upon winter precipitation. There was excellent grazing in the Hoggar during 1873-1880, and in 1875 the summit was covered in snow for a month (Dubief 1963:248).

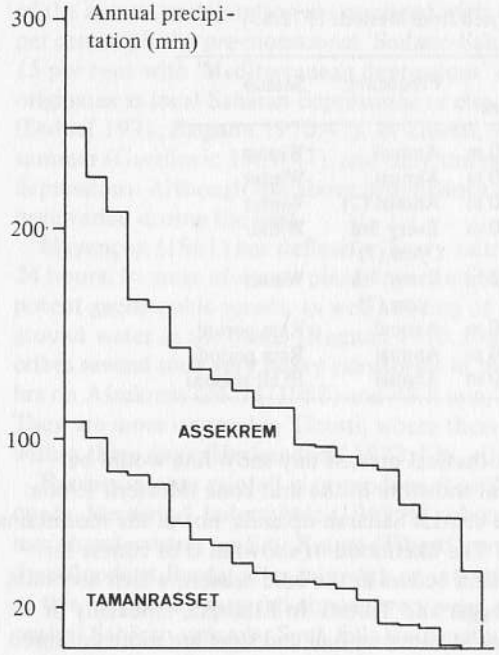


Figure 5.3 Distribution of the annual rainfall totals for Tamanrasset (1 376 m) and Assekrem (2 706 m) 1955-1974 (Dubief 1971; completed)

5.2 CLIMATIC AND ECOLOGICAL ZONES

5.2.1 *Problems involved in comparing climatic and ecological zones*

Vegetation associations and their boundaries are closely related to annual and seasonal fluctuations in temperature, precipitation and evapotranspiration. Mountain areas are ecological as well as climatic islands and differ markedly from the surrounding lowlands (see also Chapter 13).

Within the tropics Lauer (1975a:29) proposed a schematic vertical division into warm and cold tropics for both arid and humid areas, with the boundary at the 16-18°C mean annual isotherm. This subdivision also reflects a floristic distinction between tropical and Afro-montane regions. Within a specific floristic region, the vertical distribution of plant species or associations is in many respects directly related to a particular combination of climatic factors. But comparisons between different floristic regions in our transect from Mediterranean to equator are more problematic. Likewise, comparisons between tree lines involve comparisons between quite different species, such as *Quercus* and *Juniperus* in the High Atlas, *Olea laperrini* in the Hoggar and *Erica arborea* in Ethiopia and Kenya. Despite these difficulties, there have been a number of fruitful attempts to relate vegetation to climate, both in the mountains of the wet tropics (Troll 1959; Lauer 1975a) and in the central Saharan uplands (Quézel 1965, and Chapter 4 of this volume).

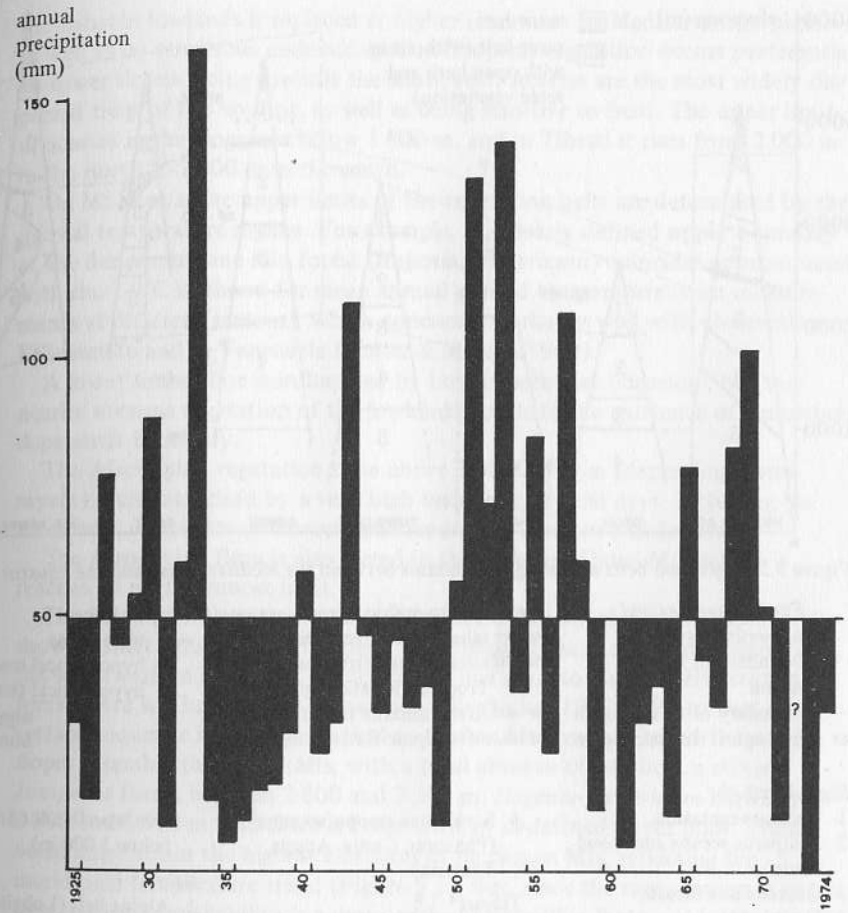


Figure 5.4 Variations of the annual rainfall total for Tamanrasset (1925-1974) (Mean appr. 48.5 mm) (Dubief 1971; completed)

5.2.2 *Actual vegetation boundaries*

Figure 5.5 is a compilation of ecological zones and floristic regions based on a number of sources. Limiting factors are mainly temperature (higher levels of the High Atlas, the Ethiopian and East African mountains) or humidity (Sahara, and, in more moderate form, the lower levels of the Ethiopian and East African mountains).

In the Hoggar and Tibesti the vegetation is largely confined to the oueds, and depends almost entirely on the available ground water. A sparse steppe vegetation covers less than 50 per cent of the surface at higher elevations. An ephemeral plant cover appears behind the confines of the valleys once sufficient rain has fallen, and may last for several weeks or even months.

Depending upon rainfall and to a lesser extent upon temperature, the various floristic regions may overlap vertically (Figure 5.5). The Saharo-sindic flora of

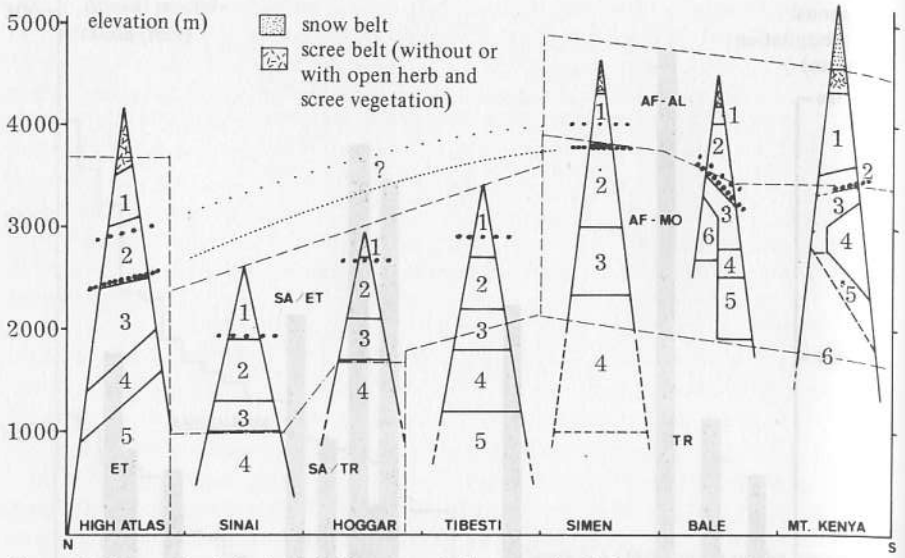


Figure 5.5 Vegetation belts in the high mountains between the Mediterranean and the equator

Floristic regions and subregions (sr)
- - - -boundary of floristic region
– – –boundary of fl. subregion
ET Ectropical floristic region
SA Saharo-arabic floristic region
SA/ET saharo-arabic/ectropical sr
SA/TR saharo-arabic/tropical sr
TR Tropical floristic region
AF-MO Afro-montane floristic region
AF-AL Afro-alpine floristic region
• • • tree-line
timber-line
. . . hypothetical tree-line
..... hypothetical timber-line
supp. suffici humidity

High Atlas[2 10]
1 Thorny vegetation
2 Juniperus scrubs and woodlands
3 Quercus ilex forests
4 Dry woods
5 Steppe vegetation

Sinai[13]
1 Upper montane desert steppe (Artemisia)
2 Lower montane desert steppe (Phlomis, Olive-tree, Cupressus)
3 Montane desert savanna (Tamarix)
4 Desert steppe (Acacia)

Hoggar[3 7]
1 Upper montane desert steppe (Artemisia)
2 Lower montane desert steppe (Artemisia, Lavandula, Olea lap.)
3 Montane desert savanna (Tamarix)
4 Scrub/tree steppe/savanna (Panicum, Cassia, Acacia, Tamarix)

Tibesti[3 7 8]
1 Upper montane desert steppe (Artemisia, Erica arb.)
2 Lower montane desert steppe (Aristida, Linaria)
3 Desert steppe vegetation (single Acac., Tamar.)
4 Montane savanna (Acacia, Tamarix)
5 Tree savanna (Acacia, Cassia, Panicum)

Simen[5 9 11]
1 Afro-alpine grassland (pasture) (Lobelia, Helichrysum)
2 Montane forests (Erica arb., Hypericum)
3 Tall savanna forests
4 Dry savanna zone, combretum woodlands (Adansonia below 1 000 m)

Bale[2 6 12]
1 Alpine belt (Lobelia, Senecio, Alchemilla)
2 Erica scrub (Erica arb., Helichrysum)
3 Hagenia-Hypericum woods
4 Bamboo zone
5 Montane rain forest
6 Juniperus woods (with Podocarpus in lower areas)

Mt Kenya[1 2 4]
1 Alpine belt (tussock grassland, Lobelia, Senecio, Helichrysum)
2 Erica belt (Erica arb., Helichrysum)
3 Hagenia/Hypericum forest
4 Bamboo zone
5 Mont. rain forest (Junip., Olea, Podocarp.)
6 Savanna

the Saharan lowlands is replaced at higher elevations by Mediterranean plants as well as by numerous endemic species. Tropical vegetation occurs preferentially on lower slopes facing towards the southwest. Acacias are the most widely dispersed trees of the savanna, as well as being sensitive to frost. The upper limit of acacias in the Hoggar is below 1 800 m, and in Tibesti it rises from 2 000 m in the north to 2 300 m in the south.

On Mt Kenya, the upper limits of the vegetation belts are determined by the diurnal temperature regime. For example, the clearly defined upper boundary of the dense montane rain forest (*Hagenia, Hypericum*) coincides approximately with the 7-9°C isotherm for mean annual ground temperature (own measurements at different seasons), which concurs remarkably well with observations on Kilimanjaro and in Venezuela (Walter & Medina 1969).

A lower timber-line is influenced by human activities (clearing), but the nearby savanna vegetation of the lowlands points to the existence of a moisture-dependent boundary.

The Afro-alpine vegetation zone above 3 000-3 600 m (depending upon aspect) is characterized by a very high incidence of frost days. Including the *Erica* belt, it consists of tussock grasslands with *Senecio* and *Lobelia.*

The Afro-alpine flora is also found in the Bale and Simen Mts, where it reaches its northernmost limit.

The Bale Mts reflect the variable influence of the southwest monsoon and show distinct variations with aspect, with dense tropical rain forest mantling the southwestern lowlands. In the transitional zone to *Hagenia/Hypericum* forest there is a narrow belt of bamboo (Werdecker 1962:139), so that the vertical sequence is almost identical to that on Mt Kenya. The northeastern slopes resemble the Simen Mts, with a total absence of bamboo, a mixed *Juniperus* forest between 2 800 and 3 300 m, *Hagenia-Hypericum* between 3 300 and 3 500 m, and *Erica arborea* with an ill-defined upper limit. These boundaries attain the highest elevation in the Simen Mts, reflecting the meridional temperature trend (Figure 5.1). But, since the rainy season is not as long, moisture availability is a more critical controlling factor, at least along the northern foothills. The boundary with the northern semi-arid belts is probably at about 1 000 m (Troll 1974:213), where the wet savanna forests give way to *Adansonia.*

The Atlas ranges mark the northern limit of the arid zone. Here the Sahara-arabic floristic region meets the ectropical (Mediterranean) flora (Lauer & Frankenberg 1977:6). Once again, aspect influences the vertical zonation, especially at lower elevations, where boundaries are up to 1 000 m higher on the arid side of the range (Figure 5.5). The higher localities again contain a high proportion of endemic species. In contrast to the other mountains, the growing season in the High Atlas is limited by temperature, and snow cover may persist for six or seven months.

References: 1. Hedberg 1968; 2. Knapp 1973; 3. Lauer & Frankenberg 1977; 4. Lind & Morrison 1974; 5. Messerli 1975; 6. Messerli et al. 1977; 7. Quézel 1965; 8. Scholz 1967; 9. Troll 1974; 10. Walter 1970; 11. Werdecker 1955; 12 Werdecker 1962; 13. Exkursionsbericht 1975.

Figure 5.6 Limiting climatic parameters for vegetation cover and morphodynamic processes in African high mountains

Vegetation cover and dominant morphodynamic processes

- vegetation cover <50% frost activity = dominant morph. proc.
- vegetation cover <50% water erosion (areal and linear) = dominant morph. proc.
- vegetation cover >50% water erosion (linear) = dominant morph. proc.

SN1 Sierra Nevada (Monachil 1 000 m)
SN2 Sierra Nevada (Mulhacen 3 478 m)
A1 High Atlas (Amizmiz 1 000 m)
A2 High Atlas (Ouarzazate 1 135 m)
A3 High Atlas (Toubkal 4.165 m)
SI1 Sinai (Elat Mo)
SI2 Sinai (Mt Catharina 2 621 m)

H1 Hoggar (Tamanrasset 1 376 m)
H2 Hoggar (Assekrem 2 706 m)
T1 Tibesti (Bardai 1 020 m)
T2 Tibesti (Trou au Natron 2 706 m)
S1 Simen (Debarek 2 860 m)
S2 Simen (Geech Camp 3 600 m)
S3 Simen (Ras Dashan 4 543 m)

B1 Bale (Goba 2 740 m)
B2 Bale (Dinshu 3 200 m)
B3 Bale (Tullu Dimtu 4 450 m)
B4 Bale (Rira valley below 3 000 m)
K1 Mt Kenya (Nanyuki 1 945 m)
K2 Mt Kenya (Met. station 3 048 m)
K3 Mt Kenya (Top hut 4 770 m)

Mt Kenya has a distinct timberline (*Hagenia, Hypericum*), but in the arid zone the tree line is more diffuse. In transitional zones, like the High Atlas and Ethiopian mountains, individual trees or groups of trees may grow many hundreds of metres above the timberline proper, forming a separate tree line.

5.2.3 *Climatic controls upon ecology and upon geomorphic processes*

The geomorphic processes and ecological peculiarities characteristic of a particular mountain range are strongly influenced by temperature and humidity. Figure 5.6 shows how these two factors may be used to delineate altitudinal zones dominated by completely different morphodynamic processes. The results of this model may be summarized as follows:

Given sufficient moisture (rainfall) and relatively few frost cycles, a dense plant canopy will cover the ground. Erosion by freeze-thaw processes and by running water is minimized except perhaps along the streams and valleys. If vegetation is destroyed by clearing or ploughing, geomorphic instability supervenes.

If rainfall is low or frost is common, the plant cover becomes sparse or disappears. Erosion is then effective, with running water the dominant agent in arid areas and freeze-thaw processes in high moist areas. In the higher parts of the arid zone, freezing may be limited by the absence of water, just as at lower elevations plants would colonize were rainfall to increase.

High mountains usually comprise several morphodynamic zones. These are arranged vertically in regions of homogeneous climate (e.g. the Hoggar), but in climatically transitional areas differences related to aspect may modify the vertical zonation, as in the High Atlas and Bale Mts.

5.3 GLACIAL AND PERIGLACIAL FORMS AND PROCESSES

The high mountain regions throw some light on the late Quaternary climates of Ethiopia and the Sahara, although it is often difficult to assign an absolute age to events in the uplands. It is not easy to date landforms fashioned by glacial, nivational and periglacial processes. At lower elevations, the intense and oft-changing denudational processes render interpretation and dating of the resultant landforms exceedingly difficult.

On the other hand, mountains, with their different climatic, geomorphic and ecological zones, are sensitive indicators of very slight environmental changes. Since the most successful palaeoclimatic studies have concentrated upon river valleys and lake basins, it is necessary to compare inferences drawn from investigations in the uplands with results obtained from analyses of lake sediments and organic deposits in the lowlands.

To sum up, three difficulties confront those working in mountains. First, there is a constant need to integrate information from the uplands with the growing body of data from the lowlands. Second, absolute dating of late Pleistocene and Holocene environmental changes is often not possible. Third, it is still not possible to draw up a reliable palaeoclimatic history of events preceding the last glacial interval.

5.3.1 *Present-day glacial and nivational forms and processes*

Glaciers and glacial processes are active only at rare localities in the Mediterranean mountains and appear only above 4 500 m in East Africa, with considerable variations between the various mountain systems (Messerli 1967, 1973, 1979).

Nivational processes impinge more upon the arid zone, both in the winter rainfall uplands (Atlas Mts) and in the summer rainfall Ethiopian highlands. The snowfall data listed in Table 5.3 reveal the potential for nivational activity, which is ineffective today, but was very intense during the last cool and relatively wetter phase.

In the Ethiopian mountains where snow falls regularly, active periglacial processes are developed mainly by a combination of meltwater and alternating frost. These processes, more periglacial than nivational, are dominant in the higher parts of the summit regions devoid of vegetation. The detritus formed at these levels is reminiscent of desert areas, but is here produced by snow or hail in a zone of alternating freeze-thaw activity.

5.3.2 *Glacial activity during the last cold period*

During the last cold period the higher mountains in the transitional zone from the Mediterranean to the arid zone were covered with sizeable mountain glaciers, and the snowline in the Taurus, Lebanon, Hermon and Atlas mountains was 300-900 m below their summits (Messerli 1967:164). The geomorphic impact of this cold period diminished towards the desert, where nivational forms are all that remain today in the Saharan uplands.

In the Hoggar Rognon (1967, 1977) distinguished a cryonivational zone of slow mass movement at 2 200-2 400 m, a nivational zone on east-facing slopes at 2 400-2 600 m, and some forms possibly indicative of small glaciers on the summits of Assekrem and Tahat.

Distinct nivational forms are apparent only above 3 000 m in Tibesti, especially around the northern peaks (Mouskorbé 3 376 m), but are lacking in the southern area (Emi Koussi 3 415 m) which is also the highest area in the Sahara. Apart from possible volcanic disturbances there is considerable local climatic variation from north to south within this mountain range (Messerli 1972:36, Figure 5). The nivation forms are not as clear as in the Hoggar, and are not controlled by aspect.

Of primary interest, however, is the low level attained by these nivation forms compared with the high elevation of the snowline in the arid zone (Rognon 1967, 1977; Messerli 1966a, 1972, 1973). If we chose not to relate these nivation features to a snowline or glacier equilibrium level, the problem of a distinct altitudinal gradation of the Saharan uplands during the last glacial still remains. For example, the lower limit of distinct nivation activity increases from 2 400 m in the Hoggar to 3 000 m in Tibesti, pointing to important climatic differences within the Sahara during this time, not unlike the present situation (Figure 5.7).

In the Ethiopian uplands we find a completely different situation, with a progressive increase in the extent of glaciation from tiny ice caps in the north to extensive glacier-covered plateaus in the south..

Hastenrath (1974) has reviewed earlier work in the Simen Mts, and Hurni

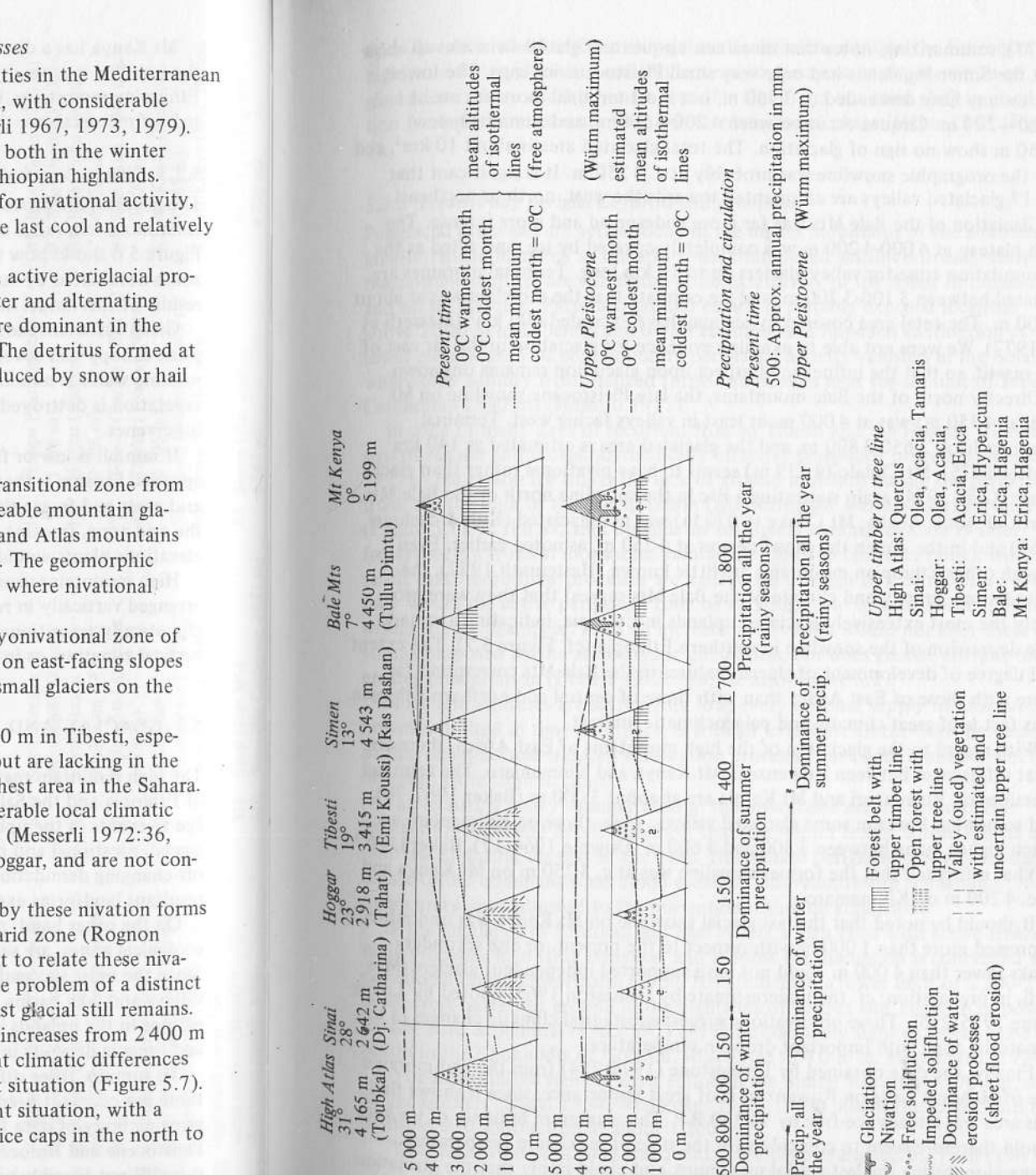


Figure 5.7 The mountains of the Sahara and Ethiopia
Horizontal and vertical zonation in the present time and in the Upper Pleistocene (last glaciation)

(1977), summarizing, notes that moraines, cirques and glacial striations all show that the Simen highlands had only very small Pleistocene ice caps. The lowest glacier may have descended to 3 760 m, but most terminal moraines are at 4 000-4 200 m. Cirques occur between 4 200-4 500 m, and summits below 4 350 m show no sign of glaciation. The total glaciated area is about 10 km^2, and and the orographic snowline was probably at c. 4 250 m. It is significant that the 17 glaciated valleys are all oriented towards the west, north or northeast.

Glaciation of the Bale Mts was far more widespread and more intense. The high plateau at 4 000-4 200 m was completely covered by ice, and acted as the accumulation zone for valley glaciers up to 10 km long. Terminal moraines are situated between 3 100-3 200 m, and we estimate that the snowline was at about 3 700 m. The total area covered by ice may have exceeded 600 km^2 (Messerli et al. 1977). We were not able to examine evidence for glaciation in the far east of the massif, so that the influence of aspect upon glaciation remains unknown.

Directly north of the Bale mountains, the late Pleistocene snowline on Mt Badda (4 350 m) was at 4 000 m, at least in valleys facing west. Terminal moraines lie at 3 650-3 800 m, and the glaciated area is estimated as 140 km^2 (Potter 1975). Mt Chilalo (4 139 m) seems to have nivational rather than glacial forms (Gèze 1974) again suggesting a rise in the snowline north of the Bale Mts. North of Addis Ababa, Mt Choke (4 070 m) was not glaciated (Kuls & Semmel 1965) and in the Simen the snowline was at 4 250 m, as noted earlier. Even though other Ethiopian mountains are little known (Hastenrath 1977), the altitude, topography and climate of the Bale Mts suggest that they were probably the most extensively glaciated uplands in Ethiopia, indicating a remarkable depression of the snowline in southern Ethiopia (cf. Figure 5.7). The extent and degree of development of glacial features in the Bale Mts correspond far more with those of East Africa than with those of central and northern Ethiopia. This fact is of great climatic and palaeoclimatic interest.

With regard to the glaciation of the high mountains of East Africa, there are great differences between Ruwenzori, Mt Kenya and Kilimanjaro. The terminal moraines on Ruwenzori and Mt Kenya are at about 3 000 m (Baker 1967:70), and somewhat lower in some glaciated valleys, while those on Kilimanjaro are much higher, lying between 3 300 and 3 600 m (Downie 1964:12). Baker (1967: 70) has estimated that the former snowline was at c. 3 750 m on Mt Kenya and at c. 4 200 m on Kilimanjaro.

It should be noted that the last glacial snowline on Mt Kenya was undoubtediy depressed more than 1 000 m with respect to the present, or else secondary peaks lower than 4 000 m could not have supported independent glaciers (Messerli, in preparation; cf. the underestimate by Osmaston 1965, quoted by Livingstone 1975:255). These observations suggest substantial climatic changes in the equatorial zone with important drops in temperature.

Finally, the date obtained by Livingstone (1975:254) from the end-moraine site of Mahoma Lake on Ruwenzori is of great importance, since it shows that this area was already ice-free by 14 750 B.P. The maximum build-up of ice here would therefore seem to coincide with the time of maximum temperature depression during the last glacial maximum, and could imply that the glaciation of Mt Kenya and the Bale Mts was broadly synchronous. However, it is still an

open question whether the striking climatic difference within the Ethiopian highlands during glaciation reflects not only an increase in the elevation of glacial levels from south to north, but also signifies a temporal shift in glaciation from glacial maximum to the wetter late glacial phase (Heine 1977: Figure 7).

5.3.3 *Present-day periglacial forms and processes*

Periglacial processes are active today in the higher mountains of the southern Mediterranean marginal to the arid zone. Unimpeded solifluction and related freeze-thaw features are still found quite extensively in the Atlas, in Lebanon, and on Mt Hermon. Patterned ground occurs in suitably exposed localities above 2 500 m in Lebanon and on Mt Hermon, and impeded solifluction at lower elevations. This contemporary periglacial activity vanishes in the Sinai, where only solitary frost-induced forms can be seen near the summit of Jebel Catharina (2 642 m) (Messerli 1977).

In spite of many days of recurrent frost in Tibesti and the Hoggar, we find no sign of regular and morphodynamically effective periglacial processes (Messerli 1977). One reason for this is the lack of ground moisture during the period of frost, for the bulk of the precipitation falls during the warmest part of the year (Figure 5.1). In the Saharan uplands an ectropical seasonal climate (winter frost) meets a tropical monsoonal rainfall distribution (summer rains), with the result that freeze-thaw processes are ineffective through lack of moisture. Not only would the active periglacial zone be very high, but in a very arid climate it would simply disappear. Even an increase in elevation would not alter these constraints imposed by the atmospheric circulation, nor does greater altitude imply greater precipitation (Dubief 1963:128; see also Figure 5.2).

Since temperatures are sufficiently low, every unusual supply of moisture, however limited in time and space, is enough to initiate freeze-thaw processes, so that isolated frost-induced solifluction processes have and doubtless will be observed from time to time.

The recurring heavy summer rains in the mountains are more important agents of erosion and debris transport than the winter frosts, whose effects are obliterated during the rest of the year. The weaker periglacial activity is subordinate to the dominant sheet flood erosion. This relationship is unstable, momentary, and adjusted to the present-day climatic conditions.

In the highlands of Ethiopia and East Africa a high zone with active freeze-thaw processes is in clear evidence, and at most the discussion is concerned with elevational limits. Hövermann (1954:108) indicated a lower limit of 2 500-2 600 m for frost-patterned ground in the highlands of Eritrea and Tigre. In opposition to this, Kuls & Semmel (1965:292) did not discern any signs of freeze-thaw action in the Choke Mts of Godjam, which rise to 4 000 m. Hastenrath (1974: 176) observed initial signs of frost action in the Simen Mts above 3 700 m, while earlier workers (Büdel 1954; Werdecker 1955, 1958) placed the lower limit of frost-induced solifluction at about 4 200 m.

These somewhat confusing statements have been evaluated by Troll (1947, 1970:201) and they may likewise be explained by referring to the unpublished climatic data now available from various elevations in the Simen Mts (Stähli

1977). The critical shift from dense mountain steppe to a bare debris-covered surface, dominated by frost action, occurs between 4 200 and 4 400 m, somewhat lower in the localities facing north and west, and slightly higher in south- and east-facing sites. All occurrences of frost-shattering below this level are isolated and insignificant. In this sense, the observations of Kuls & Semmel (1965) correspond well with the altitudinal limits in the Simen. However, the correlation with temperature data is now of special interest. The 0°C mean daily minimum is at c. 3 900 m during the dry season (December-January) and at c. 4 500 m during the rainy season (July-August). This means that the freeze-thaw activity at 4 200-4 400 m in fact occurs during the transitional months (March-April and October-November) when just enough moisture is present to activate frost processes. The exact designation of the months of freeze-thaw activity is possible here only because in this latitude a weak seasonal climate is still superimposed upon the dominantly diurnal climate. Expressing the situation more precisely, minimum temperatures occur on the higher plateaux of northern Ethiopia (2 000-3 000 m) during the rainy part and in the uplands (3 000 to over 4 000 m) during the dry part of the winter months. Consequently, since the times of lowest temperatures and of maximum moisture supply do not coincide, the zone of frost shattering will tend to be somewhat higher. The almost immediate appearance of solifluction and of frost-patterned ground is explicable in terms of a diurnal climate characterized by a significant number of frost days above a certain elevation.

If we now compare the results from the mountains of southern Ethiopia and East Africa, a striking similarity in the altitudinal belts emerges. The zone of unvegetated rock debris starts at about 4 300-4 400 m in the Bale Mts and above about 4 200-4 400 m on Mt Kenya. There are of course minor areas of freeze-thaw activity below this level, above 4 000 m in the Bale Mts, in wetter sites on Mt Kenya above 3 800 m, with some needle-ice development above 3 300 m (cf. Werdecker 1962; Furrer & Freund 1973; Hastenrath 1973, 1976).

The similar heights of the Bale and Simen highlands do not imply a similar climate, since precipitation is far higher in the Bale Mts, and has an entirely different seasonal distribution. The higher, more prolonged precipitation on Bale reduces the temperature gradient, but the greater supply of moisture produces more freeze-thaw activity. The outcome is a similar altitudinal sequence of freeze-thaw processes as in the Simen but a different combination of soils, vegetation and erosional features like lake basins, reflecting differences in the past and present climates of the two massifs. Mt Kenya is wetter still, and being higher has probably some sporadic permafrost near the summit, in sites of suitable aspect and gradient (Messerli in progress).

To sum up, from the Simen highlands to Mt Kenya there is a sharp break from a vegetated surface to a desert-like surface dominated by freeze-thaw processes, all within a height range of 200 m, which seems typical of tropical mountains. This boundary is situated at varying heights above the upper timberline: 600 m on Simen, 800 m on Bale, and 1 000 m on Mt Kenya. Small areas where both free and impeded solifluction occur together may appear some 200-400 m lower (Furrer & Freund 1973:180).

5.3.4 *Periglacial activity during the last cold period*

During the last major cold phase, mountains in the southern Mediterranean region directly adjacent to the arid zone were subject to intense periglacial activity down to 1 000 m or lower (Lebanon, Antilebanon, Hermon, Atlas; cf. Messerli 1977).

A well-preserved set of periglacial landforms is very evident on Precambrian quartz porphyry near the summit of Jebel Catharina in the Sinai. The lower limits still need to be mapped and correlated with pediments in the central part of the massif, but the periglacial solifluction mantles near the road below Jebel Catharina are a legacy of cold climate processes. The brown Holocene soils capping these deposits are now subject to erosion by sheet floods. A comparable stratigraphic sequence is widely evident in the Hoggar and Tibesti, revealing a strikingly similar geomorphic history in all three massifs.

Comprehensive descriptions of the periglacial features in the Hoggar and Tibesti are given respectively by Rognon (1967, 1977) and by Messerli (1972, 1977). We will concentrate on a comparison between the Hoggar and Tibesti, confining ourselves to the major and most comparable forms. Solifluction layers up to a few metres thick resemble those from the Sinai in particle size and fabric. They are sometimes covered by a brown soil mantle, or else have a brown soil developed at the surface, which is dissected by gullies and debris flows (Messerli 1972:56; Rognon 1977). So far the age of the stratified debris layers is not known with certainty. They may date from the time of maximum cold, but could equally have formed during a later wetter phase, when conditions were still cold.

Evidence of frost shattering and resultant debris transport appears in the Hoggar at heights of 1 100-1 400 m (Rognon 1977), and in Tibesti above about 1 800 m. Rognon (1967:245, 252, 463) also observed rock glaciers in the Hoggar above 2 000 m, and considered that some at least belonged to an earlier cold period than the one discussed here. In Tibesti similar phenomena occur above 2 200 m, and are likewise assigned to an earlier cold period (Messerli 1972:41).

Two conclusions emerge. First, the periglacial limits were surprisingly low in the Saharan uplands, indicating a distinct change of environment. Second, the differing heights of periglacial features in Tibesti and the Hoggar point to significant palaeoclimatic variation between the two massifs.

Periglacial processes produced abundant slope debris in the Ethiopian highlands, especially in the Simen. The debris adjoins but does not overlie moraines of the last glaciation, from which we infer that the glacial and periglacial deposits were formed at the same time. The debris layers are mantled by a black andept soil, 80 cm thick on average, which may have formed during the Holocene (Messerli 1975; Hurni 1977; Frei 1978; Hurni in preparation). The lower limit of this periglacial activity may have been between 3 000 and 3 500 m, a conclusion supported by another independent survey (Williams et al. 1978).

In the Bale Mts, the lower limit of former periglacial processes may have been around 3 000 m, or in suitable localities even lower, such as on Mt Kenya.

More detailed information is now being analysed (Messerli et al. 1977).

If we consider the lower periglacial limits in the Sahara and Ethiopia, we observe a rise of over 1 000 m from the former to the latter, related to the shift from a seasonal to a diurnal climate (Figure 5.7).

5.3.5 *Evidence of earlier glaciations*

Certain periglacial features in the Sahara are a legacy from earlier cold phases. Rognon (1967:251, 463) observed nivational or glacial landforms in the Hoggar, particularly rock glaciers, that may belong to an earlier cold interval. A major rock glacier in the Mouskorbé Massif of Tibesti is 2 km long, contains individual blocks up to 1 000 m^3 in volume, and terminates at 2 200 m. It was later cut by deep ravines, and its surface mantled with an even veneer of debris. It, too, doubtless relates to an earlier glacial episode (Messerli 1972:41).

If we compare this evidence of major mass-movement with the present-day climate, we must not only invoke a greater moisture supply from precipitation or meltwater, but a fall in temperature that was significantly greater than that of the last cold period. Taking into account possible effects of permafrost would give a fall in temperature of at least 10°C, but further research is necessary (Messerli 1972:45).

Nilsson (1940) argued for an earlier glaciation in the Simen Mts of Ethiopia, with terminal moraines down to 2 600 m in the Mai Shaha valley, a conclusion questioned by later workers (Hastenrath 1974; Williams et al. 1978).

There is good evidence for several cold periods in the mountains of East Africa, including at least four on Kilimanjaro (Downie 1964; Butzer 1974:144), two on Mt Kenya (Baker 1967) and two on Ruwenzori (Livingstone 1975:254). Until more accurate data become available, earlier proposals that there were four glaciations on Mt Elgon, Mt Kenya and Kilimanjaro (Nilsson 1940) should be viewed with considerable caution. Doubtless the Kilimanjaro glaciations are best established because correlation and dating with volcanic series were possible.

Taken as a whole, our knowledge of the East African mountains is more complete than that relating to the highlands of Ethiopia. However, a more thorough knowledge of all the mountain regions discussed in this chapter is essential for a full understanding of long-term climatic change.

5.3.6 *Environmental change: climatic and palaeoclimatic problems*

5.3.6.1 *The problem of altitudinal limits.* Nivational and periglacial processes are no longer active in the Saharan uplands. They are possible under the present temperature regime, but the necessary moisture supply is lacking. If moisture was increased at the same time that temperature was decreased, as was the case during the last glaciation, two effects would ensue. The present zone of potential freeze-thaw activity would become active, and its lower limit would also be depressed following the drop in temperature. The response of the desert mountains to colder and wetter conditions thus differs from that of the mountains on both margins of the Sahara.

The temperature trend across the Sahara is shown in Figure 5.7. The 0°C free atmosphere isotherm for the coldest month rises over the arid zone, and there is

a distinct temperature difference between the Hoggar and Tibesti. In addition, the Hoggar is more exposed to humid air masses. Analysis of weather satellite data (Winiger 1975:132) revealed a mean annual cloudiness of 9.6 per cent over the Hoggar during a seven-year period, as compared to 4.1 per cent over Tibesti.

If we extrapolate our knowledge of the present climates of Tibesti and the Hoggar into the past, we have to take into account not only a general lowering of winter isotherms during the last cold period, but also a probable southward shift of the zone of temperature increase caused by the southward displacement of the polar front. The east-west climatic differentiation in the Sahara was doubtless accentuated by these factors, as evidenced by the increased climatic divergence between the Hoggar and Tibesti.

The disappearance of seasonal differences in the highlands of Ethiopia, and the height of the isotherms of the coldest month together account for the very much higher location of the periglacial zone in Ethiopia. As a result of the southern shift in ectropical precipitation, periglacial processes were active in all the major uplands between the Mediterranean and East Africa (Figure 5.7).

5.3.6.2 *The problem of differences in aspect and circulation.* Nivational features in the Hoggar occur mostly on slopes of easterly aspect. In Tibesti they are higher, less obvious, and show no preferred orientation. A possible interpretation is that precipitation was mainly from the west and northwest in the Hoggar, and was less effective over Tibesti. Precipitation during last glacial and late glacial time (20 000 to c. 12 000 B.P.) must have come from the west, with high pressure over Europe controlling the path of depressions into the southern Mediterranean region and the Sahara. The polar front extended south of the Atlas as far as the north-central Sahara, but must have weakened rapidly to the east, so that far more precipitation reached the Hoggar than Tibesti. The stronger influence of easterly winds, interrupted by the periodic arrival of cold air masses from the west and northwest, could well explain the higher and less well-defined nivational landforms in Tibesti. The above argument assumes that the duration and intensity of nivational and periglacial processes were determined largely by winter precipitation.

The asymmetry of mountain glaciation in the Simen and Bale Mts of Ethiopia is not easy to explain. The west, north and northeast orientation of the glaciers could reflect the typical daily convectional cycle, with build-up of afternoon clouds. Reduced insolation on northern slopes in the outer tropics could account for the north-facing glacial valleys. The glacial asymmetry might also mean that the easterly sources of precipitation were even more important than they are today, which might correspond to expansion of the dry zone within the tropics at this time. It is still uncertain whether the asymmetrical distribution of mountain glaciers in Ethiopia stems from higher insolation and greater tropical aridity, or from precipitation of dominantly easterly provenance. Maley (1973, 1976:339) has demonstrated that trade winds were effective as far as the equator during the last glacial maximum, so that the Indian Ocean would then have been the major source of Ethiopian precipitation. Glaciers of eastern and southern aspect were well developed on Mt Kenya, but whether this was mainly a result of orographic or climatic factors is not yet known.

5.3.6.3 *The problem of dating.* Soil formation under a warm, wet Holocene climate, as shown by pollen analysis and radiocarbon dating (see part two of this Chapter), took place after deposition of the solifluction mantles. What is still not established is whether the periglacial solifluction mantles were most active during full glacial times (24 000 to 14 000 B.P.) or during the somewhat warmer and wetter late glacial between 14 000 and 10 000 B.P. Solifluction debris occurs in the well-dated middle terrace of the Saharan uplands (see part two), suggesting frost shattering and winter precipitation at that time (Hagedorn & Jäkel 1969:34; Grunert 1972:108; Gabriel 1972:121). On the other hand, the date obtained by Livingstone (1975) on Ruwenzori shows that full glacial times in the East African mountains were broadly synchronous with glaciation in the temperate latitudes. Two key questions are therefore when glacial and periglacial processes were most active in the mountains bordering the tropic, and whether there was a climatic boundary between the highlands of northern and southern Ethiopia. Heine (1973, 1974, 1976) has drawn attention to similar problems in the tropical mountains of northern Mexico.

Radiocarbon dates relating to this cold phase are rare in the mountains, where organic matter and palaeosols are not abundant, and have often been eroded. Sediments on the middle and lower slopes have been reworked so often before incorporation into debris fans and terraces that they offer few clues as to their original mode of deposition. We still lack absolute ages for the main glacial phases between 15 000 and 22 000 B.P., for the doubtless less cold and less arid phase from 22 000 to 28 000 B.P., and above all for the onset of cool, damp conditions during 32 000-34 000 B.P. that may also have initiated glacial, nivational and periglacial processes in the mountains of Africa (Van Zinderen Bakker & Coetzee 1972; Heine 1974; Livingstone 1975).

5.3.6.4 *The problem of temperature lowering during the cold period.* The development of nivational forms, the metamorphosis of snow to firn and ice, and the formation of rock glaciers indicate periodic winter temperatures around 0°C. Rognon (1977) concluded that winter temperatures must have been at least 6°C lower at this time. Figure 5.7 depicts our attempt to estimate the lowering of the free atmosphere and high mountain isotherms between the Mediterranean and East Africa: by analogy with recent morphodynamic relicts of the specific climates, morphologic relicts and palynologic results are the basis of the reconstruction of the corresponding meridional course of temperature and precipitation. Following Figure 5.7, we have to consider temperature depressions of 6-8°C (in East Africa and the Mediterranean (July and January), but in the Central Sahara 6-8°C for the summer (July) and probably 10-14°C for the winter (January), depending on the vertical temperature gradient. The reasons for these remarkable regional differences are the changes in the atmospheric circulation patterns (Winiger & Messerli 1978). The CLIMAP (1976) reconstruction of equatorial sea surface temperatures shows a drop of only 2°C in the vicinity of East Africa, although the circulation model of Gates (1976:185) is consistent with a decline in July land surface temperature of about 5°C.

Whether we can invoke a 10°C drop in temperature for an earlier, more severe cold episode remains uncertain (Messerli 1972:45). What is generally

certain is that a significant fall in temperature, acting in unison with changed moisture conditions, led to the glacial and periglacial activity which produced the erosional and depositional landforms that we see today.

5.3.6.5 *Problems and significance of mountain studies.* High mountains, with their rapid succession of ecological and climatic zones, are sensitive to very slight changes in climate. These are reflected in characteristic landforms and processes which it is sometimes possible to date radiometrically. Reconstruction of changes in former snowlines and periglacial limits may allow us to infer temperature changes not discernible from studies of lowland sediments.

Environmental changes in the mountains did not necessarily parallel those in the lowlands, as, for example, during full glacial times when the lowlands were arid and the uplands were subject to nivation.

Seasons characterized by a specific circulation and climate can trigger particular geomorphic processes, such as episodic periglacial or fluviatile activity during certain seasons. An important corollary to this is that a general climatic change cannot be inferred from specific landforms or deposits.

In conclusion, we have tried not only to consider the altitudinal zones in various mountains spanning a latitudinal range from equator to Mediterranean (corresponding to the course of the Nile), but have also sought to integrate the time factor with a three-dimensional view of spatial variation in the mountains. Future efforts to resolve some of the issues raised here will further our understanding of climatic and environmental change.

5.4 REFERENCES

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5.5 FLUVIATILE PIEDMONT DEPOSITS

By P.Rognon

Between the uplands with their periglacial landforms and deposits and the lowland margins with their late Quaternary features there is a geomorphically transitional area in which the valleys become narrow gorges. Three distinct late Pleistocene (<100 000 B.P.) episodes may be recognised in this area thanks to the abundance of alluvial remnants in the lower valleys.

5.5.1 *Widespread early upper Pleistocene aggradation*

This episode is especially evident in the Atakor. Despite the youthful thalweg profiles and narrowness of the valleys, there was a general cessation of downcutting as far upstream as the valley headwaters at this time, as for example in the upland Ilamane valley. Valley bottoms became filled with debris derived from rapid erosion of the weathered hillslope mantles. Such debris was not carried very far. In upland and intermediate valleys, the depth of alluvial fill was about 3 to 6 m, but on the Atakor piedmont, the fill was often in excess of 10 to 15 m thick, resulting in widespread burial of smaller features and total obliteration of the earlier drainage system. Once the drainage channels became reestablished after this aggradational episode, they often followed a different course, sometimes being superimposed onto resistant rock ridges or lava flows (Rognon 1970: 193-195). We may therefore conclude that a widespread geomorphic crisis of climatic origin is evident throughout the massif (Rognon 1967: 501-513).

5.5.1.1 *An interval of extreme aridity.* Investigation of the Atakor alluvial deposits reveals a progressive reduction in stream transporting capacity throughout this period. The basal sediments comprise abundant pebbles and show a lenticular stratification indicative of high flood discharge. Particle size diminishes upwards to gravel and coarse sand, and the coarse laminar stratification indicates deposition from rills and overland flow. Towards the end of this episode, only a few very large streams were carrying pebbles along their highly unstable beds. The fill always contains an abundance of fine material, indicative of very poor sorting and sporadic flows. The clay fraction comprises montmorillonite in areas of basalt and illite in areas of basement rocks, pointing to only moderate hillslope weathering prior to erosion. The sands and gravels in the upper part of the fill contain many relatively unaltered feldspars and rock fragments which were derived from nearby slopes until the weathered mantle was ultimately removed. Since basement rocks disaggregate to gravels and sands more readily than do volcanic rocks, valley aggradation continued for much longer in the granite and sandstone localities, so that the 'gravel' terrace is far thicker and more extensive in such areas.

The abundance of feldspar, the slight reddening of the fine fraction brought down from the slopes, and the weak iron cementation of certain beds impart a pinkish, pale red and occasionally reddish-brown colour to this terrace which is very characteristic of the landscape bordering the Atakor.

At the end of this interval the climate became hyper-arid, and even less geomorphically active than at present, difficult though that is to conceive. Rock pediments became mantled by gravels which runoff from the adjacent inselbergs was not competent to move. Given the excess bedload, the larger oueds were no longer able to flush out their major channels, let alone deepen their beds. Wind action was perceptible even at 1 900 m elevation in the uplands, as evidenced by the Tarhenanet section (Rognon 1967: 467-469) in which the uppermost part of the terrace has been preserved (Figure 5.8).

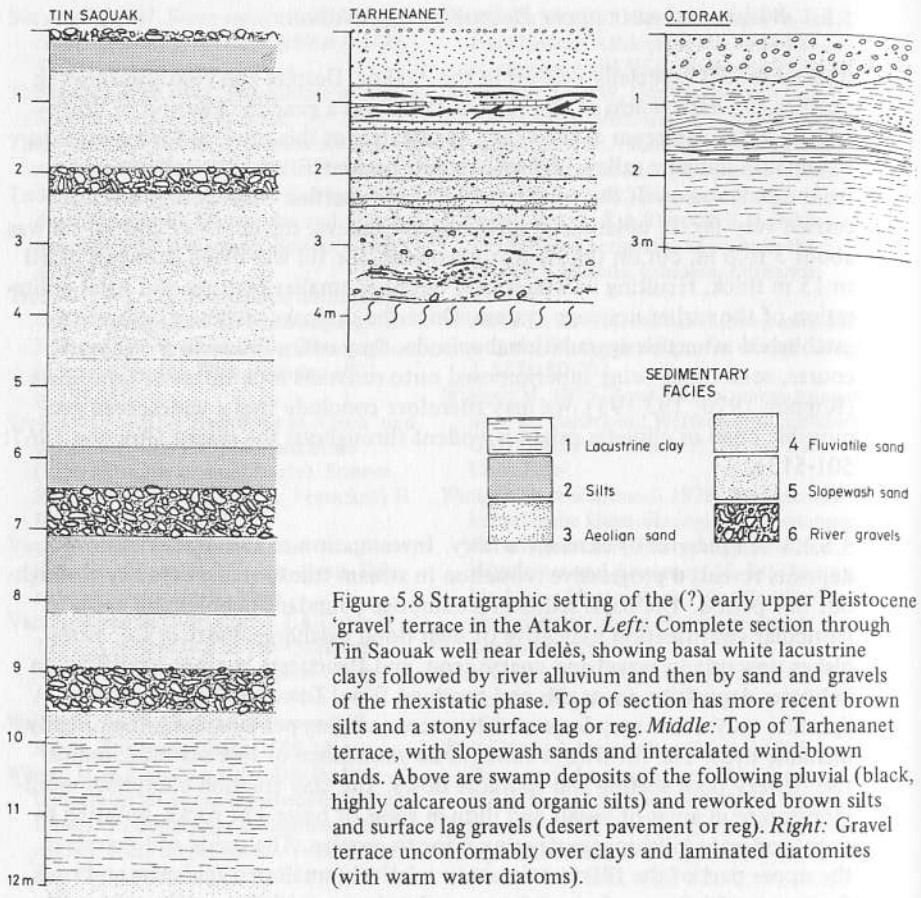


Figure 5.8 Stratigraphic setting of the (?) early upper Pleistocene 'gravel' terrace in the Atakor. *Left:* Complete section through Tin Saouak well near Idelès, showing basal white lacustrine clays followed by river alluvium and then by sand and gravels of the rhexistatic phase. Top of section has more recent brown silts and a stony surface lag or reg. *Middle:* Top of Tarhenanet terrace, with slopewash sands and intercalated wind-blown sands. Above are swamp deposits of the following pluvial (black, highly calcareous and organic silts) and reworked brown silts and surface lag gravels (desert pavement or reg). *Right:* Gravel terrace unconformably over clays and laminated diatomites (with warm water diatoms).

The reddish gravel terrace of the Atakor may be correlated with the 'Oberterrasse' described by Busche (1972: 70) in north-west Tibesti. In this sector, the terraces associated with the Enneri Bardagué catchment have been especially well studied (E. Zoumri, E. Direnno, E. Oudingueur, E. Toudoufou). The Oberterrasse is not such an important landscape feature as in the Atakor, but is preceded and followed by sometimes significant terrace deposits, although it appears to be the most continuous and best preserved of the terraces. As in the Atakor, the Oberterrasse sediments accumulated during a phase of climatic desiccation (Molle 1969; Jäkel 1971; Obenauf 1971). The sands, gravels and pebbles comprising this terrace are very similar to modern oued deposits (Jäkel 1971). Particle size and sorting vary widely along the valleys in relation to inputs from local tributaries. The thickness of the terrace fill is likewise quite variable, reaching values of 15 to 20 m. All the evidence suggests deposition by short-lived flows under an arid climatic regime (Jäkel 1971:24). The Bardagué Oberterrasse itself is polygenic, and can be subdivided into three separate alluvial formations (Jäkel 1971:23).

This terrace is well developed in the Enneri Misky valley, where it is sufficiently prominent to have been termed the 'Hauptterrasse' (Böttcher 1969:11). Lithologic and climatic factors account for this prominence, for just as this terrace is especially significant in the granite localities of the Atakor, so here it is best developed in a valley flanked by sandstone plateaux equally prone to granular disaggregation. This valley is also oriented towards the south, and such an orientation seems to have been important, for in the Atakor also this terrace is exceptionally well developed at the mouths of oueds issuing from the southern slopes (O. Outoul, Tamanrasset and Tahifet area). The same is true of the nearby Tefedest where this fill is very thick to the south-east, in the vicinity of Mertoutek.

On the other hand, this terrace is harder to distinguish in the E. Yebbigué basin which widens out northwards from central Tibesti. Here too there is an Oberterrasse which may reach relative heights of 30 m in the upper valley. In terms of its characteristics, it is reminiscent of the Atakor gravel terrace, a point stressed by Grunert (1975:77). But it seems that Grunert has grouped the lower Holocene terrace with the high terrace as a single complex, probably because they are difficult to separate here, for some of the sedimentary properties and radiocarbon ages are characteristic of the later terrace.

There are no published descriptions of this terrace from the margins of the Afar rift in Ethiopia, but it is ubiquitous around the Somalia plateau (Mussi 1974). In all the valleys leading down from this plateau there is a well-developed terrace composed of reddish sands with calcareous concretions which become brown near the surface. The sands contain pebble bands and stone concentrations indicative of a fluviatile origin, with some wind-blown material. This interval, 'which can only be of climatic origin', is one of considerably reduced discharge, which even affected the Webi Shebeli river, the largest in the area. Mussi concludes that this climatic phase occurred early in the upper Pleistocene on the grounds that reworked evolved Acheulian implements are present in the gravel lenses whereas typically Levallois artifacts occur in the basal part of the overlying brown alluvial deposits.

Despite the imprecision stemming from using artifacts as a guide to age, it is noteworthy that similar considerations led Rognon (1967:508) to assign a late Acheulian age to the geomorphic crisis resulting in the accumulation of the Atakor gravel terrace deposits. During this dry interval, implements of early to middle Acheulian type and debris eroded from the slope mantles were deposited along the valley floors, and became incorporated in the gravel terrace. Towards the very end of the Acheulian and during 'Mousterian' times, slopes became stable once more, and implements of this type occur in situ at the base of the grey or brown soils which developed at this time.

5.5.1.2 *Age of the terrace.* Using prehistoric implements as an index of age is fraught with uncertainty, especially since evidence from eastern and southern Africa points to a possible age of 100 000 B.P. for the onset of the Middle Stone Age (see also Chapter 22). Furthermore, an enduring biface tradition in the central and southern Sahara persisted until the end of the Aterian. Such deposits are well beyond the range of radiocarbon dating so that the best we

may hope for is to place this terrace within the relative sequence of upper Pleistocene climatic phases. One radiocarbon assay by J.C.Fontes yielded an age of > 34 500 B.P. for a sample of very pure calcite taken from near the top of this gravel terrace at Tassanek in the Aïr, which is again consistent with the notion of an early Würm age.

In the Atakor the sediments of this terrace contain Gramineae and Salsolaceae pollen, suggestive of a steppe vegetation and very dry climate (Rognon 1967:303). Near the base of these deposits Van Campo and her colleagues (1966) have identified pollen of a predominantly Mediterranean or temperate flora with a few tropical species characteristic of savanna gallery forests. In the only complete section extant, at Idelès (Rognon 1967:498-501) there is a transition from the gravel terrace through a fluviatile phase at a depth of 10 m, down to a white montmorillonitic clay with a very rich diatom flora probably indicative of an as yet ill-defined lacustrine phase related to a cold pluvial (Rognon 1967:498; Figure 5.8). In the Tahag basin (idem: 477) the gravel terrace immediately post-dates a river terrace composed of large pebbles, or dark silty soils with abundant montmorillonite (idem: 72). In the mountains the terrace is inset into the base of the Ilamane blockstream (idem: 464).

The relationship between the gravel terrace and the eroded cold pluvial formations remains open, however, for there is a slight unconformity between the gravel terrace and the grey lacustrine clays and diatomites on the southern flanks of the Atakor (Figure 5.8). The diatom flora indicates warm lake waters comparable to those of the large African lakes of today. Now that Gasse (1975) has demonstrated that tropical lakes were common in the Afar during the Würm interstadial between >40 000 and 30 000 B.P., it is possible that the Atakor lake phase may belong either in this interstadial, or may belong to the Riss-Würm interglacial, as believed hitherto (Rognon 1967; Jäkel 1971:35). If the former proves to be true, the gravel terrace is bracketed between this 'tropical' pluvial and the cool late Würm pluvial. If so, it may be of similar age to the short arid interval evidenced by the major regression of Afar lakes between 32 000 and 30 000 B.P., that is, between the Abhé II tropical lake phase and the Abhé III lake phase of 30 000 to 20 000-18 000 B.P. preceding the late Würm (Gasse 1975). This information is the only evidence available so far from the arid margins of Ethiopia.

In the Tibesti mountains the 'Oberterrasse' abuts unconformably onto two formations. In the E.Yebbigué drainage basin there is a terrace composed of weathered gravels embedded within a red-brown palaeosol (Grunert 1972). According to Grunert (1975:74-75) the colour results from the presence of a bright red clay matrix which developed during subsequent weathering under a Mediterranean type of climate. Thus, a period of high river discharge was followed by pedogenesis during a 'Mediterranean' pluvial, after which the soil mantle became dissected and the Oberterrasse was formed. Such a scheme recalls the first hypothesis proposed for the Atakor.

In the Bardagué basin a 'Hochterrasse' surmounts the gravel terrace between Zoui and the edge of the massif. It consists of fine, dominantly sandy material of a uniform red colour. The sands are often finely laminated and contain abundant aeolian particles, suggesting to Jäkel (1971:24-26) that both the

Oberterrasse and the Hochterrasse were laid down under an arid regime. There thus appear to be several terrace fills of fairly similar facies which were laid down during periods of instability or rhexistasis. Ages obtained from basalt flows overlying alluvial deposits at two localities in the Atakor which have facies comparable to the gravel terrace support this view. The deposits in question, especially those at Segaïka attributed to the gravel terrace (Rognon 1967: 216-217) would be at least of last interglacial age, and may even date from the Riss, which accords with Jäkel's deductions (1971:35) involving a Riss or Mindel/Riss age.

The present state of palaeoclimatic reconstruction thus allows us to put forward two hypotheses relating to the age of formation of the Atakor and Tibesti gravel terrace.

The terrace deposits may have been laid down during a mid-Würm interstadial following an early Würm pluvial during which there was widespread gravel accumulation, a lacustrine phase (in the Atakor) or an interval of red-brown soil development (E.Yebbigué). Alternatively, they may have accumulated during the Riss/Würm interglacial which must have been about as arid as today.

At the end of this arid phase conditions became wetter once more, with formation of hydromorphic soils and perennial or seasonal waterlogging along the Atakor valley bottoms where the prior drainage network had often become disorganised through accumulation of the gravel terrace fill (Rognon 1967:506-508). In addition, streams began to transport cobbles from the Tibesti uplands over a hundred kilometres further down-valley than is the case today in the E. Bardagué (Jäkel 1971:23) and the E.Oudingueur (Obenauf 1971:33). This increase in stream competence is interpreted as a return to pluvial conditions.

5.5.2 *Fine-grained end-Pleistocene and early Holocene alluviation (15 000-8 000 B.P.)*

After deposition of the gravel terrace fill the geomorphic evolution of Tibesti and the Atakor was very similar. An interval of widespread downcutting (from several metres to 20-30 m) gave way to widespread accumulation of silts and clays which are in strong contrast to the coarse, poorly sorted deposits left after the short-lived flows of today. The brown or grey silts are often highly organic, suggesting overbank accretion of suspended load deposits along swampy valleys traversed by broad, shallow, slow-moving rivers with regular flow (Figure 5.9). The lack of coarse detrital material further implies the presence of nearly stable soil mantles on the slopes, with a plant cover sufficiently dense to filter out all but the finest of particles. We are thus dealing with an unusual type of alluvium deposited during a period of relative stability or biostasis (Rognon 1967, 1976b; Jäkel 1971) under an evenly distributed rainfall of moderate intensity quite unlike that of the present-day tropical storms (Rognon 1976a).

In contrast to the rhexistatic terrace fills laid down before ('Oberterrasse') and after ('Niederterrasse'), this biostatic 'Mittelterrasse' is very discontinuous, often occurring only in the widest reaches of the valleys (Jäkel 1971). The fill is usually about 1-2 m thick, and occasionally 5-10 m. The terrace is particularly well developed in the E.Bardagué catchment of NW Tibesti, especially in the E. Tabi where Jäkel & Schulz (1972) have studied it in great detail. Here, in sec-

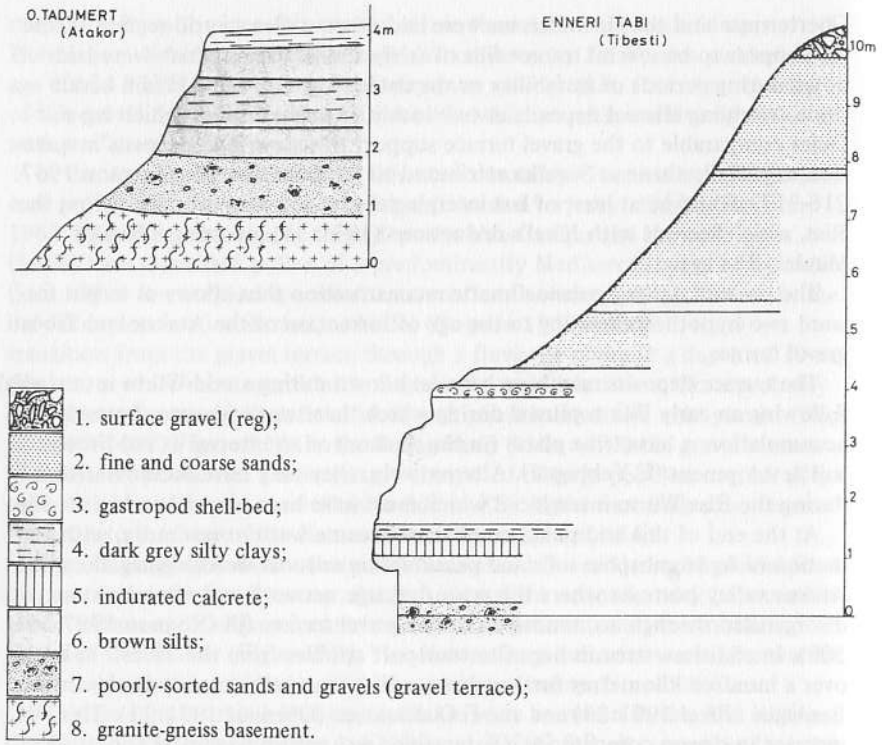


Figure 5.9 Sections through the early Holocene silt terrace in the Atakor (Tadjmert) and Tibesti (Enneri Tabi, after Jäkel & Schulz 1972: Fig. 3):

tions 10 m high, there is a rapid transition from sandy alluvium with occasional pebbles (lower one to 3 m) to finely laminated clays and silts (with laminae a few cm to a few mm thick) in which are interstratified carbonate bands, gastropod shell-beds, and occasional horizontal layers of sand. The fine-grained alluvium persists for 2-3 m before giving way to sandier, relatively unstratified deposits.

5.5.2.1 *Distribution and age of the silt terrace.* A number of radiocarbon assays on samples collected from this terrace in Tibesti, and more particularly from the E.Tabi valley, enable us to place the onset of alluviation at about 15 000 B.P. (14 055 ± 135) and the close at about 8 000 B.P. (7 380 ± 110). This terrace is evident in many of the Tibesti valleys, especially to the north in the Bardagué basin, and to the east in the E.Yebbigué, where it forms a major feature (Hauptterrasse) (Grunert 1972:106-108). In this latter valley a prior phase of intense erosion appears to have removed much of the older gravel terrace. The main terrace in this valley, with the now characteristic colour, carbonate bands and shell beds of its middle levels, displays coarser than usual gravel and pebble

facies above and below the swamp and lake deposits. Shells from the middle level have yielded an age of 8 180 ± 70 B.P.

Under the term Hauptterrasse this terrace has also been investigated in the lower valley of the E.Misky (Ergenzinger 1969), where it attains heights of 10-20 m in places, and is always fine-grained (clays, silts, sands). The terrace extends downvalley into the Angama complex 250 km south of Tibesti. This complex is a former delta of the E.Misky which accumulated in Lake Chad during the lower Holocene. The Angama scarp defining the outer margin of the delta is 70 km long. Three radiocarbon dates bracket the interval of delta formation between 10 000 and 6 000 B.P. (Servant et al. 1969).

All of these dates tally with those obtained from the upland lake sediments in the Trou au Natron (14 970 ± 400; 14 790 ± 400 and 12 400 ± 400 B.P.), at Bégour (8 295 ± 190), Tarso Yega (8 055 ± 90) and at Mouskorbé (8 530 ± 100 B.P.). There seems little doubt that this terrace did indeed form during a pluvial. The terrace was also studied in the Atakor valleys (Rognon 1967), although no radiocarbon ages were available. Two carbonate dates collected to the north (8 380 ± 300 B.P.) and to the south (11 580 ± 350 B.P.) nevertheless bracket this interval very precisely (Delibrias & Dutil 1966).

The Ethiopian counterpart of this same terrace may be dated indirectly using the many radiocarbon dates now available from the Gezira plain in central Sudan (see chapters 9 and 12 of this volume), which forms the depositional outlet for many of the major upland rivers of Ethiopia. The asymmetry of the Ethiopian watershed is discussed in Chapter 10. The depositional evidence from the Gezira suggests a fairly sudden hydrological change. From about 18 000 to 12 000 B.P. the Blue Nile was a highly seasonal braided river of steeper gradient which transported gravels and sands during flood. Between 12 000 and roughly 5 000 B.P. it became a sinuous river with large meanders flowing slowly through permanent swamps in which it deposited silty clays (Williams et al. 1975).

5.5.2.2 *Environmental setting of the silt terrace.* In reconstructing the milieu in which the silt terrace was formed, we will refer to evidence from soil materials and from pollen analysis.

The widespread deposition of silts and clays during a phase of biostasis points to some degree of soil structural instability at this time. Fine particles were washed through the soil mantles with minimal aid from runoff. The fine calibre of the deposits reflects the efficiency of the soil filter. Montmorillonite is by far the dominant clay mineral in the Atakor deposits, with a variable amount of illite, depending very closely on the clay minerals present in palaeosols developed on nearby slopes (Rognon 1967:515-517). Detailed analysis of these soils shows that we are dealing with typical brown Mediterranean soils (ibid.:190-200).

In Tibesti the clay fraction comprises about 60% montmorillonite and about 40% kaolinite, but may sometimes consist of only 20% montmorillonite with 35% kaolinite and 35% illite (Busche 1972:65-66). These analyses could in theory suggest greater hydrolysis under a wetter climate, except that there is up to 40% feldspar in the coarse fraction (>2 μ). A more plausible interpretation is one invoking lithological control, for in the Atakor these brown soils contain

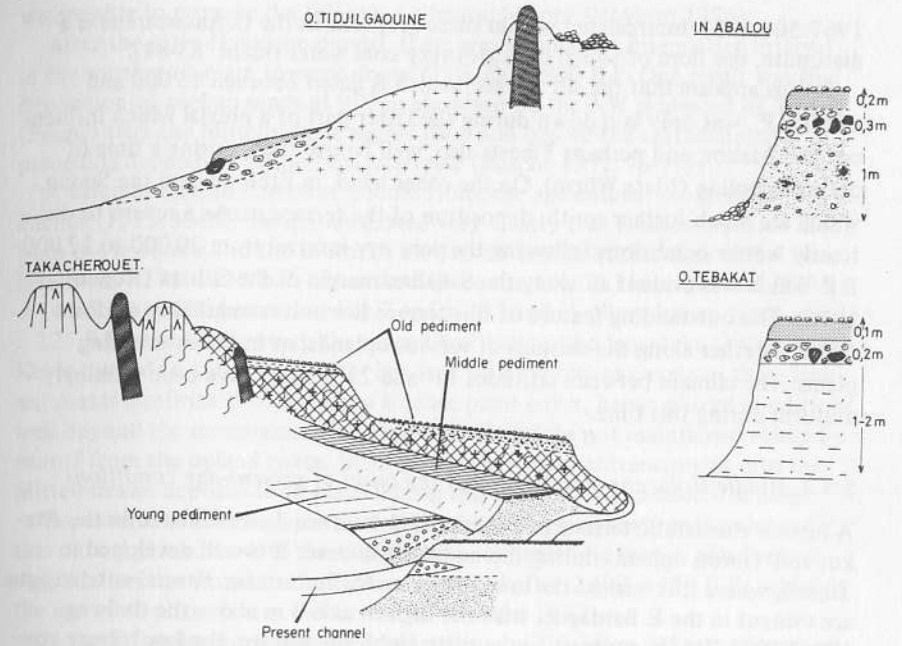
far more illite (30-50%) and kaolinite (10-20%) where there are basement rocks than where they overlie basalts. Well-drained localities in Tibesti are often situated on silica-rich volcanic rocks (ignimbrites) and sandstones (E.Misky). Climatic interpretation of the clay minerals is therefore very equivocal.

Another characteristic of this terrace is the precipitation of calcium carbonate in swamps and small lakes. Such deposits often consist only of thin bands of soft or hard carbonate, with abundant gastropod shells and plant fossils (especially *Typhas*). But in some instances the former valley floors are entirely mantled by carbonates (Seekreide or lake calcrete) with no clastic material; and thick travertine deposits blanket the slopes (Rognon 1961). In the Atakor these chemical deposits are both more abundant and more continuous along the northern margins which are exposed to Mediterranean climatic influence (Rognon 1967:522). The same seems true of the northern flank of Tibesti where such deposits as the E.Yebbigué carbonates may comprise the bulk of the terrace (Grunert 1975:52-53). The movement of carbonate over short distances in soils and along valley floors is consistent with a Mediterranean dry summer climatic regime.

Pollen analysis confirms the inferences drawn from soil studies. The pollen assemblage in samples from the Atakor terrace (Rognon 1967:467-469) contains, in addition to ferns, Gramineae and Chenopodiaceae, pollen belonging to twelve families of temperate and mainly Mediterranean trees. There is almost no tropical vegetation. At the time these analyses were undertaken it was not possible to distinguish local pollen from pollen blown in from afar. Clearly, pollen influx from north-easterly winds was adding to the Mediterranean component.

Schulz (1974) took up this problem anew. Fifteen pollen spectra obtained from samples derived from this terrace in several valleys in Tibesti were compared with four samples of the present-day pollen rain around Bardaï. The proportion of temperate or Mediterranean species present is always far higher in the fossil spectra than in the modern pollen rain, especially in northern Tibesti (upper E.Yebbigué; E.Dilennao). The presence of oaks in particular implies a precipitation of at least 500 mm with a much more even distribution throughout the year. Likewise, the seemingly frequent coexistence of *Alnus, Betula, Tilia* and *Quercus pubescens* raises the question of their occurrence so far away from the areas in which they grow today. On the other hand, the presence of a plant cover of Artemisia, Gramineae, Chenopodiaceae and Cypress with a few Pine woods towards 2 200 m; with a maquis of Mediterranean plants including *Oleacea, Myrtus* and *Erica* growing along the lower slopes of Tibesti, seems very likely. Along the piedmont slopes these trees doubtless formed a gallery forest amidst a mainly herbaceous plant cover (Jäkel & Schulz 1972).

We will now consider the clay terrace within its palaeoclimatic context. In Tibesti the deposition of clays and silts was usually bracketed by intervals of greater fluvial discharge. Busche (1972:67) noted the presence of frost-shattered fragments at the base of the Mittelterrasse, and similar observations were made along the Atakor margins. On the southern border, upstream of Tamanrasset, at about 1 550 m elevation, there is a layer of 10-20 cm quartz fragments beneath the black silts of this terrace. The quartz fragments originated from an



1. silty brown 'Mediterranean' soils
2. beds of frost-shattered rock fragments containing evolved Acheulian implements overlying grey silty clays (pseudogleys)
3. grey sandy clay
4. sands and gravels of the gravel terrace
5. older staged pediments with a cover of boulders in a sandy (A) or silty clay matrix (B)
6. deeply weathered basement rock
7. quartz vein
8. volcanic rock
9. schist
10. granite

Figure 5.10 Late Würm deposits in the Atakor

adjacent quartz reef, and were shattered by frost action prior to being spread out across the pediments by overland flow (Rognon 1967:398). In other sections along the northern slopes down to heights of 1 000-1 100 m, the layer of frost-shattered fragments very clearly separates the silts above from the grey, rusty-mottled silts beneath (Figure 5.10). The latter stem from an earlier phase characterised by the formation of hydromorphic soils or pseudo-gleys (Rognon

1967:506-508). Intercalated within these grey silts in the O.Ansassarène is a diatomite, the flora of which indicates very cold water (idem: 83-84).

It thus appears that the silt terrace, which is dated between 15 000 and 8 000 B.P., was only laid down during the latter part of a pluvial which influenced the Atakor, and perhaps Tibesti also, well before then, during a time of definite cooling (? late Würm). On the other hand, in Ethiopia and the Sudan, which are much further south, deposition of the terrace marks a return to distinctly wetter conditions following the very dry interval from 20 000 to 12 000 B.P. which was evident all along the Sahelian margin of the Sahara (Rognon 1976). The outstanding feature of this terrace lies in its remarkably uniform facies, whether along the margins of various uplands, or in the intervening plains. The climate between latitudes 11° and 23°N must have been strikingly uniform during this time.

5.5.3 *Middle Holocene alluviation and the onset of present-day conditions*

A further rhexistatic terrace (see section 5.3.1. et seq.) accumulated in the Atakor and Tibesti uplands during the middle Holocene. It is well developed in Tibesti, where it is termed the low terrace or Niederterrasse. Several subdivisions are evident in the E.Bardagué, with the highest at 6-8 m above the thalweg (Jäkel 1971:21). In contrast to the early Holocene terrace, the low terrace consists of cross-bedded coarse sands and fine to medium gravels (3-7 cm in diameter). In common with the gravelly Oberterrasse, the low terrace is a more continuous feature in the E.Bardagué than is the Mittelterrasse (Obenauf 1971: 18). Out on the piedmont, the low terrace level becomes progressively closer to modern channel-floor level. In the E.Yebbigué the terrace fill is only 1-2 m thick, although it is perched 5-7 m above thalweg level (Grunert 1975). The low terrace is very obvious on the southern slopes of the E.Misky and Wouri basins. In this last basin, it is only 1-3 m high (Böttcher 1969), but becomes higher further south, where it splits into two benches 3 and 6 m high (Ergenzinger 1969). This terrace is everywhere composed of often rounded cobbles in a matrix of gravel and silt. There is no visible stratification and the cobbles are neither weathered nor cemented. This alluvial terrace was deposited under conditions somewhat wetter than those prevalent during aggradation of the gravelly Oberterrasse (Busche 1972:76) or than exist today, since the calibre of cobbles carried by the present oueds is far smaller than that of the low terrace cobbles (Grunert 1972:112). We may envisage somewhat higher rainstorm intensities than obtain at present, although still within the same climatic regime of summer rain. Granted that stream competence was greater at this time, the question at issue is whether the influx of the coarse alluvium into the valley bottoms is merely a result of reworking of existing gravel supplies, or whether it implies renewed mobilisation of coarse debris from the hillslopes (Grunert 1972:109).

The consensus of published views points to a short interval of aggradation, which Jäkel (1971:34) places after 6 000 B.P. until somewhat after 4 000 B.P., i.e. after the middle Holocene pluvial. On the basis of many radiocarbon dates

we are able to propose the following climatic history (Rognon 1976):

After the early Holocene pluvial, there was a short but intense dry interval in the southern Sahara towards about (?) 8 000-7 500 B.P. One result was the deposition of aeolian sands at 970 m elevation on the NW piedmont of Tibesti (Fochi) after the Mittelterrasse aggradation and before the entrenchment preceding deposition of the Niederterrasse (Busche 1972:76-77).

A summer rainfall pluvial of middle Holocene age ensued (Rognon 1976:271). Pachur (1975:38-39) has demonstrated very clearly that lakes reappeared along both the northern and the southern borders of Tibesti at this time (Jebel Nero lake from 7 570 ± 115 B.P. onwards; J.Quoquim lake: 5 110 ± 295 and 5 295 ± ± 145 B.P.; giraffe bones dated at 7 455 ± 180 and elephant bones dated at 6 435 ± 225 B.P.; and to the south the mega-Chad Lake and a large lake at Ounianga Kebir towards 6 160 ± 165 B.P.). The lack of wind-blown quartz in these lake sediments confirms that there was a dense plant cover, hence pluvial conditions, well beyond the mountains. The lakes were therefore not maintained solely by runoff from the upland rivers. In all probability, river entrenchment into the Mittelterrasse deposits took place during this interval of increased discharge.

Deposition of the Niederterrasse alluvium took place towards the close of this pluvial phase. As with the Oberterrasse, a rhexistatic terrace was formed. Aggradation continued in the E.Direnna until after 2 690 ± 435 B.P., which is the age of elephant bones within the fill (Gabriel 1972).

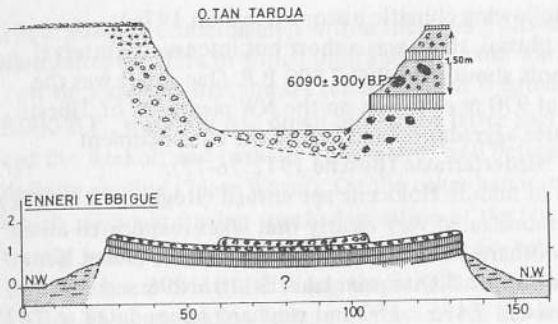
In the E.Bardagué subsequent downcutting by 1.5-3.0 m did not take place until after 1 900-1 450 B.P. (Jäkel 1972:32).

Busche (1972:79) has raised the issue of why there is no recent silty terrace in Tibesti, except for the brown silts of the date-palm groves which are not easy to distinguish from contemporary flood-plain deposits. The geomorphic evolution of the Tibesti valleys was very different from that in the Atakor at this time.

5.5.3.2 *The recent silty terrace of the Atakor.* In the Atakor this recent low silty terrace is very similar to the early Holocene silty terrace. Very often there is no clear break between them and they merge into one extensive depositional complex at the outlet of major valleys. The geomorphic differences between Tibesti and the Atakor account for the greater agricultural potential of the lowland valleys of the Atakor.

In some localities it is possible to distinguish the two silt formations. For example in the O.Tekchouli on the NW margin of the massif, the two units are superimposed with no other deposit between them, but differ in colour and texture. The lower Holocene deposit is a massive grey or black lake clay with plant remains. Above it are 3 m of alternating grey micaceous clays and sands in which are colocinth impressions (indicative of a very dry climate) and post-Neolithic pottery, pointing to a very recent age for this phase of aggradation. Since then, the O.Tekchouli has cut down 4 m into these silts (Rognon 1967: 514).

In the O.Tan Tardja on the northern margin (Rognon 1967:518-519) finely laminated sands are capped by a very hard carbonate layer which may stem from the dry interval towards 8 000-7 500 B.P. noted elsewhere. After this a pool



1. older gravel terrace
2. granitic sands with occasional basalt boulders
3. calcrete
4. grey calcareous swamp silts
5. freshwater mollusc shells
6. younger alluvium: grey silty clays (A) or coarser sediments of the present oued (B)

Figure 5.11 Sections through the early Holocene silt terrace in the Atakor (Tan Tardja) and Tibesti (E.Yebbigué).

or marsh came into being. Runoff carried in sands, gravels, and pebbles derived from the calcrete cap. The chief deposit was a calcareous mud containing freshwater mollusca, the latter dated by J.C.Fontes to 6 090 ± 300 B.P., representing the middle Holocene pluvial. During the ensuing dry phase, a second indurated calcrete horizon developed, after which the grey or brown silts of the 'Neolithic' terrace were laid down. Apart from their lesser thickness (a few dm) they are often very hard to distinguish from the early Holocene silts. No doubt they were deposited as a result of continued slow erosion of the late Würm and Holocene soils still present on many slopes (Figure 5.11).

It would seem therefore that the soil mantle responsible for supplying fine sediments to the recent silty terrace persisted longer in the Atakor than in Tibesti, for reasons as yet unknown. Only very recently have sands and gravels accumulated in the valley-floors, and the accelerated destruction of the silty terrace continues to this day (Rognon 1970:138).

In Ethiopia the vastness of the upland area and the lack of detailed studies do not allow us to draw such definite conclusions. Semmel (1971) has shown that the grey and black clays (tirs) at the foot of the Ethiopian escarpment were mainly laid down between 8 380 ± 100 and 5 775 ± 115 B.P., at a time when lake levels were high in the Afar (Gasse 1975; and Chapter 15). In other words, the climate was pluvial even beyond the uplands. To the west, in the

Sudan Gezira, freshwater mollusca were replaced towards 5 000 B.P. by amphibious mollusca capable of withstanding a long dry season (see also Chapter 12). The extent of regular flooding decreased progressively and towards 2 700 B.P. the terrestrial mollusc *Limicolaria flammata* migrated from this area to the south (Williams et al. 1975 and Chapter 12). The relationships between the Gezira clays and the brown or black upland soils are not clear. Some of the brown upland soils are dated to 3 865 ± 105 and 3 670 ± 105 B.P. (Semmel 1971), and at higher elevations soils are still actively forming.

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6

L'environnement quaternaire du bassin du Tchad

Quaternary environments of the Chad basin

Quaternary environmental changes in the Chad basin are assessed using evidence from lake levels, the diatom flora, and fluvio-lacustrine sediments. The earliest discernible changes are reflected in the first appearance of wind-blown sands (aridity) and of temperate diatoms (cooling) interstratified among late Cenozoic deposits, and took place after either 3 m.y. or 1.9 m.y. ago.

During the late Quaternary, lake levels fluctuated over varying time scales (10^1, 10^2, 10^3 years). Palaeohydrological interpretations, based upon comparative studies of a number of lakes, show the relative oscillations in the ratio of precipitation to evaporation (P/E index). In order of decreasing importance, the wettest phases were 9 000-8 000 ($P > E$), 6 000 ($P \leqslant E$), 3 000-3 500, 11 000 ($P < E$), and from 40 000 to 20 000 B.P. Driest times were 20 000-13 000, towards 10 000, 7 500, 4 000-4 500 and during historical times.

Local hydrological and hydrogeological factors often exerted a controlling influence upon lake palaeosalinity values. Salinity levels varied widely from place to place during the transition from arid to humid phases. During the more humid intervals (8 000, 6 000) salinity levels were generally low in all lakes, despite variations in the recharge mechanisms (groundwater, rainfall and local runoff, river inflow).

Trophic states, reflected in the diatom associations, are related to local hydrological influences. For instance, at any given time eutrophic lakes fed by large rivers coexisted with oligotrophic lakes fed by rainfall and groundwater.

A fall in minimum temperature levels is indicated by the dominantly temperate diatom flora during 26 000-20 000 and 12 000-7 500 B.P. Tropical associations are evident towards 20 000-18 000 and from 7 000 B.P. until present.

Except during 28 000-26 000, the dominant late Quaternary pollen spectra indicate a tropical flora. From 8 000 to 4 000 B.P., Sudan-Guinean and Sudan-type pollens abounded in what is now the Sahel zone. The present-day climatic zonation only became established after 7 000 B.P., and was not obvious during the early Holocene, when the hydrological and rainfall regimes were distinctly different from the highly seasonal tropical summer rainfall regime of today.

Quaternary palaeoclimatic fluctuations in the Chad basin seem to be related to variations in the frequency of incursions of advected cold polar air to lower latitudes. Such incursions of cold air were especially common during 26 000-20 000 and 12 000-7 500 B.P. Changes in the strength of the sub-tropical anticyclonic cells appear to have been a major factor controlling late Quaternary climatic change in the Chad basin.

6.1 INTRODUCTION

Les premiers travaux géologiques faits sur le bassin du Tchad ont montré que la limite sud de la zone désertique saharienne s'est déplacée de plusieurs centaines de km vers l'équateur pendant certaines époques du Quaternaire. Ils ont montré aussi que le lac Tchad qui s'étend actuellement sur 10 000 à 20 000 km² a eu une extension plus grande, comparable à celle de la Mer Caspienne (Garde 1911; Tilho 1925). Ces premières notions ont été précisées par les travaux de Faure (1962) et Schneider (1967) qui ont apporté les bases d'une chronologie par le ^{14}C. De nombreux lacs ont existé dans le bassin pendant l'Holocène. Ils sont apparus vers 12 000 ans B.P. après une phase climatique sèche (Servant 1967). Les périodes plus anciennes du Quaternaire ont été reconnues grâce aux sondages qui ont été réalisés près du lac Tchad (Dielmann 1963). La découverte et l'étude de plusieurs gisements à Vertébrés dans la partie nord du Tchad ont permis une première discussion sur les termes de passage du Pliocène au Quaternaire (Abadie 1959; Coppens 1972).

Au cours des dix dernières années, des travaux détaillés ont été effectués sur la stratigraphie, la sédimentologie, la flore diatomique et la palynologie du Quaternaire, au Nord du 13ème parallèle (Servant 1973; Maley 1973, 1977; Servant-Vildary 1977). Parallèlement, de nombreuses observations ont été faites dans d'autres régions au Niger, au Nigéria, au Cameroun et au Tchad (Pias 1970; Pirard 1966), dans les massifs sahariens (Jäkel & Schulz 1972; Jäkel 1977; Williams 1971). Ces travaux se poursuivent actuellement dans les domaines géologique (Mathieu, Durand, en cours) et préhistorique, notamment au Niger Oriental (Roset, Quechon, en cours). Les recherches faites sur le Quaternaire trouvent un point d'appui indispensable dans de nombreuses études concernant les phénomènes actuels ou récents de pédogenèse, d'érosion, d'altération, de transport et de sédimentation (Faure & Servant 1970; Bocquier 1973; Roche 1973; Maglione 1974; Carmouze 1976; Gac & Pinta 1973). Ces études ont été soutenues par les documents cartographiques ou par les observations climatiques et hydrologiques disponibles dans les différents Etats du bassin du Tchad.

Cet aperçu bibliographique souligne le volume des documents disponibles pour la compréhension des environnements quaternaires. Nous essayerons ici d'en extraire les résultats les plus significatifs sur le plan paléoclimatique.

6.2 QUELQUES ASPECTS DE L'ENVIRONNEMENT ACTUEL

Le Bassin du Tchad se situe au coeur du continent africain entre 8° et 22° de latitude nord (Figure 6.1). Il est assimilable à une vaste cuvette endoréique dont les points les plus bas se situent vers 180 m d'altitude.

L'environnement actuel (Figure 6.2) est étroitement dépendant des modifications qui interviennent au cours de l'année dans les circulations atmosphériques

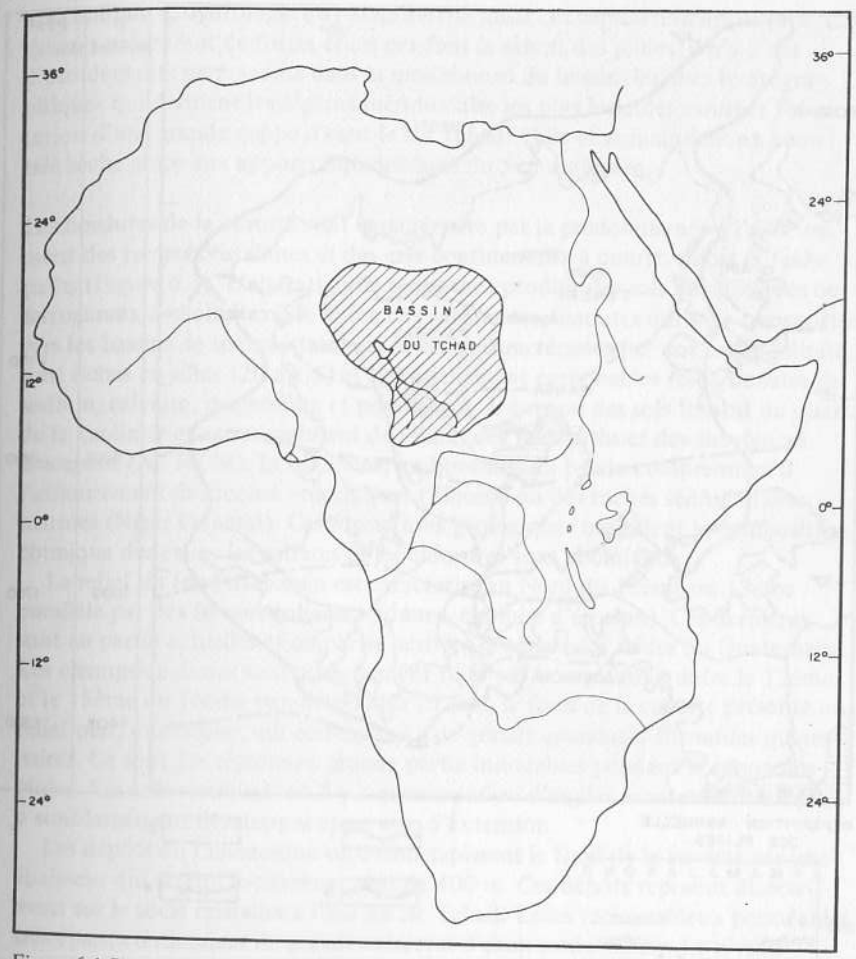


Figure 6.1 Situation du bassin du Tchad.

des basses latitudes. La Zone de Convergence Intertropicale (ZCIT) se déplace vers le Nord pendant l'été boréal. Les masses d'air humide issues du Golfe de Guinée atteignent alors le Tchad. Elles permettent les précipitations qui sont de plus en plus irrégulières et de plus en plus faibles en allant du Sud au Nord. Pendant l'hiver boréal, la ZCIT se déplace vers le Sud et le bassin du Tchad échappe à son influence. Celui-ci est alors balayé par des vents secs du NE qui renforcent l'évaporation. Le balancement de la ZCIT se traduit aux latitudes du Tchad par des climats à saisons contrastées (saison sèche hivernale, saison humide estivale) et par une zonation en latitude des isohyètes. Cette zonation s'exprime par une succession de diverses bandes de végétation: la zone soudano-guinéenne correspond à une pluviosité de 1 500 à 1 000 mm/an, la zone soudanienne à une pluviosité de 1 000 à 500 mm/an et la zone sahélienne à une pluviosité de 500 à

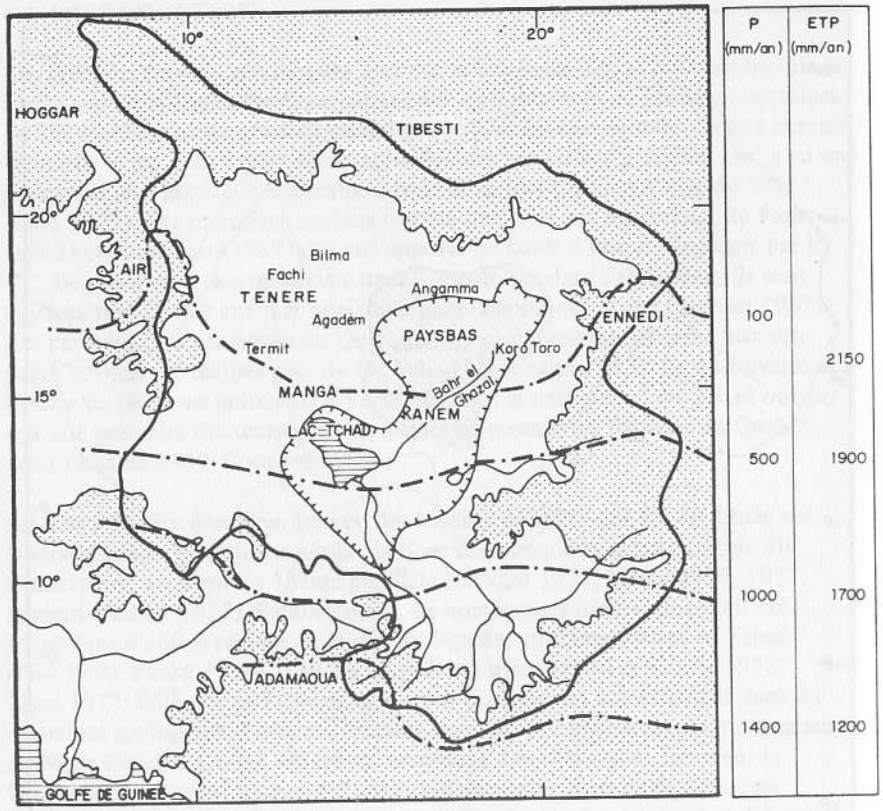


Figure 6.2 Le bassin du Tchad. Principaux caractères climatiques. 1. limite du bassin; 2. altitudes supérieures à 500 m; 3. isohyètes; 4. limite du lac Tchad vers 6 000 ans B.P. (d'après Schneider 1967); P: pluviosité moyenne annuelle; ETP: evapotranspiration potentielle moyenne annuelle.

100 mm/an. L'hydrologie du bassin reflète aussi ces caractères climatiques. Les rivières présentent de fortes crues pendant la saison des pluies; il n'y a pas d'écoulements permanents dans la moitié nord du bassin; les axes hydrographiques qui drainent les régions méridionales les plus humides assurent l'alimentation d'une grande nappe d'eau: le lac Tchad. Celle-ci se maintient en zone très sèche grâce aux apports liquides issus du Sud du bassin.

Les bordures de la cuvette sont caractérisées par la prédominance à l'affleurement des roches cristallines et des grès continentaux à quartz, micas et feldspaths (Figure 6.3). L'altération de ces roches produit des sols ferrallitiques ou ferrugineux à kaolinite. Elle libère des substances dissoutes qui sont transportées vers les bassins de sédimentation. Les eaux, caractérisées par une faible salinité, sont riches en silice (20 mg/ℓ) et essentiellement carbonatées (bicarbonates de sodium, calcium, magnésium et potassium). L'érosion des sols fournit du quartz, de la kaolinite et accessoirement de l'illite, des feldspaths et des substances amorphes (Al, Fe, Si). Localement, les bordures du bassin comprennent à l'affleurement des roches volcaniques (Tibesti) ou des roches sédimentaires marines (Niger Oriental). Ces formations géologiques modifient la composition chimique des eaux: les sulfates et les chlorures sont abondants.

Le relief du fond du bassin est caractérisé au Nord du 12ème ou 13ème parallèle par des formes éoliennes (dunes, couloirs d'érosion). Ces dernières sont en partie actuelles et en partie héritées des périodes arides du Quaternaire. Les champs de dunes sont actuellement fixés par la végétation entre le 12ème et le 15ème ou 16ème parallèles. Plus au Sud, le fond de la cuvette présente un relief plat, monotone, qui correspond à de grands épandages fluviatiles quaternaires. Ce sont des régions en grande partie inondables pendant la saison des pluies. Les sols vertiques, où il y a accumulation d'argiles montmorillonitiques, y sont largement développés et en voie d'extension.

Les dépôts du Cénozoïque supérieur tapissent le fond de la cuvette sur une épaisseur qui atteint localement plus de 400 m. Ces dépôts reposent directement sur le socle cristallin à l'Est du lac Tchad. Leurs faciès sableux perméables, très épais, contiennent de grandes réserves d'eaux souterraines. Le niveau supérieur de la nappe phréatique est très proche de la surface du sol dans de nombreuses régions au fond des dépressions y compris dans les zones les plus arides (Ténéré oriental, Pays-Bas). Ce niveau est parfois affleurant et il se forme alors des petits lacs, des mares ou des bas fonds humides à évaporation capillaire favorables au dépôt des évaporites.

6.3 VUE D'ENSEMBLE SUR LE CENOZOIQUE SUPERIEUR

6.3.1 *Les affleurements de la partie nord du Tchad*

Les dépôts tertiaires et quaternaires affleurent, de manière discontinue, dans les Pays-Bas du Tchad. Ils reposent sur des grès paléozoïques ou sur le socle cristallin. Un sondage les a traversés sur 525 m à l'Est du Bahr-El-Ghazal (Schneider 1967). Une mandibule de Merycopotamus, recueillie dans la partie

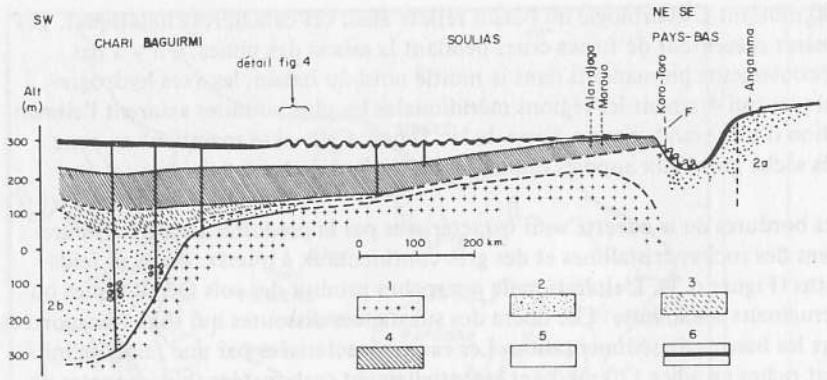


Figure 6.3 Coupe de bassin du Tchad (d'après Servant-Vildary 1973 et Servant 1973). 1. Socle cristallin; 2. dépôts fluviatiles du Miocène (Oligocène à la base?): formation Bodelé (2a), formation Chari Baguirmi (2b); 3. argiles sans diatomées; 4. dépôts lacustres à diatomées uniformément argileux au Sud (formations Koro-Toro, Alandjaga et Morouo); 5. sables éoliens à lentilles de dépôts lacustres (détail Fig. 6.4); 6. dépôts holocènes (sédiments lacustres ou fluvio-deltaïques et sables dunaires); F: gisements à Vertébrés.

inférieure, montre que la base de ces dépôts est antérieure au Miocène moyen ou supérieur. Elle pourrait se situer dans l'Oligocène (Servant 1973).

L'évolution de la série cénozoïque est marquée par deux changements lithologiques majeurs. Le premier changement correspond au passage de faciès fluviatiles (formation Bodelé) à des faciès lacustres riches en Diatomées (formations Koro-Toro et Alandjaga). Il implique l'apparition, dans le fond du bassin, d'une nappe d'eau continentale très étendue. Le phénomène semble être lié à une accentuation de l'endoréisme de la cuvette du Tchad: les eaux superficielles ne seraient plus évacuées en totalité vers l'océan et elles s'accumuleraient dans les zones les plus déprimées. Le lac, qui s'est alors individualisé, date du Pliocène: les gisements paléontologiques rencontrés dans les dépôts littoraux indiquent, par comparaison avec l'Afrique de l'Est, un âge compris entre 5 ou 4 M.A. et 3 ou 2 M.A. (Coppens 1972). La flore diatomique, étudiée de manière détaillée, montre que ce lac a connu des oscillations assez marquées: aux épisodes de haut niveau, caractérisés par des espèces planctoniques d'eaux douces, s'opposent des épisodes plus courts, de bas niveau, caractérisés par des diatomées benthiques ou aérophiles avec parfois des espèces halophiles (Servant-Vildary 1973). Ces oscillations impliquent des modifications dans le bilan hydrologique de l'ancien lac et, de ce fait, des changements climatiques qu'il est encore difficile d'évaluer et de dater avec précision. Les abaissements du plan d'eau ont pu entraîner un assèchement partiel du lac. Mais ils n'ont pas été accompagnés par des conditions franchement arides. Celles-ci ne semblent pas s'être manifestées pendant le Pliocène.

Les dépôts lacustres de la fin du Tertiaire sont caractérisés comme dans les autres régions du globe (Andrews 1971) par une flore diatomique qui comprend de nombreuses espèces éteintes ou archaïques (Tableau 6.1, 6.2). Ces espèces

Tableau 6.1 Litho- et biostratigraphie du Mio-Plio-Quaternaire ancien au Nord du Tchad

Formations (Servant 1973)	Lithologie (Servant 1973)	Diatomées (Servant-Vildary 1973)	Vertébrés (Coppens 1972)
Morouo (4 à 6 m)	Argiles, calcaires sables éoliens, cinérite	–	–
Alandjaga (>30 m)	Argiles, gypse diatomites, sables fluviatiles	Stade IV (flore moderne) Stade III Diatomées Stade II centriques Stade I archaïques ou éteintes (cf. Tableau 6.2)	Niveau type Ouadi Derdemi *(Loxodonta africanava)* 3 à 1.9 M.A. (?)
Koro-toro (>40 m)	Argiles, sables fluviatiles, diatomites	Stade 0	Niveau type Bochianga *(Anancus osiris)* 5 à 4 M.A. (?)
Bodelé (>200 m)	Argiles, sables et cailloutis fluviatiles. Oolithes ferrugineuses à la base. Cinérites, ignimbrites.	–	*Merycopotamus* Miocène moyen à supérieur

Tableau 6.2 Le Plio-Quaternaire ancien du Nord du Tchad. Association de diatomées caractéristiques sur le plan biostratigraphique.

Diatomées (Servant 1973) Stades	Espèces caractéristiques	Vertébrés (Coppens 1967)	Formations
Stade IV	Diatomées à cachet moderne	?	Morouo (Epaisseur 4 à 6 m)
Stade III	Cinq niveaux successifs caractérisés chacun par: e) *Cyclotella comta radiosa* d) *Stephanodiscus niagarae* c) *Coscinodiscus praelacustris* b) *Cyclotella nov. sp.* a) *Coscinodiscus praelacustris minor*		
Stade II	Trois niveaux successifs: c) *Stephanodiscus carconensis* b) *Coscinodiscus dispar* a) *Cyclotella transilvanica* *Coscinodiscus tuberculatus*	*Loxodonta africanava* (niveau type Ouadi Derdemi)	Alandjaga (Epaisseur 30 m)
	a) *Cyclotella pygmaea* *Coscinodiscus hungaricus* *Stephanodiscus transilvanicus*		
Stade I	*Melosira islandica curvata* (lacune probable d'observation)		
Stade 0	*Melosira praegranulata* à ocelles	*Anancus osiris* (niveau type Bochianga)	Koro-Toro (Epaisseur: de l'ordre de 30 à 40 m)

semblent constituer, au niveau des associations et de l'évolution de ces dernières, de bons marqueurs biostratigraphiques. Elles ont été utilisées pour établir des corrélations détaillées à l'intérieur du bassin du Tchad (Servant-Vildary 1973).

Le deuxième changement lithologique, observé dans la série cénozoïque, se situe à une date encore indéterminée, après 3 ou 1,9 M.A. Il se traduit par l'apparition du calcaire et surtout par des intercalations de sables éoliens dans les couches lacustres (formations Morouo). Ces intercalations correspondraient aux premiers témoignages de climats secs ou arides au Sud du Sahara dans le bassin du Tchad. Le passage à ces climats secs s'est fait par une série d'oscillations dont le détail n'est pas encore analysé. Il a finalement entraîné l'assèchement définitif du lac pliocène. Les dépôts de ce dernier ont alors été érodés puis recouverts par des sédiments quaternaires peu épais, éoliens ou lacustres, qui se rattachent au Quaternaire récent. Le Pléistocène moyen est mal représenté dans le Nord du Tchad: on peut seulement lui attribuer des nappes caillouteuses et des paléosols rouges à kaolinite que l'on rencontre sur la bordure du bassin.

6.3.2 *Les sondages de la région du lac Tchad*

Les dépôts cénozoïques ont été traversés par quelques sondages sur une épaisseur maximum de 430 m. Leur évolution verticale est tout-à-fait comparable à celle qui a été décelée au Nord du Tchad. On observe, à la base, des sables fluviatiles médiocrement classés qui passent vers le haut à des argiles lacustres à diatomées (Figure 6.3). Ces dernières comprennent, au sommet, et comme dans la formation Morouo des sables éoliens intercalés. Elles sont par ailleurs caractérisées par l'apparition d'une flore diatomique moderne qui comprend quelques espèces psychrophiles. Celles-ci vivent actuellement dans les régions des hautes et moyennes latitudes. Leur présence au Tchad est vraisemblablement liée à un refroidissement climatique.

Les dépôts qui surmontent les sédiments lacustres précédents sont plus épais que dans la partie nord du Tchad. Ils ont été reconnus sur une centaine de mètres dans la région du lac Tchad. Les coupes établies par Roche (1970) montrent que ces dépôts sont essentiellement formés de sables éoliens dans lesquels s'intercalent des couches lacustres lenticulaires (Figure 6.4). L'étude détaillée du Quaternaire récent, que nous présenterons plus loin, permet d'interpréter ces coupes. Après l'assèchement du grand lac pliocène, les remaniements éoliens ont entraîné l'individualisation de massifs dunaires. Pendant les phases humides du Quaternaire, des nappes d'eaux libres sont apparues dans les dépressions interdunaires: elles ont déposé les couches lacustres lenticulaires. Pendant les phases arides, les dunes se sont déplacées et elles ont recouvert les couches précédentes. Les sondages effectués près du lac Tchad montrent donc une alternance de périodes arides et de périodes lacustres impliquant des conditions climatiques relativement humides. Une chronologie détaillée et complète ne peut pas être établie: elle nécessiterait un très grand nombre de sondages pour s'assurer que toutes les intercalations lacustres ont été traversées.

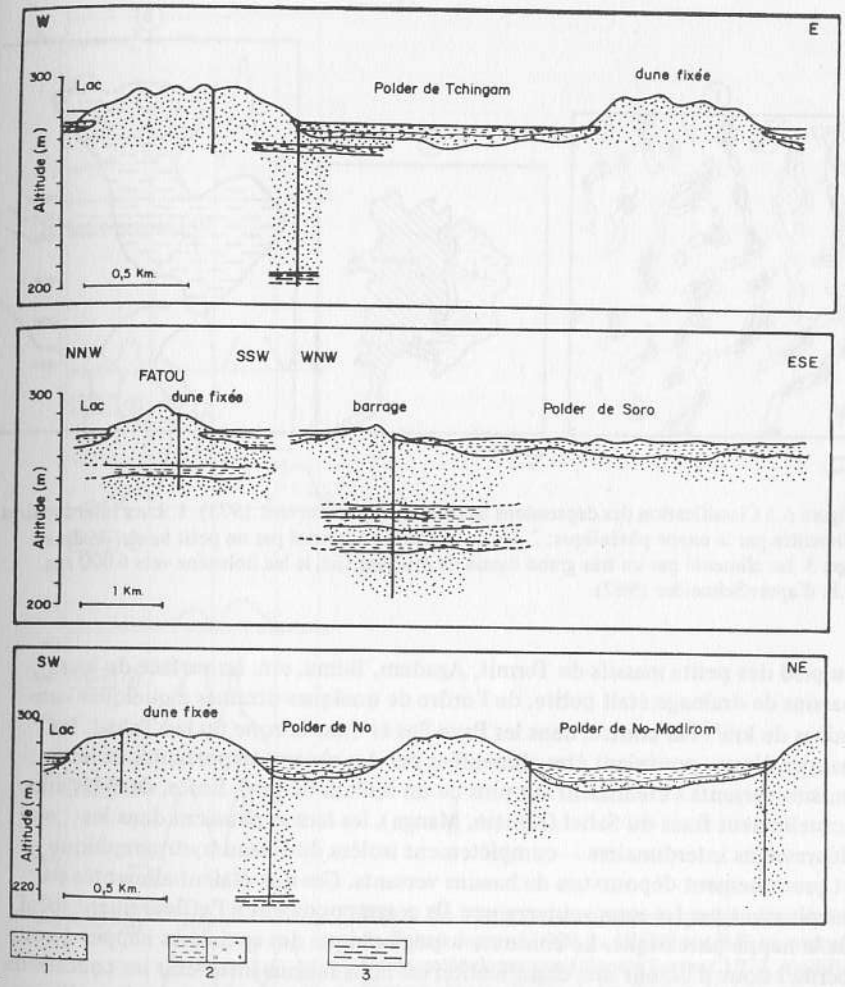


Figure 6.4 Coupes des dépôts quaternaires de la bordure nord et nord-est du lac Tchad (d'après Roche 1970). 1. Sables plus ou moins éolisés; 2. sédiments lacustres ou marécageux déposés dans des dépressions interdunaires; 3. sommet de la formation Alandjaga ou Morouo (Plio-Quaternaire ancien).

6.4 EVOLUTION DE L'ENVIRONNEMENT QUATERNAIRE DEPUIS 40 000 ANS

6.4.1 *Variations de niveau des lacs*

Les nappes d'eaux libres qui ont existé, pendant le Quaternaire récent, dans la cuvette du Tchad, se situaient dans des conditions topographiques très différentes suivant les régions (Figure 6.5). Au Niger Oriental, elles étaient localisées

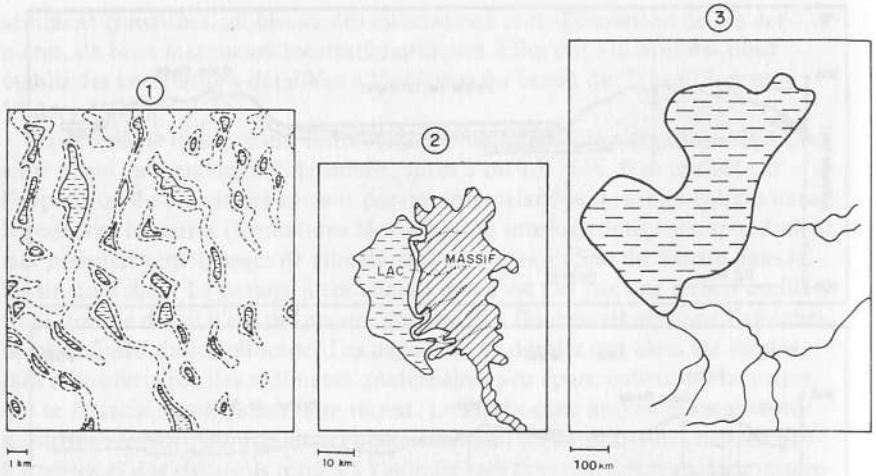


Figure 6.5 Classification des dépressions lacustres (d'après Servant 1973). 1. Lacs interdunaires alimentés par la nappe phréatique; 2. lac de piedmont alimenté par un petit bassin de drainage; 3. lac alimenté par un très grand bassin de drainage (ici, le lac holocène vers 6 000 ans B.P. d'après Schneider 1967).

au pied des petits massifs de Termit, Agadem, Bilma, etc. La surface de leurs bassins de drainage était petite, de l'ordre de quelques dizaines à quelques centaines de km². Par contre, dans les Pays-Bas et dans la zone du lac Tchad, les nappes d'eaux pouvaient être alimentées par des rivières importantes et leurs bassins versants s'étendaient sur plus de un million de km². Enfin, dans les ergs actuellement fixés du Sahel (Kanem, Manga), les lacs se situaient dans les dépressions interdunaires – complètement isolées du réseau hydrographique – et pratiquement dépourvues de bassins versants. Ces lacs étaient alimentés par les pluies et par les eaux souterraines. Ils correspondaient à l'affleurement local de la nappe phréatique. Le contexte topographique des anciennes nappes d'eau permet donc d'établir une classification où nous faisons intervenir les conditions dominantes d'alimentation: par le ruissellement dans les lacs 'de piedmont', par de grandes rivières dans les lacs 'hydrographiques', par les eaux souterraines dans les lacs 'interdunaires'.

La détermination des oscillations lacustres est le résultat d'une étude géomorphologique et géologique dont on trouvera un exposé détaillé dans l'ouvrage de Servant (1973). Cette étude a été complétée par des recherches sur la flore diatomique (Servant-Vildary 1977). L'évolution des associations de diatomées, dans les séries lacustres, enregistre les variations relatives d'extension des nappes d'eau. Les phases de plus grande extension sont marquées par la prédominance des espèces planctoniques. Les phases de sédimentation dans des eaux peu profondes, colonisées par des végétaux supérieurs, sont soulignées par l'abondance des phytolithaires et des diatomées épiphytes ou benthiques. Les phases proches de l'assèchement se traduisent par la présence de diatomées aérophiles, etc.

Les reconstitutions paléogéographiques faites à l'échelle du bassin du Tchad

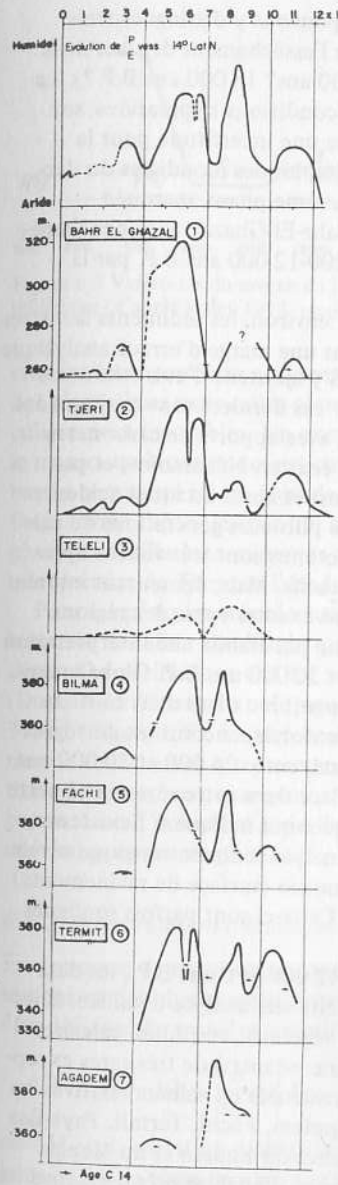


Figure 6.6 Variations de niveau de quelques lacs du bassin du Tchad depuis 13 000 ou 12 000 ans B.P. et interprétation paléoclimatique (d'après Servant 1973, modifié par Servant-Vildary 1977). 1. Oscillation d'un lac alimenté par le réseau hydrographique; 2. oscillations d'un lac interdunaire alimenté par la nappe phréatique avec apports fluviaux au cours de certaines époques (notamment vers 6 000 ans B.P.); 3. oscillation d'un lac interdunaire toujours isolé du réseau hydrographique; 4, 5, 6 et 7. oscillations des lacs du Niger Oriental alimentés par des bassins de drainage peu étendus.

(Figure 6.6) montrent que les lacs ont toujours eu une extension supérieure à celle des lacs actuels pendant le Quaternaire récent, depuis 40 000 ans, à l'exclusion d'une période comprise approximativement entre 20 000 et 12 000 ans B.P. Il y a eu alors disparition complète des nappes d'eau. Des conditions désertiques, favorables aux remaniements éoliens, se sont étendues vers le Sud au moins jusqu'au 13ème parallèle. Cette période est encore mal connue dans

son évolution paléogéographique détaillée. Nous pouvons y distinguer trois phases probables. La première est caractérisée par l'assèchement des lacs mais le phénomène n'est pas daté avec précision (20 000 ans? 18 000 ans B.P.?). La deuxième phase est marquée par l'installation de conditions hyperarides; son âge et sa durée sont indéterminés, ce qui constitue une incertitude pour la situer avec précision dans les synthèses paléogéographiques mondiales du dernier maximum glaciaire (18 000 ans B.P.). La troisième phase, marquée par au moins un épisode de creusement dans le Bahr-El-Ghazal, annonce l'amélioration climatique qui s'est manifestée vers 13 000-12 000 ans B.P. par la réapparition des lacs.

Pour les époques antérieures à 20 000 ans B.P. environ, les sédiments lacustres ont été datés par le ^{14}C. Les datations comportent une marge d'erreur analytique importante, de l'ordre de ± 1 000 à ± 2 000 ans. S'y ajoutent d'autres sources d'erreur dues à la nature des échantillons étudiés: ces derniers sont toujours des calcaires lacustres. L'éventualité d'une pollution, avec apports de carbonates plus récents après le dépôt, est a priori difficile à écarter. Néanmoins, et par datations successives sur le même échantillon avant et après attaques acides ménagées, il est possible de déceler la présence de plusieurs générations de calcite. Dans la majorité des échantillons, les âges obtenus sont très voisins après et avant l'attaque acide. Ils sont de ce fait significatifs. Mais, demeurant imprécis, ils ne permettent pas d'établir des corrélations exactes entre des régions éloignées. Pour cette raison, nous avons préféré ne pas établir une interprétation détaillée des oscillations lacustres entre 40 000 et 20 000 ans B.P. Globalement, cette période est caractérisée par la présence de nombreux lacs dans toute la cuvette du Tchad. Ces lacs étaient partout peu profonds, encombrés de végétation aquatique, sauf aux abords du Bahr-El-Ghazal, entre 26 000 et 20 000 ans B.P. environ. Les sédiments qui se sont mis en place dans cette région et à cette époque sont très riches en diatomées planctoniques qui indiquent l'existence d'une surface d'eaux libres bien développée. L'analyse sédimentologique révèle la présence, dans les séries lacustres, de discontinuités (surface de ravinements) dues à des épisodes temporaires d'assèchement. Ceux-ci sont parfois soulignés par des dépôts de sables éoliens.

Pour les périodes comprises entre 13 000 ou 12 000 et 0 ans B.P., les datations, plus précises que précédemment, permettent une analyse détaillée. Elles ont été faites sur des échantillons variés (débris végétaux, coquilles, calcaires lacustres), dont l'analyse donne des résultats concordants à de très rares exceptions près. Les oscillations des lacs ont été reconstituées en valeurs relatives ou absolues dans de nombreuses régions: Bilma, Agadem, Fachi, Termit, Pays-Bas et dans plus de cinquante dépressions interdunaires du Kanem et du Manga. Ces oscillations se montrent synchrones aux erreurs d'analyse près dans tous les domaines étudiés quelles que soient les conditions topographiques locales (Figure 6.6). Une chronologie détaillée des changements paléohydrologiques peut donc être établie à l'échelle de tout le bassin. Les courbes des variations de niveaux lacustres donnent une représentation des tendances paléohydrologiques à l'échelle du millénaire. Les marges d'erreur sur les datations et sur les observations ne permettent pas de rentrer dans le détail des différentes oscillations. Mais il est certain que chaque phase paléohydrologique est très complexe. Une

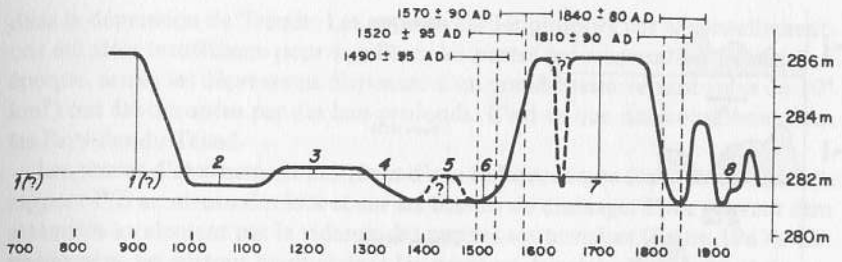


Figure 6.7 Variations du niveau du lac Tchad pendant le dernier millénaire (d'après Maley 1973, revu par l'auteur).

crue lacustre peut être accidentée par des phases momentanées d'abaissement des plans d'eau mais celles-ci ne sont observées que dans des conditions particulièrement favorables. Un exemple en est donné par l'évolution du lac Termit: le maximum lacustre qui est connu entre 7 000 et 6 000 ans B.P. dans tout le bassin comprend ici un épisode régressif qui est daté de 6 300 ± 200 ans B.P. De la même façon, la crue qui a eu lieu entre 9 000 et 7 500 B.P. comprend en fait plusieurs oscillations mineures qui ont été mises en évidence dans la dépression interdunaire de Tjéri par l'étude des diatomées.

Pour les périodes très récentes, il est possible de déterminer des oscillations lacustres de faible amplitude qui ont eu lieu à l'échelle de la décade ou du siècle. Ces oscillations ont été reconstituées par une étude sédimentologique (Dupont 1970) et palynologique (Maley 1973) des dépôts superficiels du lac Tchad (Figure 6.7). L'existence d'un réseau d'observation météorologique permet de relier, en ce qui concerne les dernières décades (Figure 6.8), les variations de niveau aux changements de pluviosité qui ont eu lieu sur l'ensemble du bassin. Le lac Tchad est assimilable à un pluviomètre qui enregistre et amplifie ces changements de pluviosité.

6.4.2 *Interprétation climatique des oscillations lacustres*

En l'absence de mouvements tectoniques, les oscillations d'un lac dépendent seulement des changements intervenus dans le bilan hydrologique. Elles peuvent être définies, de manière simplifiée, par la relation suivante:

$$\Delta H = (P - E) - \frac{V_D}{S_L} + \left[P_D - (E + T)_D \right] \frac{S_D}{S_L}$$

où ΔH est la variation d'altitude du plan d'eau pendant une unité de temps; P la lame d'eau de pluie tombée sur le lac; E la lame d'eau évaporée sur le lac; V_D le volume des eaux infiltrées ou déversées dans un exutoire superficiel; S_L la surface du lac; P_D la lame d'eau de pluie tombée en moyenne par unité de surface sur le bassin de drainage; $(E + T)_D$ la lame d'eau évaporée ou évapotranspirée par unité de surface sur le bassin; et S_D la surface du bassin de drainage.

Dans l'état actuel des observations, les paramètres précédents ne peuvent pas être évalués avec précision et la formule du bilan hydrologique peut seulement orienter une interprétation relative (Servant 1973). Si l'on néglige en première

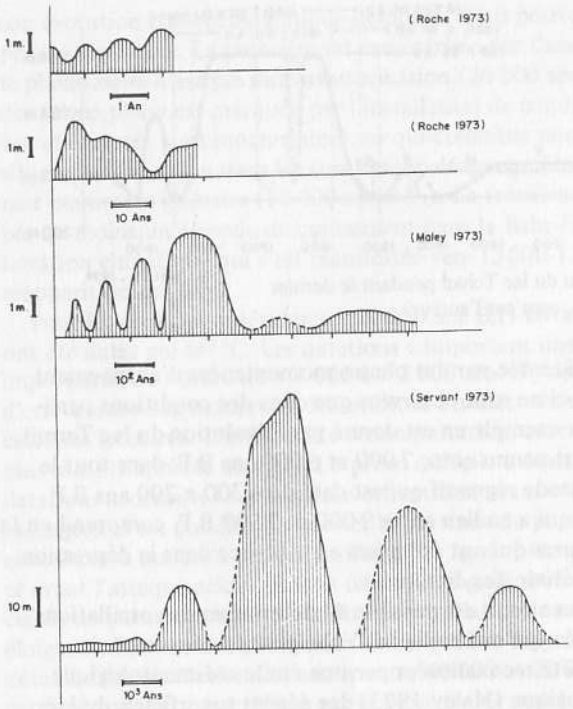


Figure 6.8 Variations du niveau du lac Tchad aux différentes échelles de temps.

approximation les pertes des lacs quaternaires (V_D), les élévations des plans d'eau supposent que les apports liquides par les pluies, le ruissellement, les rivières et les eaux souterraines sont supérieurs à l'évaporation. Dans le cas où la surface du bassin de drainage est très petite, de l'ordre de quelques dizaines de km², les apports liquides latéraux ne peuvent pas jouer un rôle déterminant dans l'histoire du lac. Celle-ci dépend uniquement des conditions climatiques locales (P/E). Un exemple en est donné, au Niger Oriental, par la dépression d'Agadem. Nous y observons un très haut niveau lacustre vers 8 000 ans B.P. Celui-ci implique une pluviosité supérieure ou égale à l'évaporation ($P \geqslant E$). Par contre, et pour toutes les autres époques du Quaternaire récent, la dépression est restée asséchée ou marécageuse. La pluviosité, inférieure à l'évaporation, ne permettait pas le maintien d'une nappe d'eau libre. Un déficit hydrologique, dû aux conditions climatiques locales, existait dans le fond de la dépression. Mais ce déficit a pu être comblé dans d'autres régions par les apports liquides latéraux. C'est ce que nous observons, vers 6 000 ans B.P., à Termit. Les eaux de ruissellement issues d'un bassin de drainage de quelques centaines de km² ont permis l'individualisation d'un haut niveau lacustre. Le même phénomène a eu lieu vers 11 000 ans B.P. Mais l'élévation du plan d'eau, plus petite que précédemment, indique des conditions climatiques plus sèches sur le bassin versant. Par contre, vers 3 000 ans B.P., il n'y a pas eu d'extension lacustre bien marquée

dans la dépression de Termit. Les apports par les pluies et par le ruissellement ont été alors insuffisants pour équilibrer les pertes par évaporation. A cette époque, seules les dépressions disposant d'un grand bassin versant (plus de 10^6 km²) ont été occupées par des lacs profonds. C'est ce que nous observons dans les Pays-Bas du Tchad.

Les phases d'abaissement des plans d'eau indiquent une forte diminution du rapport P/E au niveau des lacs et sur les bassins de drainage. Elles peuvent être atténuées localement par la vidange des nappes souterraines (Faure 1967). Le phénomène est surtout marqué dans les paysages dunaires du Kanem et du Manga. Les nappes d'eau ne s'assèchent pas complètement pendant les courtes périodes sèches des douze derniers millénaires (vers 10 000, 7 500, 4 500 ans B.P.). Ces périodes sont par contre marquées par la disparition des lacs et par des remaniements éoliens dans les autres régions, au Niger oriental et au Nord du Tchad. Les oscillations des lacs interdunaires présentent d'autres anomalies. La remontée des plans d'eau y a été générale mais faible entre 9 000 et 8 000 ans B.P. pendant la période climatique la plus humide de l'Holocène. L'alimentation de la nappe phréatique a peut-être été limitée par une forte évapotranspiration, ce qui supposerait la présence autour des lacs d'une végétation assez dense et très active. Si cette hypothèse était exacte, le niveau supérieur de la nappe n'aurait pas pu s'élever et les lacs seraient pour cette raison demeurés peu profonds.

6.4.3 *Milieux lacustres*

L'évolution des milieux lacustres a été reconstituée par une interprétation paléoécologique des associations de diatomées (Servant-Vildary 1977).

Les teneurs en éléments dissous sont variables, pour une même époque, suivant les lacs et les régions considérées. Les fortes paléosalinités (40 g/ℓ ou plus) sont géographiquement plus fréquentes pendant les périodes d'installation des nappes d'eaux libres après une phase sèche ou aride. La variabilité des paléosalinités s'explique, dans un même contexte climatique, par des conditions topographiques, hydrogéologiques et hydrologiques différentes suivant les régions. Certains lacs sont parfaitement fermés et les seules pertes qu'ils subissent sont dues à l'évaporation: les sels dissous ont tendance à s'y accumuler. D'autres lacs au contraire présentent des exutoires souterrains qui permettent l'élimination des éléments les plus solubles vers la nappe phréatique d'où une paléosalinité limitée. Ce mécanisme fonctionne dans le lac Tchad actuel où il a été étudié de manière détaillée (Roche 1973; Carmouze 1976). Les teneurs en éléments dissous sont aussi limitées par des facteurs plus complexes liés aux processus de sédimentation: précipitation des sels les moins solubles (carbonates de calcium), synthèses de minéraux argileux (smectites), fixation par les organismes (silice des diatomées et des végétaux supérieurs, calcaire des tests de mollusques). La variabilité géographique des teneurs en sels dissous a disparu pendant les phases de plus grande extension des lacs, vers 8 000 et 6 000 ans B.P. Tous les lacs du bassin présentaient alors des paléosalinités très faibles, inférieures à 1 g/ℓ. Le phénomène se manifeste quand la pluviosité et l'évaporation présentent des valeurs proches en moyennes annuelles.

Les faciès hydrochimiques des lacs peuvent être approximativement définis

par les associations de diatomées. Les milieux aquatiques à faibles paléosalinités sont souvent caractérisés par une flore calciphile. Ceux qui présentent de fortes teneurs en éléments dissous sont sulfatés, chlorurés ou parfois carbonatés sodiques au Niger Oriental, carbonatés sodiques dans les autres régions du Tchad (ou chlorurés sodiques pendant de brèves périodes ce qui correspond aux maximums de paléosalinités). Ces faciès hydrochimiques sont ceux que l'on rencontre actuellement dans le bassin et ils sont directement liés au contexte géologique. Les roches cristallines et les grès feldspathiques continentaux, largement dominants dans les bassins versants, fournissent par lessivage et altération des eaux carbonatées. Les chlorures apparaissent en abondance dans les seules régions où existent des affleurements de roches sédimentaires marines comme c'est le cas au Niger Oriental.

Les caractères trophiques des lacs quaternaires sont définis par les associations de diatomées. Ils sont liés, comme la paléosalinité, au contexte régional, à la typologie des anciennes nappes d'eau. Il est par exemple bien démontré que les lacs qui recevaient des apports fluviaux importants sont toujours eutrophes. Par contre, les lacs de piedmont dont les bassins de drainage sont petits, présentaient une flore en moyenne caractéristique des milieux distrophes. Le rôle apparemment dominant des conditions locales d'alimentation ne masque pas complètement une évolution dans le temps qui pourrait être liée à des variations climatiques. L'exemple de l'Holocène est à cet égard caractéristique. La flore diatomique eutrophe des lacs alimentés par des fleuves reste spécifiquement peu abondante jusque vers 7 000 ans B.P. mais elle s'affirme après cette date. Une évolution comparable a été mise en évidence dans les lacs interdunaires: ces derniers sont oligotrophes au début de l'Holocène mais ce caractère s'efface pendant l'Holocène moyen et récent. L'interprétation de cette évolution est encore difficile. Une première hypothèse fait intervenir le devenir des substances nutritives (nitrates, phosphates, etc.) dans les milieux aquatiques. On peut supposer que ces substances seraient peu ou mal restituées au milieu après la mort des organismes qui les ont fixées. Elles s'accumuleraient en ce cas dans les sédiments avec la matière organique. Ce processus biogénique limiterait ainsi l'eutrophie des lacs et il pourrait même favoriser l'oligotrophie dans les cas où les apports nutritifs sont faibles pour des raisons paléohydrologiques (lacs interdunaires alimentés par les pluies et par les eaux souterraines). Cette situation serait celle que l'on observe vers 8 000 ans B.P. Inversement vers 6 000 ans B.P., les substances nutritives seraient rapidement restituées au milieu par destruction de la matière organique (Tableau 6.3). L'eutrophie tend alors à s'accentuer dans les lacs recevant des eaux fluviales et l'oligotrophie ne peut plus s'exprimer dans les lacs interdunaires. Une seconde hypothèse peut être envisagée pour expliquer l'évolution des caractères trophiques. L'eutrophie s'affirmerait pendant les périodes où les apports liquides latéraux jouent un rôle déterminant dans le bilan des lacs. Il y aurait en ce cas augmentation en valeur absolue des apports en substances nutritives. Par contre l'eutrophie serait atténuée pendant les époques où les eaux météoriques joueraient un rôle plus important dans le bilan lacustre. Ce dernier cas correspond à l'Holocène ancien.

La température des anciens lacs n'a pas été déterminée avec précision. Une indication relative est donnée par les associations de diatomées. Ces associations

Tableau 6.3 Diatomées dominantes de quelques échantillons représentatifs des phases lacustres datées de 6 000 et 8 000 ans B.P. d'après Servant-Vildary (1977). *Stephanodiscus astrea:* milieux eutrophes. *Cyclotella ocellata:* milieux oligotrophes.

	Vers 8 000 ans B.P.	Vers 6 000 ans B.P.
Lacs alimentés par des eaux fluviales	KORO TORO 1166 *Melosira granulata* 51.5% *Fragilaria construens* 30% *Stephanodiscus astrea* 9% *Fragilaria pinnata* 9.4%	LARGEAU 1210 *Stephanodiscus astrea* 85% *Melosira granulata* 5% *Nitzschia fonticola* 0.6% *Cyclotella ocellata* 0.4%
Lacs interdunaires alimentés par des eaux souterraines et météoriques	TJERI 6 *Melosira granulata* var. *muzzanensis* 11% *Fragilaria pinnata* 12% *Cyclotella ocellata* 10% *Fragilaria brevistriata* 40%	KECHIRE 1364 *Melosira granulata* 37% *Stephanodiscus astrea* 13% *Cyclotella ocellata* 4% *Hantzschia amphioxis* 8% *Nitzschia* sp. 27%
Lacs de piedmont alimentés par le ruissellement	FACHI M 9 *Melosira granulata* (ocelles) 45% *Cyclotella stelligera* 12% *Melosira italica* 4.2% *Melosira granulata* var. *muzzanensis* 4.1%	FACHI 34 *Melosira granulata* var. *angustissima* 54% *Melosira italica* 21% *Melosira granulata* 6.4% *Synedra ulna* 5.3% *Melosira nyassensis* 5.3%
	AGADEM 24 *Synedra acus* 26.6% *Cyclotella stelligera* 11.5% *Achnanthes* sp. 27% *Melosira granulata* 5%	
	BILMA 4062 A *Melosira granulata* (ocelles) 21% *Cyclotella Kutzingiana* 38% *Cyclotella stelligera* 5.6% *Fragilaria brevistriata* 3.8%	4068 B *Melosira granulata* 25.5% *Melosira granulata* 7.5% *Fragilaria brevistriata* 9% *Cyclotella stelligera* 6% *Achnanthes* sp. 6.3%
	TERMIT 25 *Melosira granulata* 33% *Melosira agasizii* 29% *Melosira granulata* var. *intermedia* 30%	151 *Eunotia* (variés) 21.4% *Pinnularia* (variés) 8% *Melosira* (variés) 4% *Nitzschia amphibia* 8%

comprennent toujours une dominance de formes cosmopolites. Mais elles comprennent aussi des espèces caractéristiques du point de vue biogéographique et, en particulier, pour certaines époques, des diatomées psychrophiles (M. & S. Servant 1970). Ces dernières vivent actuellement dans les régions des hautes et moyennes latitudes.

Servant-Vildary (1977) a établi une classification des associations diatomiques présentes dans les dépôts quaternaires du bassin du Tchad. Cet auteur distingue trois groupements: (a) le premier admet un certain nombre d'espèces tropicales, les diatomées des régions tempérées sont absentes; (b) le second est surtout défini par l'abondance d'espèces qui se développent communément aux hautes et moyennes latitudes mais celles-ci sont parfois signalées dans les régions tropicales (elles sont appelées préférentielles des eaux froides); quelques espèces

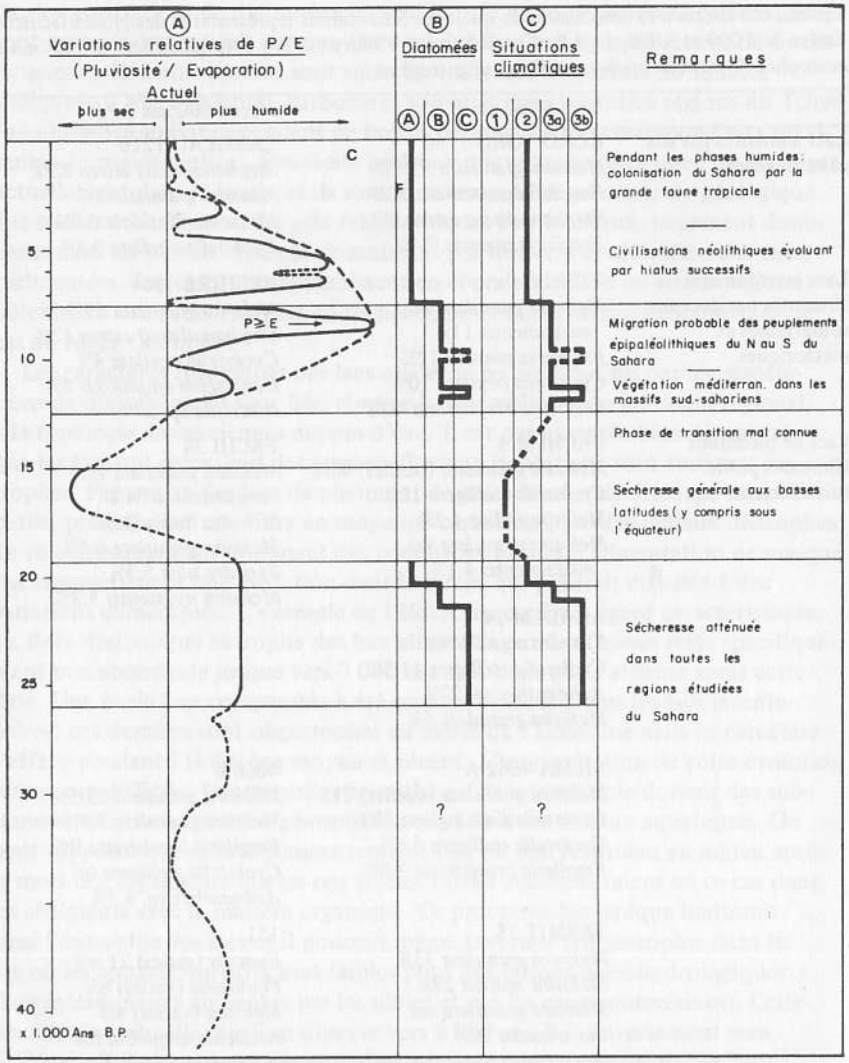


Figure 6.9 Evolution paléoclimatique du bassin du Tchad depuis 40 000 ans B.P.
A. Variation de P/E vers 14°N (d'après Servant 1973).
B. Evolution des associations de diatomées d'après Servant-Vildary (1977); A. espèces tropicales; B. espèces préférentielles des eaux froides associées à de rares espèces des hautes et moyennes latitudes et à de très rares espèces tropicales; C. espèces des hautes et moyennes latitudes, pas de formes tropicales.
C. Hypothèse sur les modifications des circulations atmosphériques. 1. Phase hyperaride. Circulation d'Est avec vents violents du NE en surface (puissants anticyclones subtropicaux décalés vers le Sud par rapport à leur position actuelle?). 2. Advections d'air polaire exceptionnelles ou rares aux basses latitudes. Climats tropicaux à pluies saisonnières et orageuses au Tchad. Zonation des isohyètes du Sud au Nord. 3a et 3b. Fréquentes advections d'air polaire aux latitudes du Tchad. Climats sans équivalents actuels dans les régions tropicales du continent africain.

psychrophiles et quelques espèces tropicales peuvent être associées aux précédentes; (c) enfin, le troisième groupement est caractérisé par l'abondance des diatomées psychrophiles et des diatomées préférentielles des eaux froides; les formes tropicales sont absentes.

La répartition de ces associations dans le Quaternaire récent depuis 26 000 ans est la suivante (Figure 6.9):

– Au Pléistocène supérieur, l'association (c) caractérise des dépôts lacustres qui sont datés à la base de 25 600 ± 800 ans B.P.

– Cette association est remplacée, après 22 400 ans B.P. environ par l'association b, puis à une date plus tardive il y a disparition des espèces psychrophiles ou préférentielles d'eaux froides: les espèces tropicales sont les seules représentées (association a). Ces changements floristiques ne sont pas datés avec précision: il est probable que l'apparition des diatomées tropicales se situe vers 20 000 ou 18 000 ans B.P.

– L'assèchement complet des lacs après 20 000 ou 18 000 ans B.P. entraîne une lacune d'observation dans les études sur les diatomées.

– Entre 12 000 ou 13 000 et 7 000 ans B.P. environ, les associations diatomiques des eaux douces sont surtout caractérisées par l'abondance d'espèces préférentielles d'eaux froides (association b). Les dépôts lacustres admettent de minces niveaux intercalés riches en diatomées psychrophiles; l'un d'eux est légèrement postérieur à 11 740 ans B.P. Malheureusement, la plupart de ces niveaux n'ont pas pu être datés avec précision.

– Enfin, les diatomées tropicales (association a) sont seules représentées et abondantes à partir de 7 500 ans B.P. Quelques espèces préférentielles des eaux froides peuvent être signalées dans certains niveaux de l'Holocène moyen et récent mais leur pourcentage semble trop faible pour être significatif.

Cette répartition stratigraphique met en évidence deux changements floristiques importants: le premier se situe vers 20 000 ou 18 000 ans B.P., le second vers 7 000 ans B.P. Dans les deux cas nous observons le passage d'une flore des régions tempérées à une flore tropicale.

6.4.4 *Sédimentation lacustre*

La sédimentation des lacs quaternaires est essentiellement siliceuse, carbonatée et argileuse. Les eaux qui ont alimenté les lacs étaient probablement riches en silice comme elles le sont actuellement (20 mg/ℓ en moyenne). La silice était en partie fixée par les diatomées ou par les hydrophytes supérieurs. Les faciès diatomitiques sont largement développés dans les sédiments quaternaires. Le carbonate de calcium s'est déposé préférentiellement dans les nappes d'eau peu profondes où il était fixé par les Mollusques et les Ostracodes. Il a aussi cristallisé, dans les mêmes milieux, sous forme de calcaire microcristallin et dans des bas fonds humides sous forme de nodules. La sédimentation géochimique fait intervenir des néoformations argileuses. Dans le cas du lac Tchad actuel, Dupont (1970) a montré que les apports solides sont caractérisés par une dominance de kaolinite. Les sédiments du lac sont surtout constitués par des minéraux du groupe de la montmorillonite. Ces minéraux sont donc en partie néoformés. Les mécanismes en jeu ont été analysés par Carmouze (1976). Les hydrates de fer et d'alumine apportés par les eaux fluviales se combinent avec

la silice pour donner suivant les régions du lac de la montronite, de la montmorillonite magnésienne ou de la montmorillonite ferrifère.

L'évolution de la sédimentation lacustre au cours du temps dépend étroitement des oscillations des plans d'eau. Ce phénomène est perceptible à l'échelle de la décade dans le lac Tchad actuel (Carmouze 1976). Celui-ci est le siège d'une sédimentation dont les constituants sont détritiques (kaolinite par exemple), néoformés (argiles) ou biogéniques. Un abaissement du plan d'eau oriente cette sédimentation vers le pôle évaporitique. Une élévation de quelques mètres accentue la participation des apports détritiques, ce qui se traduit par un enrichissement en kaolinite, illite et constituants amorphes. A l'échelle du millénaire, les oscillations des lacs se traduisent quand elles ont une grande amplitude (10 à 100 m) par une succession de séquences sédimentaires. Chacune de ces séquences est calcaire à la base, diatomitique ou/et argileuse dans la partie moyenne, calcaire au sommet. Les évaporites (carbonates, chlorures ou sulfates de sodium) sont rarement conservées mais on peut les signaler dans l'Holocène moyen et récent. Les sédiments qui se sont déposés dans des milieux carbonatés sodiques peuvent contenir des silicates sodiques qui ont évolué par déshydratation en donnant des cherts (Maglione & Servant 1973).

Le bassin du Tchad, endoréique sur le plan hydrologique, ne l'est pas sur le plan sédimentologique. Les séquences lacustres ont subi une érosion éolienne très importante pendant les phases d'assèchement des nappes d'eau. Cette forme d'érosion a joué pendant le Quaternaire un rôle déterminant dans l'exportation, hors du bassin, des matières qui s'y accumulent pendant les épisodes lacustres. Ces matières transportées par le vent atteignent l'Océan. La preuve en est donnée par la présence de diatomées continentales dans les sédiments marins au large des côtes africaines et par l'analyse des poussières éoliennes.

6.4.5 *Sédimentation fluviatile*

Les alluvions fluviatiles ont surtout été étudiées dans les massifs sahariens de l'Aïr, du Hoggar et du Tibesti. Une terrasse récente, observée dans les oueds de l'Aïr oriental (Figure 6.10) montre une évolution lithologique qui implique des modifications dans le régime des écoulements superficiels (Servant 1973).

– Des écoulements affectés de crues violentes ont permis la mise en place, sur une surface d'érosion, d'alluvions très mal classées comprenant un mélange de blocs, de cailloux et de sables grossiers. Ces dépôts (niveau 1) remanient des bifaces acheuléens et des éclats dont certains de technique Levallois. Leur âge exact n'est pas déterminé.

– Une phase d'engorgement par une nappe phréatique a ensuite entraîné une accumulation de fer et d'argiles dans les pores des dépôts précédents et autour des grains de sable.

– L'interruption complète des écoulements a permis l'ensablement du fond des vallées par des vents de secteur NE (niveau 2). Le phénomène a eu lieu au cours de la dernière grande phase hyperaride du Quaternaire. Celle-ci est vraisemblablement contemporaine de la période d'assèchement des lacs et de remaniements éoliens qui a eu lieu dans le bassin entre 20 000 ou 18 000 et 13 000 ans B.P.

– La reprise des écoulements s'est manifestée par un ravinement des formations précédentes ou par une accumulation locale de cailloux et de cailloutis

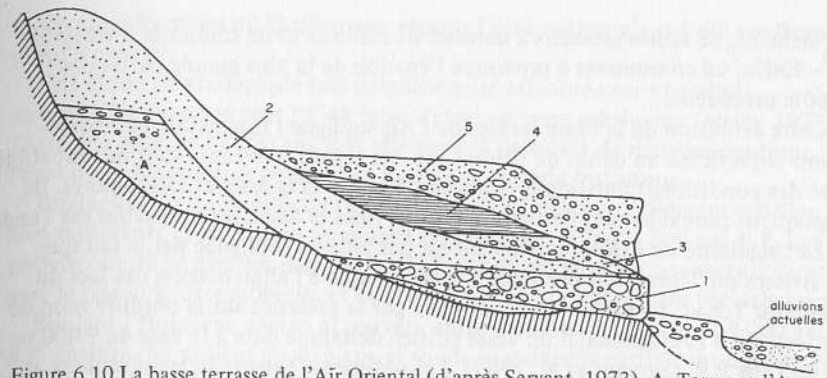


Figure 6.10 La basse terrasse de l'Aïr Oriental (d'après Servant, 1973). A. Terrasse d'Agamgam Nord à industries paléolithiques au sommet; niveaux 1 à 5: légende dans le texte.

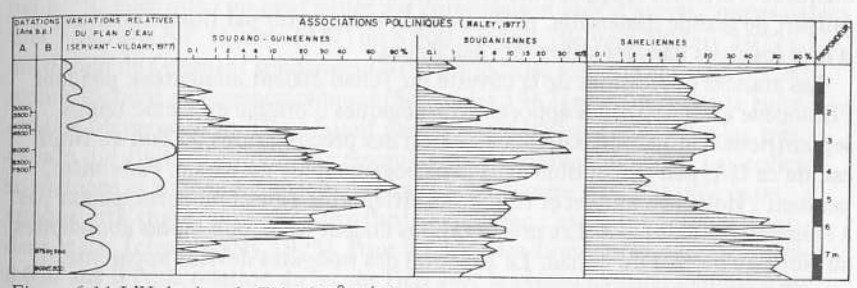


Figure 6.11 L'Holocène de Tjéri (13°44'N). Variations relatives du niveau lacustre (d'après Servant-Vildary 1977). Fréquences relatives des associations polliniques tropicales (éléments sahéliens, soudaniens et soudano-guinéens). L'échelle des pourcentages est intermédiaire entre l'échelle arithmétique et logarithmique (Maley 1977). Colonne A: âges évalués par comparaison avec d'autres coupes datées par le ^{14}C.

peu épais (niveau 3). Elle pourrait se situer approximativement vers 12 000-13 000 ans B.P. à une époque où des lacs sont apparus dans le fond du bassin du Tchad.

– Un régime hydrologique très particulier a entraîné ultérieurement la mise en place, dans le fond de toutes les vallées, de dépôts fins limoneux ou sableux, bien classés, généralement bien stratifiés, riches en phytolithaires (niveau 4). Ces dépôts impliquent des écoulements lents malgré le profil longitudinal souvent très accentué des vallées. Ils ne sont pas datés avec précision mais nous verrons ci-dessous qu'ils sont antérieurs à 5 000 ou 6 000 ans B.P. Ils sont attribuables à l'Holocène ancien et peut-être en partie à la fin du Pléistocène. Des dépôts comparables sont connus au Hoggar et au Tibesti. Dans cette dernière région ils ont été datés de 13 000 ou 14 000 à 7 000 ans B.P. environ (Hagedorn et al. 1969).

– Une phase de pédogenèse, de type vertique, a affecté les alluvions précédentes. Les accumulations calcaires ont été datées par le ^{14}C, après et avant attaque acide ménagée. Les résultats obtenus, concordants, se situent entre 5 000 et 6 000 ans B.P.

– Le retour à des écoulements affectés de fortes crues a entraîné le dépôt, après

ravinement, de sables grossiers à lentilles de cailloux et de cailloutis (niveau 5).

– Enfin, un creusement a provoqué l'érosion de la plus grande partie des dépôts précédents.

Cette évolution de la basse terrasse de l'Aïr souligne l'originalité des écoulements superficiels au début de l'Holocène. De tels écoulements sont incompatibles avec des conditions climatiques tropicales à pluies orageuses et saisonnières. Ils impliquent probablement des précipitations fines et assez bien réparties sur l'année.

La singularité de l'Holocène ancien est par ailleurs soulignée par le fait que les rivières du Tibesti ont participé à cette époque à l'alimentation des lacs du bassin du Tchad. La preuve en est donnée par la présence sur la bordure nord de ces lacs, dans l'Angamma, d'un vaste édifice deltaïque daté à la base de 9 000 ou 10 000 ans B.P. (Servant et al. 1969). Les sédiments essentiellement sableux et limoneux, avec localement des lentilles de cailloutis, sont très riches en ossements de Vertébrés (Hippopotames, Eléphants, etc.) et en bois fossiles pour la plupart de grande dimension, probablement transportés par flottation avant d'être fossilisés dans les sédiments deltaïques.

Les grandes dépressions de la cuvette du Tchad étaient alimentées, pendant l'Holocène ancien, par des apports hydrologiques d'origine en même temps septentrionale et méridionale. La zonation des précipitations du Sud au Nord est, de ce fait, peu perceptible dans la paléogéographie du bassin. Par contre, pendant l'Holocène moyen et récent, les rivières du Tibesti ne participaient pas à l'alimentation des lacs. Les précipitations étaient beaucoup moins abondantes au Nord qu'au Sud du Tchad. La zonation des isohyètes devient apparente.

6.4.6 *Couverture végétale*

Les études botaniques ont attiré l'attention sur la présence de relictes végétales méditerranéennes dans les massifs centraux sahariens (Hoggar, Aïr, Tibesti). D'où l'hypothèse suivant laquelle le domaine phytogéographique méditerranéen a pu s'implanter au Sud du Sahara pendant le Quaternaire récent. Une terrasse fluviatile, datée de 14 000 à 7 300 ans B.P. au Tibesti, contient des associations de pollens qui suggèrent une zonation de type méditerranéen en altitude avec des associations de plantes du Sahel dans la partie inférieure (Jäkel & Schulz 1973). La végétation d'origine septentrionale semble s'être maintenue en altitude pendant l'Holocène moyen comme l'indique l'étude palynologique d'un paléosol brun daté de 6 600 ans B.P. environ (Messerli 1973; Maley 1977). L'implantation de ce type de végétation dans les plaines du Tchad est considérée comme improbable. Les pollens méditerranéens existent en faibles pourcentages dans les dépôts du Quaternaire récent avant 4 000 ans B.P., mais ils sont probablement allochtones et issus des massifs sahariens (Quézel & Martinez 1958; Maley 1977). Ces pollens sont associés à des éléments tropicaux toujours dominants. Une exception doit être signalée: les sédiments lacustres datés de 28 000-26 000 ans B.P. dans le Bahr-El-Ghazal ne contiennent pas les associations polliniques tropicales (Maley 1976).

Les travaux de Gillet (1967) ont montré l'existence au Sahara méridional (Ennedi) de relictes végétales soudaniennes et soudano-guinéennes. Ces plantes vivent actuellement à 500 ou 1 000 km plus au Sud. Leur présence en Ennedi semble indiquer un déplacement vers le Nord des zones de végétation pendant

les époques humides du Quaternaire récent. Cette notion n'a pas été confirmée jusqu'à présent.

Une étude palynologique très détaillée a été effectuée sur une série lacustre (Tjéri) située vers 13°44'N au Tchad en zone sahélienne (Maley 1977). Datée à la base de 13 000 ans B.P. elle permet de suivre de manière continue l'évolution des spectres polliniques jusqu'à la période historique.

Pendant la fin du Pléistocène et au début de l'Holocène, l'élément sahélien est bien représenté et largement dominant un peu avant 8 750 ± 200 ans B.P. Les pollens ont dû se déposer dans un lac qui n'avait pas alors de connection directe avec le réseau hydrographique et ils proviennent de la couverture végétale locale.

Pendant l'Holocène ancien et moyen, entre 8 000 ou 8 500 ans et 4 000 ans B.P. environ, les pollens soudaniens et soudano-guinéens participent largement à la composition des spectres polliniques (Figure 6.11). Le maximum des associations soudano-guinéennes (80%) se situe à une date qui n'a pas été déterminée par le ^{14}C mais que l'on peut situer par comparaison avec d'autres coupes datées vers 7 500 ans B.P. (Maley 1977) ou 6 300 ans B.P. (Servant-Vildary 1977). Le maximum de l'élément soudanien (30%) est localisé vers 6 000 ans B.P. Les reconstitutions paléogéographiques (Schneider 1967) montrent que la zone étudiée (dépression de Tjeri) faisait partie, vers 6 000 ans B.P., d'un lac très étendu qui était alimenté par le réseau hydrographique du bassin. Les pollens soudaniens et soudano-guinéens, ou une partie d'entre eux, ont pu à cette époque être apportés par les eaux fluviales comme c'est le cas actuellement dans le lac Tchad (Maley 1973). Pour les périodes antérieures, aux alentours de 8 000 ans B.P., la relation du lac de Tjéri avec le réseau hydrographique n'est pas définie avec certitude et il est difficile de savoir si les pollens ont pu ou non être allochtones. Le problème pourra être résolu par l'étude d'une ancienne dépression lacustre dont on est certain qu'elle a toujours été isolée.

Pendant l'Holocène récent après 4 000 ans B.P., l'élément soudano-guinéen tend à disparaître (moins de 2%) et l'élément soudanien régresse dans de fortes proportions (il passe de 10% à 0 ou 1%).

L'analyse détaillée de toutes les variations mineures de spectres polliniques montre que la fréquence de l'élément sahélien diminue généralement quand le niveau du lac s'abaisse. Cet abaissement implique une sécheresse plus accentuée. Mais au cours des mêmes phases sèches il y a augmentation relative de l'élément soudano-guinéen caractéristique de conditions climatiques humides. Cet élément serait donc, d'après Maley, allochtone et d'origine méridionale. Sa présence en forte proportion indiquerait qu'une phase de sécheresse vers 13-14°N ne se manifesterait pas dans les régions méridionales du bassin d'où proviendraient les pollens soudano-guinéens.

Dans l'état des données disponibles il est difficile, nous semble-t-il, d'écarter définitivement une autre interprétation. L'ancien lac de Tjéri se situe dans un paysage de dunes sableuses et de dépressions interdunaires. On pourrait peut-être concevoir, pendant une phase humide, l'implantation et le développement d'une végétation sahélienne sur les dunes et d'une végétation soudano-guinéenne autour des lacs dans les zones humides. Pendant une phase sèche, il y aurait dégradation de la couverture sahélienne mais maintien, sous forme relicte, des plantes soudano-guinéennes dans les bas fonds lacustres qui ne s'assèchent pas

complètement. Une telle situation s'observe actuellement en pleine zone désertique dans les oueds de l'Ennedi.

6.5 PALAEOCLIMATOLOGIE DYNAMIQUE

6.5.1 *Enoncé du problème*

L'environnement actuel du bassin du Tchad est largement dépendant des circulations atmosphériques. Les précipitations sont liées au déplacement saisonnier de la zone de convergence intertropicale (ZCIT). Elles ont lieu en été et elles diminuent du Sud au Nord en valeurs moyennes annuelles. Les perturbations ne sont pas associées à l'affrontement de masses d'air très différentes par leurs caractères physiques (température, humidité, densité, etc.) comme on l'observe dans les fronts polaires. Elles sont liées à des discontinuités dynamiques, c'est-à-dire à des variations de vitesse et de direction au sein des masses d'air. Ces perturbations se traduisent par des pluies à caractère orageux. Des perturbations différentes ont été signalées mais elles ne jouent pas un rôle déterminant sur les climats aux latitudes du Tchad. Elles sont liées à des advections d'air polaire vers l'équateur (Detwiller 1965) ou à un déplacement de l'air tropical sur le Sahara vers les moyennes latitudes (dépressions soudano-guinéennes Dubief 1963). Ces circulations atmosphériques, de type méridien, exceptionnelles en Afrique, sont actuellement assez fréquentes dans d'autres régions du monde, principalement sur la face Est des continents (Mer des Antilles, Amazonie, etc.). Au Sud du Brésil, les intrusions d'air polaire austral peuvent apporter des gelées en pleine zone tropicale.

Il est admis, par la plupart des auteurs, que les climats des latitudes tropicales se sont maintenus, dans leurs caractères essentiels, pendant le Quaternaire récent. Les variations de climat sont assimilées à un décalage vers le Nord ou vers le Sud des isohyètes sans modification intrinsèque des zones climatiques. Ce concept s'accorde mal avec les faits. Il est par exemple difficile d'expliquer les pluies fines et probablement assez bien réparties sur l'année de l'Holocène ancien sans mettre en discussion les données actuellement les plus spécifiques de la zone tropicale (Servant 1973). C'est sur ce problème que nous insisterons en examinant les principaux stades de l'évolution des climats depuis 28 000 ans B.P. (Figure 6.9). Nous nous limiterons ici à l'examen des tendances moyennes pour chaque époque.

6.5.2 *Principales phases paléoclimatiques et circulations atmosphériques*

Pendant l'Holocène moyen et récent (7 000 ans), les caractères généraux des climats du Tchad n'ont pas été différents de ce qu'ils sont actuellement. Les pluies étaient saisonnières et orageuses; la zonation des isohyètes est perceptible dans la paléogéographie du bassin; la flore diatomique comprenait les espèces habituelles des lacs africains tropicaux (Figure 6.9). Les climats devaient être contrôlés par un schéma des circulations atmosphériques comparable à ce qu'il est de nos jours. Les variations de pluviosité pourraient s'expliquer par un simple décalage en latitude de ce schéma. Les phases humides correspondraient à une plus grande pénétration de la ZCIT à l'intérieur du Sahara. Cette notion, couramment utilisée dans les interprétations paléoclimatiques, devrait être nuancée. L'aridité de l'ensemble du Sahara s'est atténuée pendant le Néolithique, vers 6 000-5 000 ans B.P. Le phénomène est incompatible avec le maintien sur cette région des puissants anticyclones qui s'y observent actuellement. Ces derniers étaient au moins épisodiquement affaiblis. Cette situation pouvait favoriser le passage direct de l'air polaire vers l'équateur ou le passage direct de l'air tropical vers les moyennes latitudes. Nous rejoignons ici une interprétation de Conrad (1969) qui a été reprise par Rognon (1976). Il est donc possible que les variations climatiques qui ont eu lieu depuis 7 000 ans B.P. soient liées à des phénomènes plus complexes que le simple décalage en latitude. Mais c'est ce décalage qui est le plus apparent dans les plaines du Tchad.

Pendant la fin du Pleistocène et l'Holocène ancien (12 000-7 000 ans B.P.), les climats du Tchad présentaient des caractères incompatibles avec les mécanismes qui contrôlent actuellement l'environnement tropical. Les précipitations étaient dépourvues de caractère orageux et probablement assez bien réparties sur l'année. La zonation des isohyètes n'apparaît pas dans la paléogéographie du bassin vers 8 000-7 000 ans B.P. La végétation était de type méditerranéen en altitude, etc. Ces données peuvent être interprétées à partir des informations fournies par les diatomées. La flore diatomique des lacs comprenait des espèces qui vivent de nos jours exclusivement ou préférentiellement aux hautes et moyennes latitudes. Nous poserons, comme hypothèse préalable, et en accord avec la plupart des spécialistes, que ces diatomées indiquent des climats relativement froids ou, tout au moins, des températures minimum basses (Figure 6.9).

L'existence de climats froids au Tchad, entre 12 000 et 7 000 ans B.P., ne s'accorde pas avec l'évolution à cette époque du contexte paléoclimatique mondial. Les températures ont alors augmenté rapidement avec des oscillations mineures. Les climats froids du Tchad sont donc assimilables à une anomalie régionale. Une explication du phénomène peut être recherchée dans des situations météorologiques actuelles de nature exceptionnelle. Nous savons que l'air polaire froid gagne parfois les basses latitudes. Cela se produit rarement en Afrique, plus souvent en Amérique du Sud (Brésil, Bolivie). Les intrusions d'air polaire se traduisent par un abaissement brutal des températures (de l'ordre de 10° à 15°) et par des perturbations frontales avec chutes de neige en altitude. Le phénomène a lieu surtout en hiver parfois en été. Ces exemples montrent qu'une fréquence plus grande des advections d'air polaire dans les régions tropicales pourrait provoquer les chutes de température qui sont signalées au Tchad par l'étude des diatomées. De plus, l'introduction d'air froid entraînerait des discontinuités de température au sein des masses d'air de la zone tropicale. Les mécanismes des précipitations seraient très différents de ce qu'ils sont actuellement. On comprendrait ainsi beaucoup mieux le caractère particulier des précipitations vers 8 000-9 000 ans B.P. (même s'il n'est pas encore possible de définir avec précision les processus en jeu). On comprendrait aussi qu'une végétation d'origine septentrionale se soit développée en altitude (Tibesti). Mais il est difficile pour le moment d'établir si le phénomène a affecté la couverture végétale en plaine.

La période comprise entre 20 000 et 12 000 ans B.P. est encore assez mal connue dans son évolution paléoclimatique détaillée. Elle comprend une phase hyperaride qui a été probablement de courte durée, trois ou quatre millénaires tout au plus. Cette phase hyperaride est caractérisée par des vents dominants du

NE qui ont laissé des traces spectaculaires dans la morphologie du Nord du Tchad (dunes, couloirs d'érosion éolienne). Les vents, très secs, trouvaient leur origine dans de puissantes cellules anticycloniques situées sur le Sahara ou en Eurasie.

Pendant la période comprise entre 28 000 et 20 000 ans B.P., les climats étaient plus humides qu'actuellement mais ils ne sont pas définis avec précision. L'étude de la flore diatomique des anciens lacs donne une indication importante. Cette période correspond au développement maximum pendant le Quaternaire récent des espèces des hautes et moyennes latitudes. Elle devait être caractérisée par des températures basses. Le contexte paléoclimatique mondial, alors défini par un refroidissement général, pourrait rendre compte du phénomène. Mais cette explication n'est pas suffisante. Les diatomées des régions tempérées sont remplacées vers 20 000 ans B.P. par une flore tropicale (Figure 6.9). Ce changement floristique ne peut pas être relié à un réchauffement général du globe. Il faut donc lui rechercher une cause locale. Les climats froids qui sont notés entre 28 000 et 20 000 ans B.P. pourraient s'expliquer par de fréquentes advections d'air polaire aux latitudes du Tchad. Nous retrouvons ici le phénomène déjà envisagé dans l'interprétation des paléoclimats entre 22 000 et 7 000 ans B.P. Mais il a pu être beaucoup plus accentué. Le contexte mondial froid favorisait le maintien de températures basses au sein des masses d'air polaire se déplaçant en direction de l'équateur. Nous comprenons mieux ainsi la disparition des diatomées tropicales et l'abondance des espèces des hautes et moyennes latitudes au Tchad entre 28 000 et 20 000 ans B.P. La couverture végétale semble avoir été affectée par l'arrivée de l'air polaire et par la chute des températures: Maley (1976) note l'absence de pollens tropicaux pendant une courte période dans des sédiments datés de 26 000 à 28 000 ans B.P. environ. L'apparition des diatomées tropicales vers 20 000 ans B.P. souligne la fin d'une phase climatique: les intrusions d'air polaire sont devenues exceptionnelles et les caractères spécifiques de l'environnement tropical ont pu s'affirmer à nouveau.

6.5.3 *Schémas d'interprétation*

La discussion précédente dégage un schéma d'interprétation. Au niveau de leur organisation générale, les circulations atmosphériques évolueraient entre deux situations extrêmes. La première est caractérisée par de fréquents échanges méridiens, ce qui implique un affaiblissement des anticyclones sur le Sahara. Ces derniers ne s'opposent pas au passage direct de l'air polaire vers l'équateur et au passage direct de l'air tropical vers les moyennes latitudes. La deuxième situation, proche de l'actuelle, correspond à une fréquence bien moindre des échanges méridiens. Cela implique un renforcement des cellules anticycloniques subtropicales.

Ce schéma explique en partie les variations de pluviosité et d'évaporation que nous avons individualisées au Tchad. Le renforcement des anticyclones générateurs d'air sec, réalise des conditions favorables à l'aridité. Leur affaiblissement favorise une atténuation de la sécheresse. Mais d'autres facteurs interviennent dans les oscillations de pluviosité. L'hypothèse classique du 'balancement' en latitude des zones climatiques demeure applicable. Le décalage vers le Sud des anticyclones par rapport à leur position moyenne actuelle entraîne l'extension de la zone désertique vers l'équateur. Ce phénomène a vraisemblablement eu lieu entre 20 000 et 13 000 ans B.P. et avec une moindre amplitude pendant les phases sèches de l'Holocène moyen et récent. Inversement, la Zone de Convergence Intertropicale peut s'étendre plus profondément à l'intérieur du Sahara ce qui entraîne une augmentation de pluviosité dans le Nord du Tchad. Il faut par ailleurs tenir compte de l'humidité des masses d'air qui sont à l'origine des précipitations. Ces masses d'air se sont déplacées avant d'atteindre le Tchad sur des régions océaniques ou continentales où l'évaporation et l'évapotranspiration ont pu connaître des variations importantes pendant le Quaternaire récent en relation avec les changements de température et les modifications de la couverture végétale. Les transferts de vapeur d'eau depuis le Golfe de Guinée jusqu'en Afrique Centrale étaient certainement limités pendant les périodes glaciaires, caractérisées par une diminution de la température et de l'évaporation océanique et par une destruction presque complète, au moins vers 20 000 ans B.P., de la forêt aux basses latitudes (Bernard 1962; de Ploey 1964).

Les profondes modifications que nous envisageons dans l'organisation des circulations atmosphériques donnent une explication cohérente aux données paléoclimatiques dégagées au Tchad. Il resterait à vérifier le schéma proposé en le replaçant dans un contexte paléogéographique plus vaste.

Les mises au point les plus récentes (Rognon 1976) s'opposent sur deux points essentiels aux interprétations que nous présentons: elles admettent l'existence d'anticyclones puissants pendant les périodes qui seraient caractérisées, selon nous, par de fréquents échanges méridiens (entre 28 000 et 20 000 ans et entre 12 000 et 7 500 ans B.P.). Mais une grande imprécision existe sur le plan chronologique et sur celui des interprétations paléoclimatiques régionales dans de nombreuses zones du Sahara. La présence d'une bande désertique étroite, liée à des anticyclones, sur le Sahara Central entre 40 000 et 20 000 ans B.P. ne reçoit aucun argument au niveau de l'observation. Les conditions climatiques du Sahara septentrional entre 14 000 et 8 000 ans B.P. sont controversées (Chavaillon 1964; Conrad 1967) et il serait prématuré d'admettre une permanence de climat sec dans cette région et à cette époque. Les remaniements éoliens qui sont observés localement ont pu avoir lieu pendant de courtes périodes de sécheresse comme cela se produit au Tchad à la même époque (par exemple vers 10 000 ans B.P.). Les nombreux travaux effectués au Sud du Sahara, de l'Atlantique à la Mer Rouge, dégagent des données plus précises (Hébrard 1972; Michel 1969; Gasse 1975, 1977). Celles-ci concernent surtout les variations de pluviosité et d'évaporation. L'évolution des climats se fait, au niveau des tendances générales, de manière parallèle et approximativement synchrone: le maximum d'humidité se situe partout vers 8 000-9 000 ans B.P. et une augmentation de la sécheresse est notée à partir de 5 000 ans B.P. environ; la phase hyperaride du Pléistocène supérieur (vers 16 000-17 000 ans B.P.?) est générale au Sud du Sahara, etc. (Servant 1974). Les oscillations mineures, qui s'effectuent à l'échelle du millénaire, semblent aussi avoir une grande extension géographique mais les corrélations, situées à la limite des marges d'erreur, doivent être envisagées avec précaution. Les informations disponibles sur les régimes des pluies et sur les températures sont peu nombreuses. Elles ne permettent pas de vérifier l'intervention éventuelle des advections d'air polaire dans

les régions tropicales. Les diatomées des hautes et moyennes latitudes ne sont pas connues dans le Quaternaire récent de l'Afrique Orientale sauf vers 25 000-30 000 ans B.P. (Gasse 1977). Elles sont par contre signalées (et abondantes) dans des dépôts lacustres de Mauritanie d'âge probablement fin Pleistocène ou Holocène ancien (Marciniak, communication orale). Ces indications suggèrent que les anomalies thermiques reconnues au Tchad intéresseraient surtout l'Afrique Centrale et Occidentale. Le phénomène pourrait s'expliquer si les intrusions d'air polaire se sont faites, comme actuellement, suivant des itinéraires privilégiés.

Finalement, deux mécanismes essentiels sont envisagés au niveau des circulations atmosphériques pour expliquer les variations climatiques du Tchad. Le premier, évoqué de longue date par tous les auteurs, fait intervenir un décalage en latitude des zones climatiques et en particulier des zones sèches liées aux anticyclones subtropicaux. Le second fait intervenir une fréquence accentuée ou diminuée des mouvements méridiens des masses d'air (Servant 1973), ce qui implique un affaiblissement ou un renforcement des anticyclones subtropicaux. Les deux mécanismes proposés posent le problème paléoclimatique à l'échelle du globe. Le déplacement des zones climatiques tropicales, comme les déplacements saisonniers actuels, ne peut pas être compris sans prendre en considération les circulations des hautes et moyennes latitudes des deux hémisphères (Maley 1973). Il en est de même pour l'évolution des anticyclones subtropicaux. Mais il serait prématuré, avant d'avoir réuni tous les éléments d'observation sur de grandes unités géographiques, de rechercher une explication plus approfondie.

6.6 CONCLUSION

L'environnement du bassin du Tchad dépend d'une donnée très instable à toutes les échelles de temps: le climat. Cette instabilité apparaît dans les variations de pluviosité et d'évaporation dont l'amplitude et la chronologie ont été déterminées, avec plus ou moins de précision suivant les époques, par l'étude des oscillations lacustres.

Des changements climatiques, moins spectaculaires dans leurs effets paléogéographiques mais en réalité plus profonds commencent à apparaître. Ils concernent, par exemple, le régime des pluies et la température. Ces changements impliquent, nous semble-t-il, une réorganisation à chaque phase climatique du Quaternaire des circulations atmosphériques. Ils suggèrent, avec vraisemblance, que le phénomène majeur se situe au niveau des anticyclones subtropicaux qui, en se renforçant ou en s'affaiblissant, favorisent ou freinent les échanges méridiens des masses d'air entre les moyennes et basses latitudes. Si cette notion devait être confirmée, des perspectives nouvelles apparaîtraient dans les interprétations paléoclimatiques globales: il faudrait par exemple réexaminer les transferts d'énergie et de vapeur d'eau entre les régions tempérées et les régions tropicales. Les modifications de climat s'exercent sur un contexte topographique et géologique qui n'a pas subi de changements pendant le Quaternaire. Une certaine stabilité existe de ce fait, au niveau qualitatif, dans les possibilités offertes à la sédimentation. Le Bassin du Tchad est un bassin à sédimentation siliceuse et carbonatée favorable aux synthèses argileuses à montmorillonites.

6.7 REFERENCES

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7

Apports de la préhistoire à la stratigraphie et la chronologie au Sahara et au Maghreb

The contribution of prehistoric studies to our understanding of the Quaternary stratigraphy of the Sahara and Northwest Africa

Judicious use of prehistoric stone tool assemblages enables us to supplement our often scanty knowledge of Saharan Quaternary stratigraphy and palaeo-environments. This thesis is illustrated using selected examples drawn from the Pre-Acheulian, Acheulian, Moustero-Aterian, late Palaeolithic, Epipalaeolithic, and Neolithic traditions of the Maghreb (Northwest Africa) and the Sahara.

The onset of a Neolithic way of life in the uplands of the Northwest coincided with a cold, wet climate during the 5th to 3rd millennia B.C. Caves occupied during summer by herders of sheep and/or goats were abandoned during the winter months.

In the western Sahara the advent of the Neolithic period during the 7th millenium B.C. coincided with wetter conditions from the Atlantic to the Nile. Cattle rearing during the 5th to 3rd millennia B.C. was confined to the well-watered margins of the uplands. As the lakes and rivers of the Sahara began to dry out the Neolithic herders sought refuge in the mountains, along the banks of major rivers like the Niger and the Nile, and along the shores of scattered lakes. By the end of the 3rd millenium, the Neolithic communities in the central Sahara had become confined to isolated oases and other sources of permanent water, in contrast to the situation in the more densely settled and better watered northern and southern margins of the desert.

7.1 INTRODUCTION

Au Quaternaire, le Sahara a eu ses Nils et ses Fayoums lacustres; mais seuls ont survécu la Saoura, pauvrement alimentée par l'Atlas présaharien, et le lac Tchad. On a parlé d'une branche occidentale du 'Croissant fertile', qui se ramifiait en 'guirlandes' à travers l'actuel Grand Désert. Et pourtant ces vallées aujourd'hui sèches, les rives de ces lacs et lagunes disparus, sont invraisemblablement riches de témoignages d'une occupation humaine préhistorique. Un lien est souvent évident avec les pays méditerranéens du Maghreb, aux milliers de gisements préhistoriques. La vallée du Nil paraît bien plus pauvre à cet égard, et plus encore le delta méditerranéen et ses bordures.

Les temps préhistoriques de l'ensemble Maghreb-Sahara d'une part, de l'Egypte d'autre part, ont néanmoins dans l'état actuel de nos connaissances un trait commun: l'insuffisance de la chronologie absolue. A l'Ouest, pratique-

ment rien en deçà des possibilités du radiocarbone, qui offrent un foisonnement de dates pour l'Epipaléolithique et le Néolithique. A l'Est un raccordement très précis à la chronologie historique, dès le quatrième millénaire au moins, alors qu'il faudra attendre le premier au Maghreb et bien plus tard encore au Sahara.

Néanmoins, les documents préhistoriques fournissent des données qui conbribuent à une meilleure connaissance du Quaternaire (Balout 1955). Nous allons en examiner quelques exemples: le 'Pré-Acheuléen' ou 'Pebble Culture'; l'Acheuléen 'africain'; le Moustéro-Atérien; la fin du Paléolithique et l'Epipaléolithique; et les Néolithiques. Nous verrons qu'à chaque période l'apport de la Préhistoire s'exerce dans les domaines de la géomorphologie, de la paléontologie et de la paléogéographie.

7.2 LE 'PRE-ACHEULEEN'

Depuis le Congrès Panafricain de Dakar (1967) et en application d'une recommandation du Symposium de Burg Wartenstein (1965), le terme Pré-Acheuléen est substitué à 'Pebble Culture' (Balout 1967), et ceci très judicieusement, car la 'Civilisation du galet aménagé' (Biberson 1961a, b) ne peut exclure l'existence d'éclats, et il n'est pas du tout impossible que l'usage d'éclats quelconques ait précédé celui des galets taillés. Ceux-ci sont, dans l'ensemble Maghreb-Sahara, d'un intérêt multiple.

Lorsque purs de tout mélange avec des formes acheuléennes ou plus récentes, ils s'observent à la surface d'un reg ou d'une terrasse, ils donnent une fragile orientation chronologique: il s'agit très vraisemblablement de vieilles surfaces villafranchiennes, sinon plus anciennes encore (Arambourg 1949). Les sites d'Aoulef (Tidikelt) et d'In Afaleleh (Ténéré) peuvent être cités comme exemples. C'est sur de telles séries que furent testées les premières classifications morphologiques (Ramendo 1963).

Dans deux cas importants seulement, les galets aménagés entrent dans l'interprétation d'une stratigraphie: au Maroc, dans le cadre du Quaternaire du littoral atlantique (Biberson 1961a, b), au Sahara occidental, dans le cadre des dépôts alluviaux de l'Oued Saoura (Chavaillon 1964; Alimen 1975).

Biberson rapporte les industries à 'galets aménagés' du Quaternaire littoral atlantique du Maroc aux étages Moulouyen et Salétien, les plus anciens de la série quaternaire. L'Acheuléen apparaîtrait dans la seconde partie du Salétien. Il n'est pas certain que l'on doive conserver les quatre stades de Pebble Culture proposés par Biberson, et ceci pour des raisons, non pas stratigraphiques, mais typologiques: le 'stade ancien I' soulève les mêmes problèmes que le défunt Kafuen: l'attribuer à une industrie bien humaine est à la limite de la preuve. Quoi qu'il en soit, Biberson aboutit à une évolution de la taille des galets qui rejoint les classifications fondées sur la typologie: taille uniface (unidirectionnelle), bifaciale (bidirectionnelle), et multifaciale (multidirectionnelle).

Que l'on puisse définir des formes (ou types) démontre une systématique de la taille qui n'a plus rien de 'primitif'. Malheureusement, les faits observés au

Maroc ne sont pas corroborés par les découvertes récentes en Afrique orientale: le 'galet taillé' de l'Omo est déjà bidirectionnel, et la belle coupe d'Olduvai ne nous impose pas la même séquence.

Dans les formations quaternaires de la Saoura, Alimen (1955) et Chavaillon (1964) situent la Pebble Culture au Mazzérien et au début du Taourirtien, ce qui n'est pas en désaccord avec Biberson (1961b), l'évolution des formes est difficile à préciser.

Le dernier cas que nous ayons à examiner est celui des galets aménagés provenant de gisements paléontologiques. Le type est évidemment l'Aïn Hanech (région de Sétif, Algérie) (Arambourg & Balout 1952). L'industrie, les sphéroïdes à facettes, constitue des sortes de 'Marker beds' dans l'évolution de la faune, bien que survivent, à côté de mammifères quaternaires, des éléments pliocènes comme *Elephas africanavus* ou un Equidé tridactyle. Le passage à l'Acheuléen se fait au sommet de la série (niveau démantelé du cimetière). Le document préhistorique joue là un rôle essentiel, le remblaiement fluvio-lacustre du 'lac sétifien' des géologues, continu depuis le Pontien, est ici marqué par l'apparition de l'industrie humaine.

L'Aïn Hanech est unique en importance, mais d'autres sites pourraient le compléter s'ils faisaient l'objet de fouilles aussi considérables. Gobert (Castany & Gobert 1954) avait recueilli une trace d'industrie lithique dans le gisement villafranchien des rives du lac Ischkeul (Tunisie septentrionale). Il en est de même à l'Aïn Brimba (Tunisie présaharienne).

Il y a donc, dans le Maghreb, un 'Pré-Acheuléen' d'âge géologique villafranchien, que l'on est évidemment tenté de rapprocher de l'Olduvaien de Tanzanie, bien que les données de chronologie absolue nous fassent totalement défaut.

7.3 L'ACHEULEEN 'AFRICAIN'

On sait que la définition de l'Acheuléen, ancienne mais toujours valable, est typologique: ce sont des industries à bifaces. Elle a donc une signification chronologique très vaste, qui peut aller du Mindel au Riss-Würm, en Europe occidentale. Les coupures proposées par le préhistorien sont également typologiques: apparition de la taille au percuteur tendre (Acheuléen 'moyen'); raréfaction, sinon disparition des formes archaïsantes: galets aménagés – trièdres – bifaces de style 'abbevillien' – apparition de la technique Levallois de débitage – évolution des hachereaux (sur éclat) – technique du 'nucléus-éclat' (Victoria West-Kombewa). Mais ces observations ne peuvent être classées dans le temps que si elles trouvent un support stratigraphique et paléontologique.

A cet égard, le Maghreb et le Sahara sont pauvres par rapport à l'Europe occidentale et à l'Afrique orientale et méridionale.

Pour ce qui est des stratigraphies, nous retrouvons les deux cas déjà cités à propos du Pré-Acheuléen: le Quaternaire du littoral atlantique du Maroc et les formations alluviales de la Saoura. Dans le premier cas, la conchyliologie représente l'élément paléontologique essentiel, si l'on met à part les restes d'*Antlanthropus*

mauritanicus (Balout et al. 1967). Pour des raisons qui relèvent de la géomorphologie littorale, l'Algérie n'est pas aussi favorisée. Rien de semblable n'existe en Tunisie.

Dans le second cas, les gisements acheuléens d'alluvions fluviatiles, nous constatons leur rareté et pauvreté par rapport à l'Europe, et leurs relations stratigraphiques et paléontologiques sont le plus souvent imprécises. Là encore, le seul système chrono-stratigraphique est celui de la Saoura (Chavaillon 1964). Les autres sites sont mineurs et ne servent que la préhistoire (Oued Melah, au Maroc; Ouzidane, près de Tlemcen; Champlain, près de Médéa; Tamda, en Kabylie; Mansourah, à Constantine; Clairefontaine, S'Baïkia et surtout El-Ma El-Abiod, dans la région de Tébessa, en Algérie; Rédeyef (Gafsa), en Tunisie). Il faut mettre à part Sidi Zin (région du Kef, en Tunisie) où un niveau à hachereaux est pris entre deux autres à bifaces, sans hachereaux, ce qui est une donnée capitale car il y a, en Afrique, des Acheuléens *à* et *sans* hachereaux.

Les lacs d'origine artésienne ont attiré les hommes de l'Acheuléen à l'Atérien: Tit Mellil (Casablanca), Aïn Fritissa (S. d'Oujda) au Maroc – 'Lac Karar' (Tlemcan) et Chetma (Biskra), en Algérie: on ne retiendra ici que Ternifine (Mascara) (Arambourg & Hoffsteter 1970). Encore ne faut-il pas se faire trop d'illusion: l'industrie est d'un extrême intérêt, la faune d'une prodigieuse richesse, à *El. Atlanticus;* et c'est là qu'on découvrit l'Atlanthrope; mais la stratigraphie pose problème. L'ensemble des documents s'insère dans un éventail chronologique qui va des galets aménagés à l'Acheuléen moyen. C'est beaucoup trop! De plus, il n'y a pas de sol d'occupation: ni habitat, ni atelier. Ce sont seulement des affûts de chasse: rien de comparable à Olduvai ou Olorgessailie.

On doit enfin parler des gisements 'lacustres' du Sahara. De la Mauritanie (El Beyyed) au Tassili n-Ajjer (Tihodaîne-Admer), l'Acheuléen repose sur la rive de pièces d'eau disparues, qu'il contribue à dater, aidé parfois par la faune. Le 'Sahara des Tchads' a été un visage fugitif du Sahara pléistocène de position chronologique encore imprécise, certainement le dernier 'humide', et sans doute avant. L'Acheuléen semble perdurer en Afrique, jusqu'aux 'temps néandertaliens' de l'Europe. Plongeant des racines dans le 'Pré-Acheuléen', il constitue un élément essentiel: sa durée a pu dépasser le million d'années.

L'Atlanthrope est un *Homo erectus* plus proche du Sinanthrope que du Pithécanthrope (Balout 1954). Le problème est posé des contacts de cet Archanthrope et de son industrie avec l'Europe, donc en franchissant le canal de Sicile ou le détroit de Gibraltar. La diffusion du hachereau sur éclat sert ici d'argument. Cet outil n'est pas exclusivement africain, comme on l'a cru: il est connu en Israël (Ubeidya) et au Pakistan (Soan); et aussi en Europe, dans l'Acheuléen de l'Espagne (Manzanarès) et plus tard au nord des Pyrénées.

Contrairement à ce qu'attendait son Maître, Marcellin Boule, Vaufrey démontrait dans sa thèse, l'inexistence d'isthmes méditerranéens pléistocènes (Vaufrey 1955-1969). Il est aujourd'hui établi que c'est au Néolithique, ou peu avant, qu'est née la navigation en Méditerranée. Alimen a récemment soulevé (1975) le problème du passage Afrique-Europe, grâce aux possibilités offertes par l'abaissement du niveau marin au Rissien, comme il en fut à Behring. Cette hypothèse mérite d'être prise au sérieux, elle expliquerait l'extension septentrionale de l'Acheuléen venu d'Afrique.

7.4 LE MOUSTERO-ATERIEN

Le Paléolithique moyen apporte à la connaissance des temps préhistoriques plusieurs données essentielles. La première est l'existence d'un Moustérien assimilable aux faciès européens (Balout 1965); la seconde est que le porteur de cette civilisation est, ici comme ailleurs, l'Homme de Néandertal; la troisième est la transformation rapide, étendue, expansionniste de ce Moustérien en Atérien, d'Alger au Niger et de l'Atlantique au Nil.

L'intérêt pour la connaissance de cette partie du Pléistocène est le lien entre ces industries et le cadre naturel: Homme, flore, faune, conditions climatiques, sols, morphologie littorale.

Aux deux extrémités géographiques, nous avons le témoignage des hommes: les Néandertaliens du Djebel Irhoud (Maroc) et le monument moustérien consacré à la source d'El Guettar (Tunisie) (Gruet 1954). C'est au sud d'El Guettar qu'est connue la flore dont les pollens trahissent une évolution climatique vers la sécheresse. La faune à *Gazella atlantica* a fait l'objet d'études systématiques de C. Arambourg. Encore le plus riche gisement est-il inédit. Ce lieu de chasse atérien (près d'Alger), dit 'gisement des Phacochères' en raison de l'abondance de ces suidés, a révélé les bois de *Cervus pachygenis*, la mandibule d'*Homoioceras antiquus*, etc.

Des relations stratigraphiques ont pu être précisées entre l'Atérien et le Quaternaire continental ou marin, tant au Sahara que dans le Maghreb, et en chronologie relative qu'absolue. Le 40ème millénaire n'est sans doute pas la date la plus haute qui puisse être envisagée pour l'apparition de l'Atérien. Notre gêne vient des limites de fiabilité du 14C. Mais les dates obtenues dans le Maghreb et au Sahara constituent un écheveau cohérent entre 37 000 et 30 000 B.C.

Concordantes sont les relations avec les formations quaternaires. Il arrive que l'Atérien, non roulé, imprègne les plages néotyrrhéniennes tout juste exondées par le début de la dernière grande régression marine (ex. à Karouba, près de Mostaganem, Algérie). La fin de cet insterstade würmien (W.1-2– se situerait vers 48 000 B.C. Les formations continentales, généralement rubéfiées, riches en Atérien, qui recouvrent ces plages de la 'mer à strombes', plongent sous la mer actuelle: elles datent de la régression, qui a pu atteindre 150 m. Ces observations paraissent valables pour le littoral du Maghreb dans son ensemble (F.E. Roubet 1966).

L'expansion de l'Atérien à travers le Sahara paraît démontrée, avec toutes ses implications paléoclimatiques, et s'arrêterait sur les rives des grands lacs à Diatomées, qui ont été en eau, au Sahara méridional, jusqu'au septième millénaire B.C., c'est-à-dire jusqu'à la veille de la néolithisation. Il n'y a là qu'une hypothèse de travail (Hugot 1966).

7.5 LA FIN DU PALEOLITHIQUE ET L'EPIPALEOLITHIQUE

Beaucoup plus ancien qu'on ne le croyait, l'Ibéromaurusien est contemporain *pro parte* du Solutréen et du Magdalénien, dans le Maghreb seulement, car il n'atteint pas le Sahara. Il est en grande partie littoral, ce qui ne veut pas dire

côtier, compte tenu de la régression marine. Ceci est particulièrement net en Tunisie orientale. Datés grâce au 14C, les gisements ibéromaurusiens nous font connaître une faune terrestre (à mouflons: *Ammotragus lervia*) et marine très proche de l'actuelle. L'homme ibéromaurusien est bien connu par de nombreux documents parfois groupés en ossuaires, voire en nécropoles. Ces Cromagnoïdes constituent le 'type de Mechta-el-Arbi'. Il n'est pas d'origine européenne et sa venue de l'Est n'est pas prouvée. Sur le plan anthropologique, on a pu envisager qu'il descendait des Néandertaliens par l'intermédiaire, encore très imprécis, des Hommes atériens. Contemporains des Magdaléniens, ils ne partagent en rien les aptitudes artistiques de ceux-ci. En revanche, ils se maintiendront jusqu'au Néolithique, et seront les premiers à coloniser l'archipel canarien, vers la fin du troisième millénaire av. J.-C.(Ferembach et al. 1962; Ferembach 1970; Chamla 1970, 1973; Balout & Roubet 1970).

Les industries à lamelles, auxquelles participe l'Ibéromaurusien (Roche 1963; Tixier 1963, 1967; Roubet 1968), ont posé un problème original en Tunisie, dans leurs relations chrono-stratigraphiques avec les 'terrasses' de l'Oued Baiech (Gafsa) et les 'escargotières' capsiennes. Il est aujourd'hui démontré que ces industries de la Tunisie présaharienne ('l'horizon Collignon' de la cuvette de Gafsa) sont antérieures à toute la série capsienne, et se situent à un stade avancé de la sédimentation lagunaire, avant la subsidence qui a entraîné une reprise de l'érosion. Le Capsien, typique et évolué, occupe les paliers de cette érosion, voire les buttes-témoins. Aucune position chronologique ne peut encore être précisée, si ce n'est qu'il y a un peu de Moustérien à la base de la sédimentation.

Le Capsien nous intéresse ici par ses gisements plus que par son industrie, si belle soit-elle (Gobert 1951-52, 1963; Morel 1953; Balout & Roubet 1970). Le site des 'escargotières' (Rammadyat) capsiennes retient l'attention par son insertion dans ce paysage naturel, en particulier les sources, points d'eau, rives de lagunes. En second lieu, ces tas de déchets livrent par centaines de milliers des coquilles d'escargots, appartenant à des espèces encore actuelles, mais dont la répartition est différente. D'autre part, les charbons ont permis, en plus de très nombreuses datations, les premières déterminations botaniques. On assiste en particulier à la mise en place de l'association Pin d'Alep-Génévrier de Phénicie, dont la disparition conduira à la steppe à alfa et betoum (pistachier). Généralement peu de faune, mais *Homoioceras antiquus* (le grand bubale) est encore présent. Grâce au 14C, nous savons qu'un habitat capsien peut avoir duré un millénaire et plus. Or la civilisation capsienne n'en a peut-être duré que deux, et on connaît plusieurs milliers d'escargotières . . . Il y a donc un phénomène de sédentarisation très remarquable, puisqu'il est à la fois pré-pastoral et pré-agricole: tout au plus la cueillette. En tout état de cause, cette ethnie capsienne portée par des Méditerranéens, est en mesure d'accueillir la néolithisation, véhiculée par d'autres Méditerranéens, dès le cinquième millénaire.

7.6 LES NEOLITHIQUES: LEUR ENVIRONNEMENT ET LES DONNEES PALEOCLIMATIQUES

Entrer dans l'ère néolithique, c'est pénétrer dans un monde en mutation capitale, sans jamais voir disparaître un certain savoir-faire parfois rattaché à un certain savoir-vivre.

Les mutations s'opèrent différemment selon les régions et les substrats culturels; elles concernent le climat, affectent l'environnement, coincident avec l'instauration de nouveaux genres de vie.

Au Maghreb, en région capsienne, la néolithisation s'accompagne d'un changement dans le choix de l'habitat, très certainement lié à de nettes modifications climatiques. En effet, grottes, cavernes, abris en montagne succèdent aux escargotières de plein air. Le remplissage de celles-là renferme de nombreuses informations climatiques, écologiques et culturelles, utiles aux quaternaristes (Souville 1958-59; Mauny 1967;Roubet 1968b, 1971, 1978).

Bien conservé, le gisement néolithique est révélateur de faits de préhension. Leur interprétation prudente conduit à esquisser dans ses grandes lignes l'environnement fréquenté, exploité par les hommes (restes d'alimentation, de combustion; déchets de fabrication, etc.). Les exemples qui pourraient être cités sont nombreux, mais rares sont pourtant les analyses aboutissant à une reconstitution paléogéographique. La grotte Capéletti, située sur le piémont septentrional de l'Aurès, donne des renseignements concordants pour aborder les trois objectifs fixés ci-dessus (Roubet 1978).

L'environnement proche et lointain est évoqué grâce aux multiples documents végétaux qui ont été préservés. Un paysage forestier à caractère méditerranéen, proche du site, est attesté par nombre de charbons, graines de fruits d'ifs, de cèdres, de chênes, de frênes, de génévriers, de châtaigniers, etc. Des très hauts sommets du massif proviennent pollens et bois d'essences à caractère boréal comme l'orme, le charme, le noisetier, le bouleau et l'aulne. Des zones lagunaires qui frangent au Nord et au Sud le massif arrivent les essences à caractère sub-tropical tel l'acacia. La grotte Capéletti a donc joué le rôle de réceptacle privilégié favorable aux apports divers d'origine atmosphérique et humaine.

Si de tels paysages ont couvert sommets et pentes du massif Nord entre le milieu du cinquième et celui du troisième millénaire sans connaître de trop grands changements dans leur composition, il faut que se soient maintenues en équilibre des conditions climatiques et pédologiques telles que celles que l'on connaît actuellement en haute montagne, au Maroc par exemple (Santa 1958-59; Le Houérou 1959). Le climat propre à l'Aurès entre le cinquième et le troisième millénaire a été froid et très humide, soumis à de fréquentes précipitations de neige et de pluie susceptibles de bloquer hommes et bêtes pendant de longs mois.

La grotte Capéletti servit donc de refuge pastoral saisonnier. En effet, la faune consommée est très abondante; elle comporte toujours plus de 70% d'Ovins et Caprins domestiques. Nul doute, dans ces conditions écologiques et climatiques, que cette grotte néolithique ait été volontairement abandonnée l'hiver. Nomadisme, transhumance vers le Sud du massif en hiver, remontée

vers le Nord au printemps, c'est à ce rythme que la grotte dut être alternativement abandonnée et occupée. Le rythme des remues se soumit à celui des saisons.

Ces conclusions, difficiles à étendre à d'autres secteurs que celui de l'Algérie orientale, pourraient toutefois convenir au massif oranais du Murdjadjo percé de nombreuses grottes, occupées sans doute à la même époque, mais par des populations enclines à d'autres traditions.

La néolithisation en région saharienne occidentale, qui débute au septième millénaire av. J.-C., coïncide également avec un épisode climatique humide s'étendant de l'Atlantique au Nil.

Ainsi que l'un de nous l'avait déjà exprimé (Balout 1967b) et comme le dit à nouveau Camps (1974), il y a tout lieu d'envisager l'existence de communications privilégiées, facilitées d'Est en Ouest par un chapelet de lagunes verdoyantes et prospères au pied des massifs sahariens (Hoggar, Tassili, Tibesti), indépendamment des artères fluviales.

Le site granitique d'Amekni, occupé au début du septième millénaire, non loin d'un oued aux eaux abondantes qui purent fournir *Lates* et *Claria*, est celui de tribus prédatrices jusqu'au cinquième millénaire.

Même dans un environnement favorable, la néolithisation partielle n'affecte pas le genre de vie qui demeure pré-pastoral (absence d'espèces animales domestiques) et pré-agricole (absence de céréales à l'exception d'un grain de pollen de *Pennisetum*). D'autres exemples pris en bordure du Tanezrouf, dans l'Adrar Tiouiyne, démontrent l'installation de pêcheurs sur les rives de l'oued Amded, vers la fin du quatrième millénaire. Et pourtant, nous avons la preuve de changements des genres de vie. La découverte d'ossements de bovidés au Niger, au Tassili algérien et libyen, ainsi que les représentations picturales (Vaufrey 1939; Balout 1968), plaident en faveur d'un pastoralisme de gros bétail entre le cinquième millénaire et le troisième, cantonné dans les régions montagneuses, seules à connaître des conditions écologiques favorables. C'est déjà le déclin de cet épisode humide et, pour survivre, les hommes se réfugient dans les massifs, sur les rives des grands fleuves africains: Niger, Nil et des grands lacs: Tchad. Le Sahara, assoiffé, se dépeuple et se meurt biologiquement; c'est alors que prolifèrent les armatures de flèches.

La néolithisation saharienne ne connaît donc son épanouissement qu'en région montagneuse: art et genre de vie vont de pair; ailleurs, dans les plaines, on retourne à un certain savoir-faire seul possible pour survivre, tout empreint de traditions épipaléolithiques.

Vers le septième millénaire, le Sahara est culturellement précoce par rapport au Maghreb mais sans doute pas par rapport au Nil; d'autre part, vers le troisième millénaire, il est climatiquement bloqué sans qu'aient pu s'étendre les mutations capitales qui se manifestent sur le bassin méditerranéen. L'Atlas saharien joue alors le rôle de refuge au Nord, le Sahel celui d'une terre d'asile au Sud; çà et là se constituent des îlots auprès des points d'eau, comme une préfiguration des oasis-jardins. Pas de Nil ici, pour que naissent ces longues bandes de terres cultivées. Il faudra attendre l'arrivée du métal, du cheval.

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8

Saharan climates in historic times

Climats sahariens aux temps historiques

Lors du Néolithique, il y a cinq ou six mille ans, les climats des bordures méridionales et septentrionales du Sahara, ceux du Sahara même, et ceux de l'Afrique orientale ont été bien plus pluvieux qu'à l'époque actuelle. Cette période s'est achevée vers 5 000 ou 4 000 ans B.P., lorsque la tendance vers l'aridité actuelle a commencé. Les conditions climatiques en Afrique ont été relativement stables durant les derniers deux mille ans, et les fluctuations peu importantes par rapport à celles du Néolithique et du Pléistocène. Mais il y a eu pendant ces deux millénaires des épisodes où les climats de l'Afrique ont été assez différents de ceux d'aujourd'hui. Un épisode récent se situerait aux XVI, XVII et XVIII siècles; et serait donc contemporain avec une période de refroidissement aux hautes latitudes boréales (petit âge glaciaire). A cette époque, les régions sahélienne et soudanienne (zones semi arides au sud du Sahara), et probablement la côte méditerranéenne de l'Afrique du Nord, ont connu des climats plus humides comme au Néolithique, mais certaines régions de l'Afrique orientale ont été plus arides que maintenant.

Le caractère de cette période de pluies plus abondantes au Sahel a été reconstruit à partir des vestiges des anciennes limites des lacs et des cours des fleuves, des chroniques des peuples africains, de l'archéologie, et des témoignages historiques. Les crues du Niger étaient plus fortes qu'actuellement, le lac Tchad était bien plus étendu, et les populations de la boucle du Niger et de Bornu (Tchad) connaissaient une période de 'grande prospérité' (d'après les chroniques) marquée par l'absence de famine et de sécheresse. Quelques régions du Tibesti, et probablement du Niger et du Soudan, qui sont actuellement peu hospitalières en raison de l'aridité, étaient alors peuplées. Les voyageurs européens ont décrit un paysage verdoyant au nord de Darfur (Soudan), où la pluviosité n'atteint que 250 à 300 mm par an aujourd'hui, et une abondante végétation tropicale au Sénégal où une forêt occupait les rives du fleuve Sénégal dans une région qui reçoit actuellement 200 à 250 mm par an.

Cette période humide au Sahel a pris fin au cours du XVIII siècle. Le début de la dégradation a été marqué par une grande sécheresse aux environs de 1681 à 1687, dont on trouve des témoignages en zone sahélienne du Sénégal jusqu'au Soudan. Puis l'assèchement de cette région a entraîné une grande sécheresse de 1738 à 1756 environ qui a ravagé toute la zone sahélo-soudanienne. Néanmoins, les conditions climatiques au XVIII siècle se rapprochaient davantage de celles des deux siècles précédents que de celles du siècle actuel. A la fin du siècle il y eut une améliora-

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tion passagère avec de grands débordements du lac Tchad et des inondations dans les régions désertiques du Niger (à Agadez) et de la Libye (près de Murzuq). A partir de 1800, la tendance à l'aridité, qui avait commencé une centaine d'années auparavant, s'est accélérée, culminant en grande sècheresse dans les régions sahéliennes et soudaniennes et au Sahara de 1828 à 1839 environ, et produisant l'assèchement partiel du lac Tchad.

Les conditions climatiques du XIX siècle ont été en général proches de celles du siècle actuel, mais à partir de 1870 environ le climat en Afrique boréale est devenu encore plus humide. Une période de pluies bien plus abondantes, qui a duré une trentaine d'années, a affecté le Sahel entier, la zone soudanienne, le Sahara central et les bordures septentrionales du désert, la côte méditerranéenne de l'Afrique du Nord, et toute l'Afrique orientale. Une pluviosité en hausse s'est manifestée par de grandes transgressions des lacs dans toute l'Afrique orientale (de l'Ethiopie au Mozambique) et au Tchad, par des crues fortes du Niger et du Sénégal, par une prospérité agricole et des récoltes exceptionnelles dans la boucle du Niger et au Sahara central, et par une augmentation marquée des pluies mesurées dans ces régions.

Ces conditions se sont achevées vers 1895 ou 1900, lorsque les sécheresses sont devenues bien plus fréquentes. Les lacs ont baissé rapidement, et les crues des fleuves sont devenues bien plus faibles. Une longue période de sécheresse et de famine, résultant de cette diminution des précipitations, s'est installée de 1910 à 1920 environ, comparable à la sécheresse de 1968 à 1973. Vers 1920, les conditions climatiques dans les régions affectées auparavant par la sécheresse se sont améliorées et jusqu'à 1950 environ les fluctuations du régime pluviométrique ont été peu importantes. Mais les conditions marquées par des pluies plus abondantes, qui ont caractérisé les XVI, XVII et peut-être XVIII siècles, puis la fin du XIX siècle, n'ont jamais reparu au siècle actuel.

En ce qui concerne les conditions météorologiques des périodes humides (du XVI au XVIII siècle et de 1870 à 1895 environ), il semble que le Front Inter-Tropical (FIT, ou en anglais ITCZ), zone de convergence qui sépare le vent (NE) aride du désert du vent (SO) humide du Sud, était déplacé au nord de sa position moyenne actuelle. Comme la saison des pluies commence et prend fin en fonction du mouvement de cette zone de convergence, un déplacement du FIT vers le Nord se manifesterait par une saison des pluies plus longue au Sahel et à la bordure méridionale du Sahara, donc par une augmentation de la pluviosité. Il semble que ces conditions plus humides ont régné en même temps en Afrique septentrionale. Une explication possible est un déplacement vers l'Equateur des cyclones méditerranéens qui traversent l'Afrique septentrionale en hiver. Mais cette explication est trop simple. Il faut considérer aussi les systèmes météorologiques à plus petite échelle (synoptic-scale), comme par exemple les dépressions sahariennes qui produisent des précipitations au Sahara et sur ses bordures au printemps et en automne.

8.1 INTRODUCTION

Other chapters in this volume have shown that during the Neolithic (c. 6 000-5 000 B.P.) the climates of both the tropical and temperate margins of the Sahara, the Sahara itself, and eastern Africa were considerably wetter than at present. At the end of this period, about four or five thousand years ago, a major change of climate occurred throughout Africa, and a trend began toward conditions approaching those of present. The past two millennia have been climatically relatively stable, as fluctuations within them have been small in comparison with those of the Pleistocene and early Holocene. There were, however, several episodes within the past two millennia in which the climate of

various parts of Africa was significantly different from that of present.

A very recent such episode occurred in about the 16th, 17th and 18th centuries, and was probably synchronous with a period of glacial advance and frequent severe winters in the higher latitudes (especially in Europe) generally referred to as the 'Little Ice Age'. The climate of Africa during these centuries was somewhat analogous to that of the Neolithic, in that there was increased rainfall along the tropical margin of the Sahara (including parts of eastern Africa) and in the desert, and possibly also in North Africa. There may, however, have been decreased rainfall in parts of equatorial East Africa. These conditions were well-established by the mid-16th century and lasted until at least the late 17th century. A decline began towards 1700 but the 18th century as a whole probably resembled the preceding two centuries more than the present. By the 19th century, a climate similar to present had been established, although a brief return to more humid conditions occurred in two or three decades of the late 19th century.

Evidence of this period of increased precipitation several centuries ago comes from many sources. We will begin here by looking at some of the longest records: lake-level fluctuations, the Nile, and two regional climatic chronologies based on several types of evidence. These will be complemented with information from famine and drought chronologies from northern Algeria, a region dependent on winter rains of Mediterranean origin, and from areas in the Sahel and Sudan zones, the semi-arid regions south of the Sahara which depend on summer tropical rains associated with the Intertropical Convergence Zone (ITCZ) (Figure 8.1). Added to this information will be geographical and climatic descriptions found in historical sources, and occasional meteorological observations. In Figure 8.1, the locations of various places cited in the text are superimposed upon a rainfall map of Africa which also depicts the position of the Sahara.

8.2 LONG-TERM CHRONOLOGIES

The few available long-term chronologies are depicted in Figure 8.2. Only the fluctuations of Lake Chad have been well-dated radiometrically, but the dating of the fluctuations of the Nile is also accurate, as year-to-year records are available. The climatic chronologies for Senegal and Mauritania are also historically dated. The chronologies for Lakes Abhé and Rudolf are more speculative.

The curve for Lake Chad is from Maley (1976) and is presented in revised form in Chapter 6 of this volume. It is of first order importance because of the accurate radiometric dating; and thorough studies of this lake, based on analysis of both sediments and pollen, have clearly established that from about 1600 until some time in the 18th century the surface of Lake Chad was about 4 m above the present mean level (within the 20th century, the lake never stood more than 1 m above this mean). This suggests increased precipitation in the Chad Basin (Niger, Chad, northern Cameroon, Central African Republic), including the more humid Sudano-Guinean zone as well as the semi-arid Sahel and Sudan.

Further east, Butzer (1971) found evidence of a recent higher stage of Lake Ruldolf, on the border of Kenya and Ethiopia. Radiometric dating of its fluc-

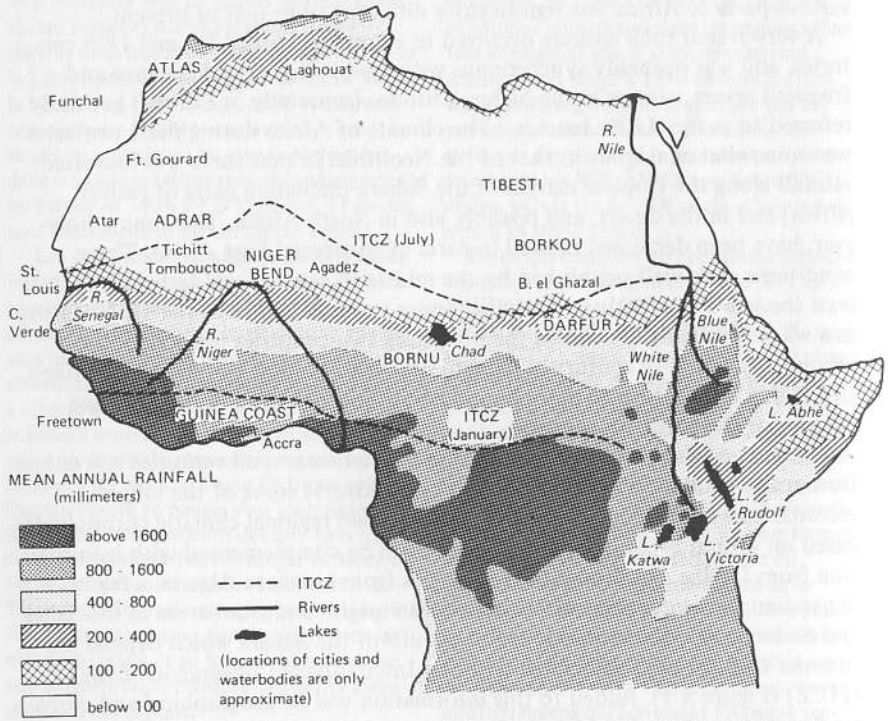


Figure 8.1 Map of mean annual rainfall in Africa (based on Trewartha 1954), including the location of the ITCZ and various geographical locations mentioned in the text.

tuations is lacking; rather he dates its recent evolution on the basis of estimated time of formation of geomorphological features. According to his 'short' (i.e. minimum time necessary) chronology, this stage would have lasted from about 1680 to 1765, but according to the 'long' chronology (the more likely one) this stage, in which the lake stood about 8 to 15 m above its 20th century mean, lasted from about 1545 to 1695. In any case, this transgression would have taken place in about the 16th to 18th century. Throughout most of the 19th century, the surface of the lake was low, but in the late-19th century the lake rose, and until about 1895 stood again about 8 to 15 m above the 20th century mean; then the surface fell 15-20 m before reaching its present level.

The studies of Gasse (1975) show a final, recent transgression of Lake Abhé in the Afar, which was dated to 110 ± 50 B.P. Six dates all fall within this range and, although radiometric dates as recent as this are subject to considerable error, the accuracy of them is convincingly shown by several points of evidence, including total isotopic analysis of the carbon and historical witness. It cannot be firmly established when this transgression began, but evidence suggests that, after a regression of the lake which began toward 1 000 B.P., a final transgression of the lake occurred within the past few centuries and ended abruptly in the late 19th century. Gasse (1975) presents no evidence for the continuity of

this higher stage. Thus it seems possible that a trend similar to that of Lakes Rudolf, Stefanie, and various other East African lakes also characterized Lake Abhé: lower levels throughout most of the 19th century, but a return to higher levels from about 1860 to 1895 (Nicholson 1976). No traces of such a transgression were found in other lake basins of the Afar or in the Danakil depression; thus the one evidenced by Lake Abhé must be attributed to a climatic fluctuation affecting only the Ethiopian plateau and/or escarpment (Gasse 1975).

A recent transgression of Lake Katwe, a self-contained salt lake lying in a crater at the foot of the Ruwenzori (Uganda), was dated radiometrically to 250 ± 150 B.P. (van Zinderen Bakker & Coetzee 1972), with earlier transgressions dating to c. 900 B.P. and 1 200 B.P. Thus, the fluctuations of this lake are similar to those of Rudolf and Abhé during earlier centuries.

It should be pointed out that the higher lake levels of the 16th and 17th centuries occurred during a period of glacial advance in the Ruwenzori (De Heinzelin 1962) (17th and 18th centuries) and of lowered snowline in Ethiopia (Hövermann 1954) (late 16th and early 17th centuries). A lowering of temperature alone, however, could not account for the increased volume of water in the lakes discussed above.

The levels of the Nile shown in Figure 8.2 are related to precipitation in the Ethiopian highlands and in Uganda. From 600 A.D., the levels (50-year means) were calculated from the levels of the Nile recorded at the Roda gauge at Cairo and reported by Toussoun (1923). Both the flood level and minimum level were recorded annually, but there are gaps in the record. Historians have criticized this record on several grounds; these include, for example, falsification of the records for revenue purposes, as taxes paid to the state were levied according to flood height; silt accumulation in the gauge; and change of the length of the 'cubit'. However, there is geological and archaeological evidence which suggests that the data presented by Toussoun is indeed accurate (Nicholson 1976). The height of the flood, which is dependent on rainfall in the Ethiopian highlands, implies increased precipitation there in 16th through 18th centuries, and again in late 19th century, thus supporting the conclusion of Gasse (1975), based on the fluctuations of Lake Abhé.

The minimum levels of the summer Nile, however, show the opposite trend, being very low in 16th through 18th centuries. As the flow of the summer Nile is determined by outflow from Lakes Victoria and Albert, hence on the rainfall of equatorial East Africa, a trend toward low summer minima in these centuries is somewhat inconsistent with the regime of increased precipitation suggested by Lake Katwe for that region and by Lake Rudolf for northern Kenya and the southern Ethiopian highlands. There might be several explanations for this. First of all, one cannot neglect the possibility that the summer Nile minimum levels recorded then, admittedly sparse, are either inaccurate or unrepresentative of the entire period. Secondly, more local factors may have had important effects on climatic fluctuations in these various regions of eastern Africa. Lake Katwe, for example, lies on the border of the tropical rain-forest, and may be subject to different climatic influences than the areas near Lakes Victoria and Rudolf. Furthermore, a nocturnal thermal circulation enhances precipitation over Lake Victoria (Flohn & Fraedrich 1966); the lower temperatures of this

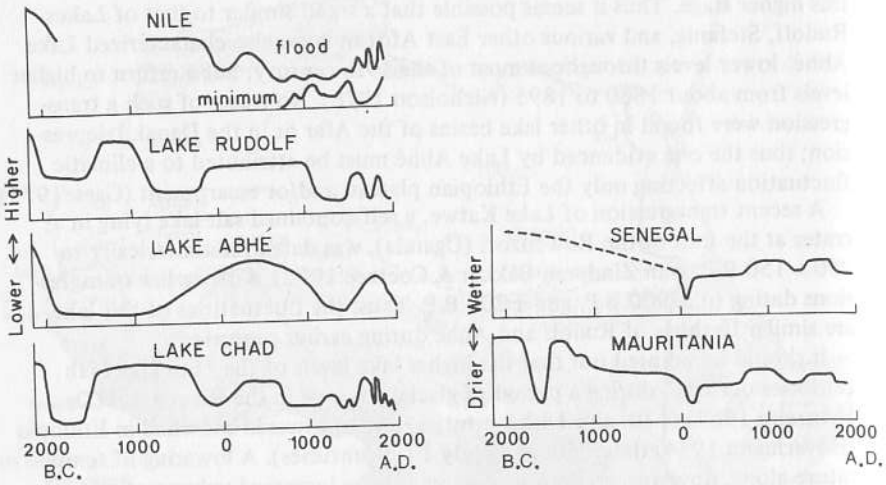


Figure 8.2 Fluctuations of lake levels and climate in Africa during the last 2 000 years.

period, suggested by the glacial advances in the Ruwenzori, would tend to decrease the strength of this circulation, hence the amount of precipitation thereby produced. Another more local factor to be considered is the effect of high Nile floods (determined by the flow of the Blue Nile) on the volume of water in the White Nile, which determines the summer minimum level. High floods, by barricading the flow of the White Nile, increase the evaporative losses from this latter river, thereby decreasing the volume of the summer Nile flow. Thus, the high floods of the 16th through 18th centuries may have had some effect on the minimum, but this could probably not totally acount for the change, as both flood and minimum stage were high in the late 19th century.

The long-term fluctuations of precipitation in Senegal and Mauritania (Figure 8.2) aiso suggest increased precipitation in the 16th through 18th centuries. The curve for Senegal is based on the work of Michel (1973), that for Mauritania has been compiled from the works of several authors, including Munson (1971), Toupet (1973), Chamard (1973), Daveau (1965, 1969), Michel (1973), and Rognon (1974). The evidence for these trends, mostly historic or archaeologic, are discussed fully in a later section.

The long-term chronologies just discussed suggest that in Ethiopia and at least parts of equatorial East Africa, in the Chad Basin, and in the western Sahel the climatic conditions of the 16th and 17th centuries were wetter than those of present day. A decline began some time around 1700, but these more humid conditions probably extended well into the 18th century. By the early 19th century, however, the climate of these regions was probably as arid as now, but a return to more humid conditions occurred in the late 19th century. The rest of this chapter will be devoted to showing the generality of these trends throughout large parts of Africa. The next two sections, looking respectively at famine/drought chronologies and geographical descriptions, further

support the hypothesis of a more humid period in the 16th, 17th, and at least part of the 18th century. The fifth section deals with a climatic decline which began in the 18th century, discussing several major droughts which occurred about that time. The sixth section deals with a return to wetter conditions in the late-19th century, and incorporates actual meteorological measurements along with the other sorts of information used previously.

8.3 FAMINE/DROUGHT CHRONOLOGIES AND OTHER INFORMATION IN CHRONICLES

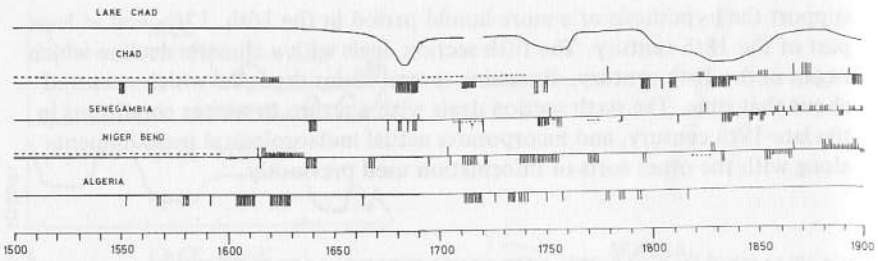
In Africa, the simple presence of extensive 'empires' south of the Sahara or in its southern regions, such as the Hausa States in northern Nigeria or the Songhay Empire of northern Mali, during at least the early part of the 'Little Ice Age' is sometimes taken as evidence of a climate more humid than today (Brooks 1970). The famine and drought chronologies derived for western Africa (Nicholson 1976) support such a supposition (Figure 8.3). The information available for Chad, Senegambia, the Niger Bend, and Algeria suggests a noteable absence of famine and drought throughout the 16th century and, until about 1680, only infrequent famines in the 17th century.

8.3.1 *Niger Bend and Senegambia*

The chronicles of Tombouctoo and the Niger Bend area describe the 16th century in broad terms, but mention essentially every year from the early 17th century through the 19th century. Cissoko (1968), who reviews these chronicles, speaks of the great prosperity of the Bend which the chronicles described during the 16th century; conditions in the Bend at that time were so good that famine simply 'could not break out'. Rather, he continues, misery was brought on by the plague, which in itself, if bubonic plague, might indicate conditions wetter than today (Nicholson 1976).

Although Cissoko may be colouring the descriptions of those times in order to show how good conditions were before the Moroccan invasion (Vansina 1976, personal communication), flood descriptions in the chronicles give support to his argument. Tremendous floods are dated to 1592 (Schove 1968) and 1616 (Cissoko 1968), and in 1618 there was very abundant precipitation (Cissoko 1968). A flood in Kabara in about 1640 (Barth 1965) converted into a lake the central part of a town called Bagindi. In the period 1618 to 1639 the Bend experienced good floods 'once again' (following a drought in 1617) at Tombouctoo: apparently the flood normally reached Tombouctoo around the 17th century. Today that city is usually separated from the Niger by 7 km of sand, and a flood reaching it would be exceptional under present conditions. Only once in the 19th century did the flood reach Tombouctoo, although the floods of the Niger in the late 19th century were generally much higher than those of the 20th century.

For Senegambia (Figure 8.3) the famine/drought chronology, until c. 1850, is based primarily on the work of Curtin (1968), whose sources are colonial



Exceptionally high floods
Above average rainfall
Period of general prosperity according to the chronicles
Below-average rainfall
Famine and/or drought
Period of generally low precipitation or drought

Figure 8.3 Chronology of famine and drought in Chad, Senegambia, the Niger Bend, and northern Algeria, 1500 to 1900.

reports found in government documents and archives and reports of European travellers in the area. No famines or droughts are mentioned before 1640, but this may be due to a lack of information. Curtin does, however, suggest that the 16th century was characterized by increased rainfall (with respect to present) in Senegambia and southern Mauritania. This will be examined in more detail later. Except for the drought c. 1640, the 17th century in Senegambia was also relatively free of famine and drought, but they occurred relatively frequently in the 18th century until about 1775.

8.3.2 *The Bornu Chronicles (Lake Chad area)*

The Bornu chronicles (Urvoy 1949) begin well before 1500, but from about that time on the conditions of the reign of each king are described in detail. Unlike the chronicles of the Niger Bend, where the Muslim calendar was used, dating of reigns was a problem here; and the works of several historians were used to provide the best estimate of dates (Nicholson 1976). Despite this problem, these chronicles are useful in deriving chronologies of famine and drought and 'prosperous' periods, providing information which is in good agreement with the rainfall changes suggested by the variation of Lake Chad.

Urvoy (1949) describes all of the reigns of the 16th century at Bornu as 'peaceful and prosperous', although occasional minor famines are mentioned under two rulers. Of course, 'prosperity' does not necessarily refer to agriculture and such description is highly subjective and subject to 'artistic license' on the part of the chronicler, but it can probably be taken to mean that during these periods no major famines or similar hardships occurred. This is especially true when the chronicler goes into great detail (as the Bornu chronicles sometimes do) in describing a reign and its events, including agriculture, the rainy season, etc.

The 'prosperous' conditions lasted until the major famine of the 1680s, but conditions apparently improved for a time after this: there was an absence of famine until the mid-18th century and the reign of Hadj-Hamdun, for example, from c. 1726 to 1738, is described as one of peace, prosperity, and even attention to learning and scholarship. From about 1790 conditions worsened and several famines occurred in the Bornu area in the early to mid-19th century.

Thus, one might conclude from the chronicles that the climate of Bornu was more humid than today during the 16th century and most of the 17th century. They do not, of course, provide very conclusive evidence, but they do help to support other types of information which also suggest this.

8.3.3 *Algeria*

A climatic trend similar to that of Chad and the Niger Bend is seen for Algeria, according to the famine and drought chronology (Figure 8.3), which applies principally to the coastal areas and the major cities such as Oran, Constantine, and Algiers. This information is derived principally from the thesis of Marchika (1927), who chronicles the occurrence of plague there from c. 900 A.D., including information on the occurrence of famines and droughts as well.

From 1500 to 1550, no famines or droughts were reported in Algeria; rather, it was the plague which occurred frequently during this period. There were occasional famines from 1550 to 1600, and a major period of famine from 1602 to 1629, but the period 1630 to 1710 was free of famine and troubled by frequent outbreaks of the plague (Marchika 1927). Throughout the 18th century, however, famines were very frequent. Information for the 19th century is inconclusive, as Marchika's (1927) plague chronology lacks detail after 1800.

Marchika's information on plague is also useful as it may in itself be an indicator of more humid conditions (Nicholson 1976). First of all, there is a high negative correlation, over several centuries, between the frequency of occurrence of famine/drought and plague. Furthermore, such a relationship might be expected, as it is an Asiatic disease of non-desert climates: the frequency of occurrence of such climatically-bound diseases does change as the climate fluctuates. The plague chronology is also useful in showing that the non-occurrence of famine during a particular period is not due to a general dearth of information covering the period.

8.3.4 *Summary of information from famine/drought chronologies*

Summarizing from the four famine and drought chronologies in Figure 8.3, a broad trend becomes apparent which is consistent with the climatic fluctuations suggested by lake-level variations discussed in section 8.2. There were prosperous conditions and very infrequent famines and droughts until at least 1680, when a general decline began which lasted throughout the 18th century. A major drought which occurred c. 1681 to 1687 (Nicholson 1976), may mark the beginning of a major change toward conditions resembling those of today. There are, however, geographical descriptions and other points of evidence, discussed in the next section, which suggest that climatic conditions for the 18th century, as

a whole, were probably wetter than today along the southern margin of the Sahara and possibly along its northern borders as well.

8.4 GEOGRAPHICAL DESCRIPTIONS

Geographical descriptions, found mostly in the reports of various European travellers and settlers, and in various historical sources, complement the information provided by the fluctuations of various lakes and by the chronicles of local African peoples. They not only similarly suggest a more humid climate in the 16th and 17th centuries, they also provide significant evidence that these conditions lasted throughout the 18th century, although a decline had begun toward 1700 and the 18th century was plagued by several severe famines. In some cases, direct climatic and meteorological observations are made and presented in such sources.

8.4.1 *Chad*

The hypothesis of wetter conditions in the Chad area several centuries ago, suggested by the variation of Lake Chad and information in the Bornu chronicles, is further supported by historical and archaeological evidence. This evidence includes the occupation of Tibesti from 1500 to 1700 and rapid depopulation towards 1700 (Plote 1974). Maley (1973) also suggests a relation between climate and migrations in the Tibesti area in the 17th and 18th centuries: the massif attracted nomads from drier areas such as the Fezzan and the Kufra area, and peoples already occupying certain wetter valleys of the area were able to disperse into areas previously too arid for grazing. Chapelle (Maley 1973) reports that the elders living in Tibesti retain a memory of an earlier time in which the massif was wooded (maximum precipitation in the area today is on the order of 100 mm annually): if this memory is factual, it may be synchronous with the 17th century transgression of Lake Chad and the wetter Sahelian conditions about that time.

It is uncertain how long these more humid conditions may have lasted in the Chad area, but several points of evidence suggest they may have characterized at least part of the 18th century. Maley's (1976) chronology of Lake Chad shows a return in late 18th century to higher lake levels similar to those of the previous two centuries, after a fall of lake levels during the severe drought of mid-18th century. Reportedly (Plote 1974) in about the 1780s or 1790s it was still possible to travel by boat as far north as Borkou, by way of the lakes of Djourab and Borkou (relevant here also are floods in about the 1780s at Agadez and near Murzuq, although, admittedly, these might only be singularities). Such a route would indicate complete flooding of the presently dry Bahr el-Ghazal valley. Flooding of this valley is also suggested by sedimentary strata recently deposited in the Bahr (Servant in Shaw 1975). Bones of hippopotami and elephants were found in these strata and radiometrically dated to c. 140 ± 90 B.P. Browne (1799), who resided in Darfur from 1793 to 1796, also mentions a forest near the Bahr el-Ghazal and talks of a small river which runs into it near Bornu: this would similarly suggest flooding of that now-dry valley in the 18th century.

8.4.2 *Sudan: a description of Darfur*

Looking further into conditions in the eastern Sahel, we have Browne's (1799) description of the rainy season at Darfur during his residence near Kutum in the 1790s. The rains normally fell from mid-June to mid-September 'in greater or lesser quantity, but generally both frequent and violent, suddenly investing the face of the country, till then dry and sterile, with a delightful verdure'. Except where the soil is too rocky, he explained, wood 'is found in great quantity'. One would not now expect such a description of northern Darfur, where he resided: Kutum and El Fasher now receive 320 mm and 288 mm annually. Furthermore, the rainy season is presently limited in most years to July and August. Brown (1799) made several other observations which might, upon further investigation of the present geography of the area, prove to be relevant here. He talks of the area where he resided (Cobbé, which he says is situated at 14°11′N, 28°8′E), and says that during the rainy season the city is surrounded by wadis and torrents, which intersect the country in all directions, and that during the dry season there are no lakes, rivers, or marshes in the area. He also makes note of wooded country at 28°E, 15°N (in fact, Cobbé is located at 14°E).

8.4.3 *Radiocarbon dates of historic age in Niger, Sudan and Ethiopia*

Radiocarbon dates of historic age may indicate that a more humid climate reigned in the central and eastern Sahel a few centuries ago. M.A.J.Williams (1975, personal communication) referred to wood charcoal samples at sites in Niger (from fireplaces in situ), the Sudan and Ethiopia dated as follows:

1. Niger – in Waggeur (16°N, 7°E) 155 ± 70 B.P. (N-2130)
2. Niger – in Waggeur (16°N, 7°E) 225 ± 60 B.P. (N-2131)
3. Niger – Janjari (15°N, 6°E) 335 ± 60 B.P. (N-2129)
4. Sudan – Gezira, White Nile (15°20′N, 32°20′E) 220 ± 85 B.P. (SUA-213)
5. Ethiopia – Metahara (10°53′N, 39°52′E) 225 ± 80 B.P. (I-7968)

All of these sites are presently semi-arid and seasonally grazed, but are generally not attractive for occupation. Except for the fourth site, there is no permanent water at any of them; none are now settled, but they were occupied during Neolithic and earlier times. These findings may suggest at least temporary occupation around now-defunct or ephemeral waterholes towards 150 to 350 B.P. (M.A.J.Williams 1975, personal communication) but further investigation is needed to confirm this.

8.4.4 *Senegal and Mauritania*

There is evidence to suggest that farther west in Africa the climate was more humid than today during the 16th, 17th and perhaps 18th centuries. Michel (1969) refers to this period as a last 'pluvial' in Senegal. Waterways and former mouths of the Senegal delta which were navigated by the Portuguese in approximately the 16th century were not blocked by sand until the end of the 17th or the beginning of the 18th century: this also indicates that a climatic decline began about the time of the 1680s famine.

Chambonneau's description, from 1677, further supports the hypothesis of a more humid climate in Senegal and at least southern Mauritania in the 17th century; he reported thick mangrove stands and palm trees along the banks of the Senegal and in its valley from Saint Louis to Cape Verde (Chamard 1973). Despite the blockage of the mouths of the Senegal and other waterways towards 1700, Adanson's description of Senegal in 1749-1755 suggests that the more humid conditions lasted until this time (Adanson 1759). He says the island of Sor (near the mouth of the Senegal) was bordered by a very thick wood and thorny bushes. He describes forests on the river's banks near Podor – tamarisks, redgum trees, and thorny acacias – and the thriving orange, lemon, lime and fig trees which the French planted. Vansina (1976, personal communication) says that several other sources from about this time present similar description of Senegal. Adanson's maps show certain lakes in northern Senegal and southern Mauritania which have since dried up, and a forest in southern Mauritania up to c. 18° N, where precipitation today is about 200-250 mm per year. Further mentioned is the abundance of potatoes in the wet, marshy lands near Podor.

Adanson's climatic observations may be of further significance. He mentions the great drought c. 1749, a time which corresponded to the extremely severe Sahel drought c. 1736-1758, and qualifies it by stating that the area near Saint Louis and Podor had been rainless from December to June or July: today, that is normal. Schotte, who was in Senegal for some time in late 18th century, speaks of an east wind that is extremely hot, especially when it blows in April (Winterbottom 1969). If this wind is, as I suspect, the northeast Harmattan, his statement suggests that it did not occur regularly in April, whereas today it prevails during this month.

Robert (1973) similarly suggests that the lack of protection of the buildings of Tichitt (Mauritania) from blowing sands implies that a reasonably dense vegetation cover surrounded this city several centuries ago. Naegelé (1957) similarly suggests on the basis of the city's architecture and agriculture that the area near Atar was wetter than today during the 17th century.

Reports of navigators and travellers would also indicate that the climate of Senegal and Mauritania was, in about the 16th century, wetter than today. The Portuguese explorers of the 16th century described a regime of precipitation which fell more abundantly and perhaps earlier in the year than it does today (Daveau 1969; Chamard 1973). Fernandes, speaking of the Adrar-Baffor Serra of Mauritania in c.1506-1510, stated that 'there are in the mountains of Baffor fourteen wadis which are completely dry and contain no water except during the period of tornadoes from February to May' (Daveau 1969). He goes on to describe the abundant flow in these streams during this season, and the planting of wheat, barley and millet in March by the inhabitants of this region. Today, the rare rains which reach this region are in late summer. The diary of a Dutch voyage in 1609 (van den Broecke 1950) also mentions a tornado at Cape Verde in February which supposedly sank a French ship. Rodrigues's description of the Kedia d'Ikjill area further north (near Ford Gourard) suggests that this area was also wetter than today. He speaks of its sedentary inhabitants whose food was provided by goats and donkeys and who had an abundance of water.

Today there is no perennial water source in the area and the little water in wells could not support such a sedentary population.

The above description would suggest an increase in rainfall probably associated with Saharan depressions which bring rain in the transition seasons to North Africa and occasionally produce the 'heug' rains in winter in western Mauritania. There are, however, other descriptions from Senegal and Mauritania which suggest an earlier summer rainy season there in the early 16th century (Daveau 1969), implying a more rapid northward advancement of the ITCZ in summer.

8.4.5 *Conditions in the Guinea Coast region*

Reports from the Guinea Coast, while providing no information on the amount of precipitation the area received, indicate that the annual distribution of precipitation and storms in the 17th century differed from that of today. Greenhill, who was at Cape Coast (near Accra) in the 1680s, said that the rains normally began c. 10 April (Barbot 1732). Johnson's (1974) references to famine and drought on the Guinea Coast lead to a similar conclusion: the rains were apparently anticipated in April and May, and corn was planted in March in the 17th century (Barbot also verifies this). When the rains arrived as late as May or June, which they do today and often did during the 1680s drought, they were considered 'late' and sometimes there was famine or food scarcity. The Dutch described the Gold Coast (Castle El Mina, near Cape Coast and Accra) similarly in 1602 (de Marees 1912): winter consisted of the rainy months April, May and June, when the tornadoes were also frequent, and summer was terribly dry. Around 1700 this area was similarly described by Bosman (1705) as having rains in April and May. He further stated that the rainy season was longer towards 1700 than it was in the 1680s and 1690s, when the Gold Coast apparently experienced a short climatic episode resembling the mean of today. Furthermore, Barbot (1732), speaking of the mid- to late-17th century, indicated that the tornado season there was April, May and June, in agreement with Dutch reports from 1609; today near Accra and Cape Coast it is generally March, April and May.

A brief sketch of the meteorology of the Gold Coast and semi-arid Sahel and Sudan zones will show the relevance of these changes of rainfall season along the Gold Coast. Rainfall in this entire area is governed by the northward advance (in summer) and southward retreat (in winter) of the Intertropical Convergence Zone (ITCZ) (Figure 8.1), which separates the dry desert air (with generally northeast flow) from the moisture-bearing southwest monsoon flow to the south. In general, the rains in West Africa begin only after the ITCZ has reached an area and the area lies in the deep moist layer about 500 km to the south of it. Thus, in the Sahel and Sudan zones, the length of the rainfall season is determined by the movement of the ITCZ and in general the amount of rainfall received is proportional to the length of the rainy season. In the Guinea Coast area, on the other hand, the rainy season is confined to the periods of the year in which the ITCZ is situated between about 500 and 1 000 km north of this area; there is an early rainy season in late spring and early summer, then a later one in fall. The end of the rainy season in the Guinea Coast area marks the

northward advance of the ITCZ and 'monsoon' rains associated with it. Thus, according to this scenario, an earlier rainy season along the Guinea Coast may imply an earlier northward advance of the ITCZ, which in turn would mean a longer rainy season in the semi-arid Sahel and Sudan zones and hence increased precipitation there. Therefore, the climatic description from the Guinea Coast in the 17th century supports the hypothesis of a wetter climate in the Sahel at that time.

We can also look at this in reverse. A longer rainy season in the semi-arid Sahel and Sudan zones might mean a shorter rainy season to the south of these areas, hence decreased precipitation along the Guinea Coast region of West Africa and in coastal countries from Sierra Leone to Nigeria. Winterbottom's (1969) observations at Freetown (Sierra Leone) in the 1790s suggest that this may have been the case. He regularly measured rainfall in the three years 1793 to 1795, and in each year about 2 000 mm fell. Today, in the drier parts of Freetown, the mean is 3 400 mm and was 4 800 mm in late 19th century. Of course, the accuracy of Winterbottom's measurements cannot be guaranteed, but his observations likewise show a greatly decreased frequency of rainfall, as do Matthews' (1966) observations at Freetown in 1785/86, a year in which the rains were (relative to late 18th century) extremely frequent and abundant and the 'dry season' was not as invariably dry as usual (yet much drier than today). In the late 17th century Bosman (1705) and Hillier (1697) made similar observations at Cape Coast (Accra, Ghana): nothing can be said about the quantity of rainfall but the frequency of rainfall was much lower than it is today, although the years they are referring to are supposed to have been ones with ample or excess precipitation.

8.4.6 *North Africa*

For North Africa, historical information which can be related to climate is very rare. The famine and drought chronology (Figure 8.3) suggests that at least the coastal areas of Algeria were wetter, or perhaps the rainy season was more reliable, in the 16th and 17th centuries, when the semi-arid zones south of the Sahara were wetter than today.

Rainfall measurements made at Funchal, Madeira, during the seven years 1747 to 1753, though bearing no direct relationship to conditions in northern Algeria, might help to support the above hypothesis. The annual mean for these seven years was 780 mm, compared with an annual mean today of 618, and this value seems to have been normal for the 18th century (Nicholson 1976). A very marked shift of the rainfall maximum at Funchal similarly suggests a change of the rainfall regime there: whereas today there is a small November maximum and a little rain in the months of January to March, during the years 1747 to 1753 there was a very pronounced December-January maximum.

Thus the measurements at Funchal indicate a change of the rainfall regime, increased precipitation, and a much more pronounced rainy season. Considering that both northern Algeria and Madeira are dependent on Mediterranean cyclones for their rain, and that increased penetration of cyclones into more southerly latitudes would increase precipitation in both regions, northern

Algeria may well have had more rainfall at that time also.

These measurements at Funchal, however, say something at most about the mid-18th century and cannot support the idea of a climate different from today's in the 16th and 17th centuries. Two other points of evidence suggest that a major climatic change did in fact take place in North Africa around the 16th century, but they provide no evidence that the episode which began then ended in the 18th century or differed from present conditions there. Vita-Finzi's (1969) geomorphologic studies of Algeria suggest that about 1600 a climatic change occurred involving changes in the seasonality of rainfall. Munaut's (1976, personal communication) dendrochronological studies in the Rif and Middle Atlas of Morocco also indicate a pronounced change. The specimens of *Cedrus atlanticus* he studied indicated rapid tree-growth before 1500 (i.e. increased precipitation), a marked drop of ring width between 1500 and 1600 and slower tree-growth after 1600. The drop in growth rate from 1500 to 1600 is very large in comparison with the inter-annual variability of growth before and after this period.

Other dendrochronological studies are available for northern Africa and the Sinai, but that for the former area is only speculative, as it is based on only one tree, while that for the latter area cannot be directly related to conditions in northwestern Africa, which we have been discussing. Work with a specimen of *Pistacia atlantica* from Daias de Laghouat (near Laghouat in Algeria) indicates very rapid growth from the mid-17th to mid-18th centuries (Fahn et al. 1963), a marked drop in growth rate in the mid-18th century, but increased growth late in the century until about 1800. It cannot be established that the earlier period of wide rings is not due to juvenile growth, and conclusions based on only one tree are highly speculative, but the trends shown, when viewed in terms of precipitation, are very consistent with the changes of precipitation suggested by the famine and drought chronology for Algeria (Figure 8.3) and meteorological observations in 19th century. Much further east, specimens of *Juniperus phoenica* from the north central Sinai have been used by Waisel & Liphschitz (1968) to estimate rainfall changes there from 1500 to 1900. These likewise show a very pronounced drop in ring-width sometime in the 17th century, and suggest rainfall two or three times greater than today from about 1500 to 1630 or 1680. Both these studies and the one from Daias de Laghouat suggest climatic fluctuations similar to those seen in the Sahel of tropical Africa: decreased precipitation beginning about 1700, with a possible return to wetter conditions in the late 18th century, then decreased precipitation in the 19th century, until about 1850 or 1870, and again increased precipitation from about 1870 to 1895 or 1900.

8.4.7 *Conclusions drawn from geographical descriptions and dendrochronological studies*

Geographical descriptions from the semi-arid regions south of the Sahara support the hypothesis that a period of increased precipitation occurred in these regions in about the 16th and 17th centuries. These descriptions further suggest that, despite frequent droughts in the 18th century, the climate was still generally wetter than during the present century.

For northern Africa conclusions drawn concerning this time period are more speculative. Information from northern Algeria and Madeira suggests that these areas may also have been wetter during those centuries, but that by the 19th century conditions similar to those of present probably prevailed. Dendrochronological studies from Algeria and the Sinai further support this conclusion; but those from the Moroccan Atlas suggest that, although a significant climatic change occurred toward 1500 or 1600, it was toward drier conditions in this area.

8.5 A DECLINE OF THE MORE HUMID CONDITIONS: SEVERE DROUGHTS IN THE 18th CENTURY

The information in the previous section suggests that in general the climate of the semi-arid regions of northern-hemisphere Africa was, in the 18th century, still wetter than today, although a climatic decline had probably begun in the previous century. Geographical descriptions from Senegal, Mauritania, Chad, and the Sudan provide evidence of a regime of increased precipitation well into the 18th century, as do the variations of Lake Chad and meteorological observations from several areas in West Africa. The decline of these more humid conditions is evidenced by severe droughts in the late 17th and 18th centuries.

The first of these droughts (Nicholson 1976) occurred in about the 1680s (Figure 8.4) and seems to have affected the entire east-west extent of the Sahel and Sudan zones. It is referred to in chronicles and reports from Ouaddai (Chad) and Darfur (Sudan) as a great 'seven-year' famine. This cannot be taken literally to mean seven years, as such a reference is quite common and is traditionally based on the biblical story of Joseph's seven lean years and seven fat years (Vansina 1976, personal communication), but it does imply a long and severe famine in both these areas. The Funj area of the Sudan was plagued by famine and drought from 1680 to 1692. The drought is similarly reported at Agadez (Niger), Bornu (near Lake Chad), Dahomey, Ghana and Senegambia.

Another lengthy period of famine and drought occurred c. 1710 to 1720 in Bornu, the Niger Bend area, the Cape Verde Islands and possibly Senegambia, and in northern Algeria. It was probably neither severe nor extensive, and no traces of it were found in other regions.

In the mid-18th century an extremely long and severe drought (Figure 8.5) ravaged the entire Sahel-Sudan zone of central and West Africa from the 1730s to the 1750s, supposedly killing half the population of Tombouctoo and other parts of the Niger Bend (Curtin 1975). This period of famine and drought, perhaps the most severe one ever recorded, was reported in Senegambia, Mauritania, Mali, Upper Volta, Dahomey, Ghana, Nigeria and Chad. It was accompanied by very high floods of the Nile (the highest of the entire period 1700 to 1840), implying increased precipitation in the Ethiopian highlands, and was probably synchronous with increased precipitation in northern Algeria (Nicholson 1976).

After the drought of the mid-18th century, the more humid conditions of the two previous centuries probably dominated once again until about 1795 or 1800 (Nicholson 1976). A minor famine plagued parts of West Africa in the 1770s, but it was probably very localized. For the 1780s, however, there are several indications of remarkably wet years or periods, but it cannot be shown

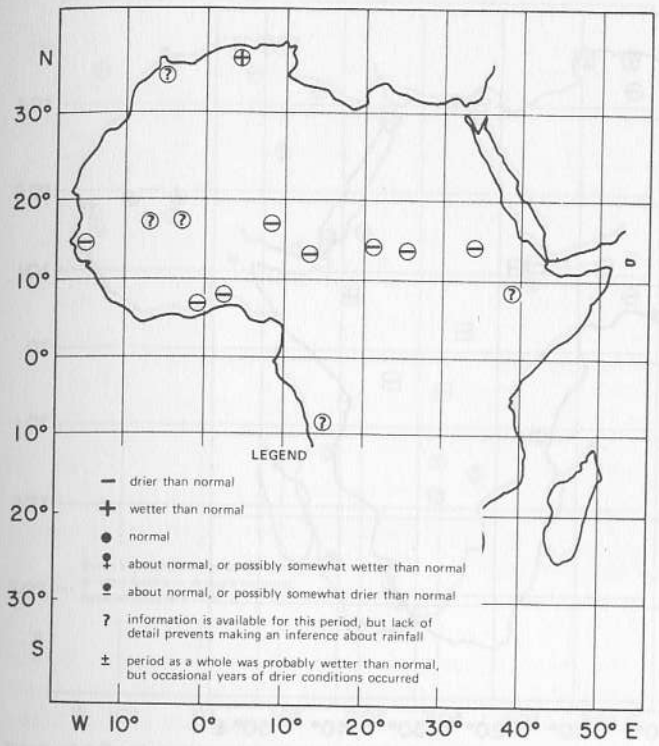


Figure 8.4 Precipitation anomaly map for 1681-1687.

whether or not these were singularities. A tremendous flood at Agadez (mean annual precipitation = 159 mm today) in Niger destroyed many buildings and ruined the town in c. 1780. According to the Asben Chronicles (Palmer 1936) 'God sent rain to Agadez from early morning until early afternoon'. In about the 1780s, a 'deep and rapid stream' flowed near Tessawa in the Libyan desert (near Murzuq), but was overwhelmed by moving sands by the end of that decade (Dalzel 1793). The now-dry Bahr el-Ghazal valley of Chad was probably flooded also at that time – recall the reports of travelling up the Bahr by canoe from Lake Chad to Borkou, Browne's (1799) report of a forest and river there, and sedimentary deposits in the valley dated to about that time.

By the end of the 18th century, however, a marked change began throughout tropical (northern-hemisphere) Africa. In the 1790s a severe drought plagued Chad, Bornu and the Kano area of Nigeria, and forced the evacuation of Agadez (Lovejoy & Baier 1975), where only a few years earlier a tremendous flood occurred, while the level of Lake Chad began to fall continuously until about the 1830s (Plote 1974). There was drought in Hausaland (Nigeria) in the late 1780s or 1790s, according to Jackson (1820), and Park (1799) reported that the rains near Bamako and Segou in 1796 did not begin until late June, whereas today they normally begin in April or May. This drought was also evidenced in

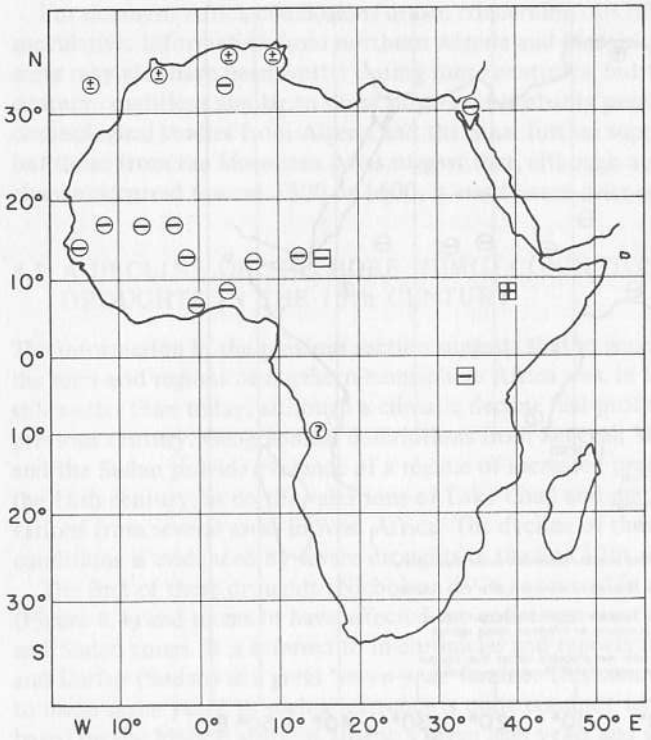


Figure 8.5 Precipitation anomaly map for 1738-1756 (legend see Figure 8.4).

the Guinea Coast region and in the Ethiopian highlands, and a drought plagued northern Algeria at that time also.

The period of drought in the 1790s seems to have begun a trend toward increased aridity which culminated in a severe drought c. 1828 to 1839. This latter drought appears to have been the climax of a dry period (Nicholson 1976) which plagued much of tropical Africa and the Sahara from the early 1820s to the 1850s or 1860s.

On the map in Figure 8.6 is indicated, in most cases, the number of years for which famine or drought was reported during the twelve-year period 1828 to 1839. Chad appears to have been the most badly affected area: in all twelve years of famine and drought were reported in Ouaddai and near the lake; and the lake was partially desiccated for the entire twelve-year period, equalling its minimum stage during the droughts of the mid-18th and early 20th century.

Other regions of drought (Nicholson 1976) include parts of Zambia, Rhodesia and Angola; Tete (Mozambique); Senegal; parts of Ethiopia; Bornu; Oualata and Takrour (Mauritania); Araouane and much of Mali; much of South Africa; and Ghat (Algeria), which was without rain for eight or ten years from c. 1835 to 1845. Tripoli and Madeira experienced below-average rainfall, and the flood

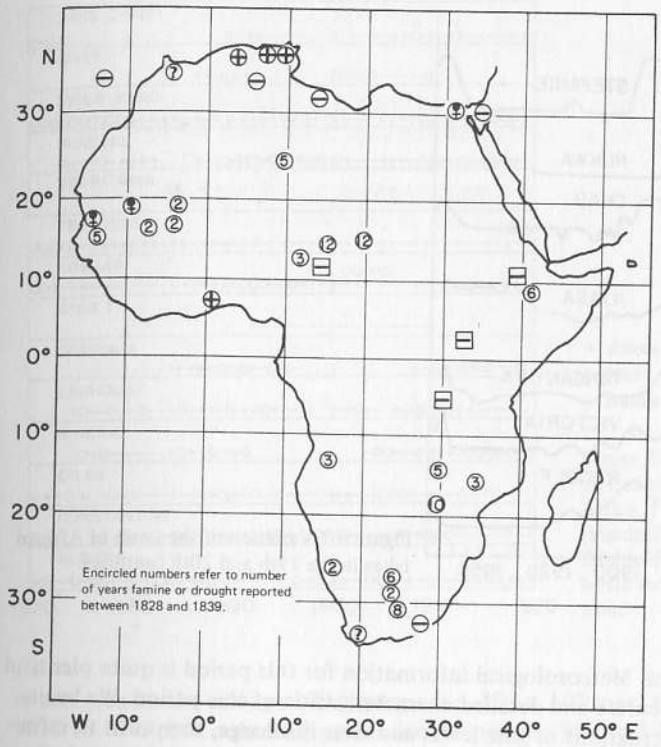


Figure 8.6 Precipitation anomaly map for 1828-1839 (legend see Figure 8.4) (Numbers plotted within circles are the number of years, during this period, that famine or drought occurred.)

and minimum levels of the Nile and the level of Lake Tanganyika indicate drought over much of eastern Africa from Ethiopia to Tanzania.

Parts of northwestern Africa and perhaps the Guinea Coast were, however, relatively wet at this time. Stations with above average precipitation include Constantine and Algiers, in Algeria, and Christiansborg, in Ghana (near Accra), where rainfall was measured for the years 1829-34 and 1839-42. Saint Louis and Cairo showed precipitation totals just above average in the early 1830s, but in 1828 and 1829 Oualata experienced a magnificent harvest, and no famines are reported during the entire period 1828 to 1839 in the Tichitt Chronicles (Marty 1927; Monteil 1939).

8.6 A RETURN TO WETTER CONDITIONS IN THE LATE 19th CENTURY

The increased aridity described for earlier in the 19th century gave way to more humid conditions toward 1870. From about 1875 to 1895 precipitation was continuously above the present normal on both the tropical and temperate margins of the Sahara, in the central Sahara, throughout East Africa, and in parts

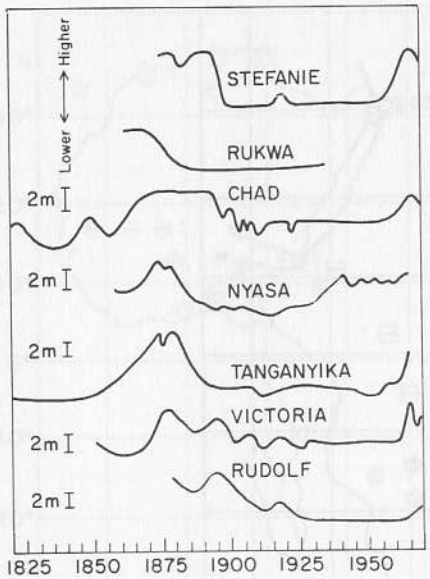


Figure 8.7 Variation of the levels of African lakes in the 19th and 20th centuries.

of northern Africa. Meteorological information for this period is quite plentiful and allows for accurate and detailed characterization of this period. We begin by looking at fluctuations of lake levels and river discharge, then turn to information derived from the chronicles and other historical sources. This includes information on harvest quality and rainfall. Finally, actual (measured) precipitation records are added.

8.6.1 *Fluctuations of lake levels and river discharge*

The recent fluctuations of several lakes are shown in Figure 8.7. The curve for Lake Chad is from Nicholson (1976). The curve for Lake Rudolf comes from Butzer (1971), that for Lake Stefanie, from Grove et al. (1975), Hobley (1914), and Butzer (1971). The curve for Lake Rukwa is also from Hobley. Curves for other lakes are derived primarily from Lamb (1966), supplemented by information in Brückner (1890) and Grove (1972).

Noteable in all curves is a tendency toward very high lake levels (several metres higher than at present) in the late 19th century, with a sharp decrease generally toward 1900, and a sharp rise again in the 1960s. This late-19th century oscillation is indicated also for lakes Magadi, Ngami and several others. The lakes continuously diminished until about 1914 (Hobley 1914). Lakes Awasa and Shala in the Ethiopian rift (Grove 1972) also appear to have been higher at the end of the 19th century than at any time since. Most of the lakes then remained stable in the 20th century until the 1960s; the level of Lake Victoria, for example, varied by only 1.5 m between 1902 and 1960.

Similar trends are seen for the Nile (Grove 1972). The annual discharge at

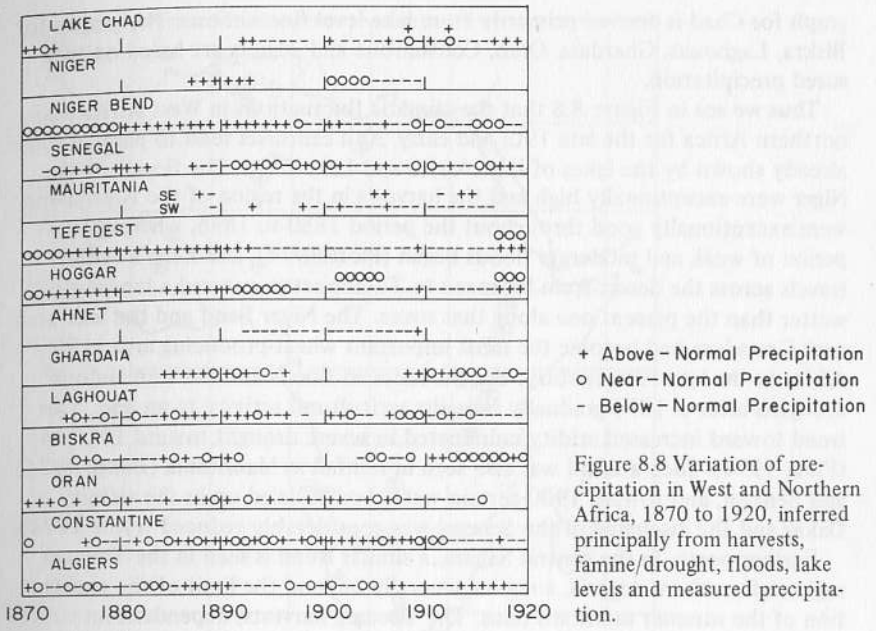


Figure 8.8 Variation of precipitation in West and Northern Africa, 1870 to 1920, inferred principally from harvests, famine/drought, floods, lake levels and measured precipitation.

Aswan was on the average 109 gigatons (i.e. 109 x 10^9 tons) for the period 1870 to 1899, but only 83 gigatons for the period 1900 to 1949. Discharge for the decade 1899 to 1908 was below the 20th century mean, thus there was a large drop toward 1900; for 1899/1900 it totalled 64 gigatons, the second lowest value ever recorded.

During the 1870s and 1880s, there was also increased discharge of the Senegal and Niger rivers in West Africa and increased stream flow out of the Atlas near Biskra (Pejml 1963; Plote 1974). As we will see in the next section, these trends are confirmed by rainfall measurements and other evidence.

8.6.2 *Rainfall in the 19th and 20th centuries in West and North Africa*

Figure 8.8 shows the period 1870-1920 for parts of West and North Africa (Nicholson 1976). The chart describes year-to-year fluctuations, with + implying wetter than normal (i.e. as known in the 20th century), 0 implying average conditions, and – indicating drier than normal conditions. Information for the Hoggar, Ahnet, and Tefedest is based on harvest quality reported by the Touareg, and the curve relates to winter rains (Dubief 1947). That for Mauritania is derived mainly from the chronicles; in the upper curve for Tichitt/Néma/Oualata years of excess precipitation refer primarily to winter rains. The graphs for Niger (near Agadez) and the Niger Bend are based on reports of harvest quality, level of the Niger flood, conditions of wells, and famine and drought. That for Senegal is based primarily on precipitation at Saint Louis, supplemented by reports of famine and drought and desiccation of certain lakes. The

graph for Chad is derived primarily from lake-level fluctuations. The graphs for Biskra, Laghouat, Ghardaia, Oran, Constantine and Algiers are based on measured precipitation.

Thus we see in Figure 8.8 that the climatic fluctuations in West Africa and northern Africa for the late 19th and early 20th centuries tend to parallel those already shown by the lakes of East Africa and Lake Chad. The floods of the Niger were exceptionally high and the harvests in the region of the Niger Bend were exceptionally good throughout the period 1880 to 1896, whereupon a period of weak and moderate floods began (Plote 1974), and Lenz's (1886) travels across the desert from Morocco to Tombouctoo covered a landscape wetter than the present one along that route. The Niger Bend and the lake area near Goundam had become the most important wheat-producing area in West Africa in the late 19th century, but the reduced floods and the tremendous droughts after c. 1896 gradually brought agricultural activity to an end. This trend toward increased aridity culminated in severe drought toward 1913-14 (Plote 1974). Such a trend was also seen in rainfall in Mauritania (Bonte 1974) and Senegal, and toward 1900 certain water bodies dried up in the vicinity of Dakar and the discharge of the Senegal was considerably reduced (Plote 1974).

Farther north, in the central Sahara, a similar trend is seen in the Touareg region of southern Algeria, a region generally beyond the limit of the penetration of the summer monsoon rains. The Touareg harvests, dependent on winter rainfall, were exceptionally good from c. 1872 to 1892, the period of high lake levels in East Africa and high Niger floods. From about 1892 the harvest quality rapidly declined, bottoming out in a long period of drought at the beginning of the 20th century (Dubief 1947). Similar trends can be seen in the rainfall (Figure 8.8) at Ghardaia and Laghouat, and to a lesser extent at the coastal stations Oran and Constantine.

By the late 19th century rainfall was being measured regularly at many stations in Africa. These records have been compiled (Nicholson 1976) and added to the information presented earlier in this section in order to draw a series of precipitation anomaly maps. Maps have been drawn for the six periods 1870-74, 1875-79, 1880-84, 1885-89, 1890-94, 1895-99 (Nicholson 1976), but only three are included here and they illustrate well the general character of the entire three decades. During the period 1870-95 there was increased precipitation throughout most of northern-hemisphere Africa, including both the tropical and temperate margins of the Sahara and the central Sahara itself (Figures 8.9 and 8.10). In East Africa, this increase was particularly marked from about 1870 to 1880, but within the 1880s (Figure 8.10) several lakes in the area exhibited sharp falls, although they were still probably above their 20th-century levels. The situation quickly reversed itself toward 1895 (Figure 8.11), and in nearly all regions studied a marked tendency toward lower rainfall culminated in severe drought c. 1910-1920 (Nicholson 1976).

The precipitation records, in addition to providing greater spatial climatic detail for late 19th century, give some hint as to the meteorological circumstances evoking increased precipitation in North Africa. In Algeria, rainfall c. 1870-1890 was not only above the 20th century average, but its seasonal distribution had also changed (Queney 1937). There was then greatly increased precipitation

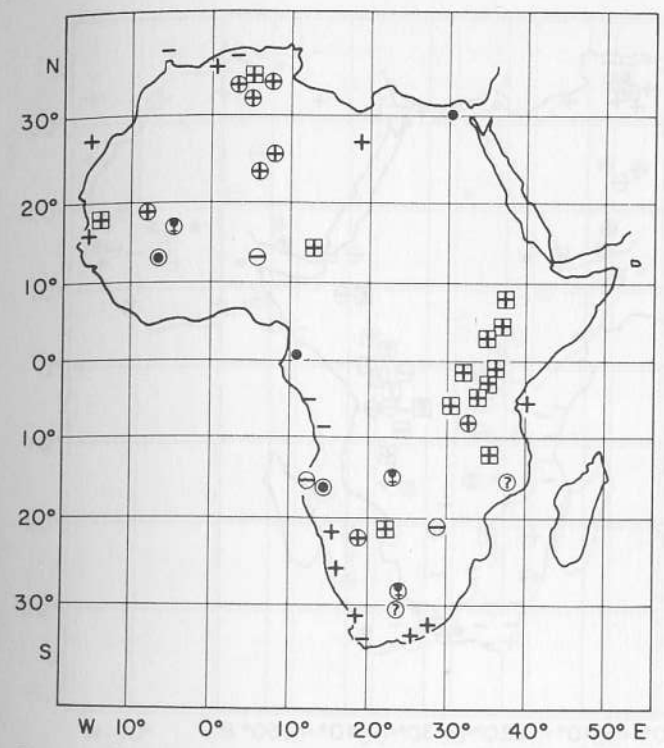


Figure 8.9 Precipitation anomaly map for 1870-1874 (legend see Figure 8.4).

in April and May in the western sectors of the Atlas. A tendency toward double rainfall maxima in December/January and March in the period c. 1860-1900 (very marked 1870-1880) contrasts with a strong, single November/December maximum in the preceeding and following periods. The double maxima c. 1860-1890 suggests a southward displacement of the tracks of Mediterranean depressions (with respect to the 20th century), but the sharp increase in April and May rains suggests that the Saharan depressions or cyclones formed in the Atlas in the transition seasons may have played a considerable role in the late 19th century.

8.7 SUMMARY AND CONCLUSIONS

Within the past few centuries there have been several periods in which the climates of northern-hemisphere Africa (particularly the semi-arid tropics) differed significantly from those of today. One such period occurred during the 16th to 18th centuries: the semi-arid Sahel and Sudan zones south of the desert were wetter than today, as was probably also non-tropical Africa, but the Guinea Coast area (Sierra Leone to Dahomey) was probably drier. Although

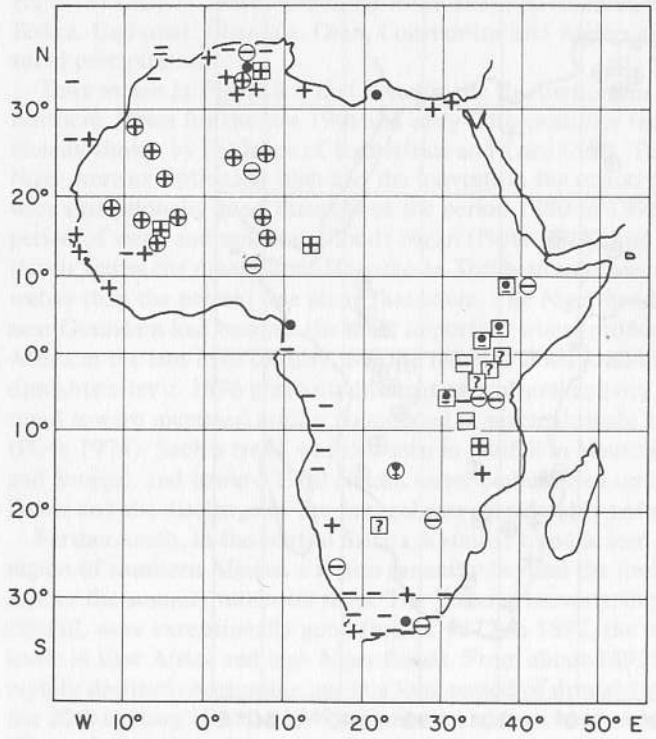


Figure 8.10 Precipitation anomaly map for 1880-1884
(legend see Figure 8.4).

several major droughts troubled the Sahel and Sudan in the 18th century, geographical descriptions of several areas suggest that in general a more humid climate still prevailed there. By about 1800, however, the present state of aridity had been reached. Late in the 19th century, from about 1870 to 1895, the more humid conditions of a few centuries earlier returned: a wealth of historical and meteorological information clearly shows that a period of increased precipitation affected both the tropical and temperate margins of the Sahara, the central Sahara, and all of eastern Africa.

These conclusions are based on a wide variety of information and data, many of which are somewhat ambiguous in their interpretation. We take for example water bodies, such as Lake Chad or the River Niger, which are regional precipitation integrators whose fluctuations may depend on rainfall from quite distant and varied areas. Good floods of the Niger, which centuries ago helped Sahelian empires to thrive near Tombouctoo, may derive from abundant rain in the Sudano-Guinean zone far to the south. The same holds true for Lake Chad, lying in the Sahel but fluctuating to a greater or lesser extent in accordance with its source waters, rivers originating in the more southern Sudano-Guinean zone. Maley even suggests that the fluctuations in these two geographical regions

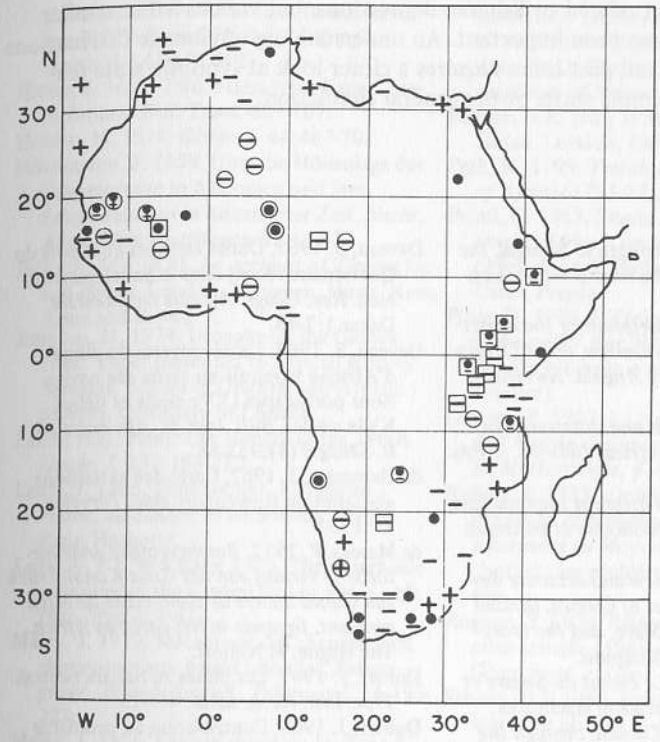


Figure 8.11 Precipitation anomaly map for 1895-1899
(legend see Figure 8.4).

are out-of-phase, that high levels of these Sahelian Lake Chad may, for example, correspond to a drier Sahel. This naturally complicates the interpretation of such proxy climatic indicators and underscores the need for extensive information deriving from numerous regions, ideally accurately dated and representative of fairly long time periods. Even in consideration of these difficulties, it is felt that the general climatic trends and anomalies described above are accurate. An extensive body of as yet unused information can prove or disprove this.

These recent climatically anomalous periods have not yet been studied thoroughly enough to allow for a meteorological explanation of the changes which occurred, but the study has suggested several conclusions about this. First of all, any meteorological explanation which is concerned with basically a simple zonal shift of climatic zones is insufficient. There are clear examples of expansion and contraction of the desert belt. Furthermore, changes in the ITCZ-related 'monsoon' rains system of West Africa and the regime of Mediterranean cyclones in northern Africa are also insufficient to explain recent climatic fluctuations in these regions. In both the period c. 1870-1895 in Algeria and in the 16th and 17th centuries in West Africa, rains in the transition seasons (unrelated to these two systems) contributed to the increased precipitation. This suggests that

changes were in part related to Saharan depressions, but various other smaller scale factors have also been important. An understanding of climatic fluctuations in Africa in recent and past times requires a closer look at synoptic scale features, rather than simple shifts of the general circulation.

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Part Two: The Nile
Deuxième partie: Le Nil

For at least 2 000 years, scholars and travellers have written and speculated about the sources of the Nile and about the link between the summer floods in Egypt and climatic conditions in the Nile headwaters. The annual rate of alluvial sedimentation in Lower Egypt aroused the interest of Napoleon's engineers, just as it had that of Herodotus some 22 centuries earlier. A related question is the antiquity of the summer flood regime, and its relation to prehistoric settlement in the Nile Valley.

The geological evolution of the Nile basin is outlined by M.A.J. & F.M.Williams, who review the tectonic history of Ethiopia, Uganda and the Sudan, after which D.A.Adamson & F.M.Williams analyse the influence exerted upon Nile drainage patterns by structural geology and both major and minor tectonic lineaments. Two important conclusions to emerge from these introductory chapters are the antiquity and importance of NE-ENE and SE-SSE trending structures throughout the Nile basin, and the close agreement between estimated volumes of material eroded from Ethiopia and deposited in the Nile cone. Furthermore, although the Nile drainage network has operated, albeit with intermittent connections, since the Tertiary uplift and rifting of East Africa, there have been significant deletions from the catchment area in western Sudan, as well as major additions to the Nile basin in Ethiopia and Uganda, all within the last 20 million years.

Butzer's detailed analysis of the depositional record left by the Nile and its tributaries in Upper Egypt shows that the influx of Ethiopian sediments into Egypt goes back to at least Middle Pleistocene times. The Upper Pleistocene record is one of alternating aggradation by a seasonally very competent Nile, and downcutting during or shortly before more arid intervals when dunes are active and local wadis cease to flow.

The phenomenally high floods evident in Upper Egypt towards 12 000-11 500 B.P. have their counterparts in Sudan, where M.A.J.Williams & D.A.Adamson have found and dated higher end Pleistocene and Early Holocene flood levels of both the Blue and White Nile rivers. Palaeohydrological models for the Holocene and Late Pleistocene Blue Nile based upon reconstructed Late Quaternary environments in Ethiopia are fully confirmed by the depositional history preserved in the alluvial sediments of central Sudan.

Further to the west, lying midway between the Nile valley and the Chad basin, Jebel Marra volcano is crucially located in the zone of transition between desert and forest, west and east, Nile and Sahara. A recent reconnaissance survey by M.A.J.Williams, D.A.Adamson and colleagues shows that conditions around Jebel Marra were significantly wetter earlier in the Pleistocene, and that during the Late Pleistocene and Early Holocene, rivers flowed south from the massif across the now dry sandplains of the Qoz Dango into the Bahr el Arab, a tributary of the White Nile.

The Late Quaternary flood history of the Nile becomes clear once we turn to Ethiopia and the Nile headwaters. In Uganda, as D.A.Livingstone points out, reduced rainfall and lower temperatures resulted in the replacement of forest by grassland during the Late Pleistocene. The level of Lake Victoria fell, as did that of Lake Albert, until both became closed basins. Overflow into the swamps of the southern Sudan did not recommence until very soon after 12 500 B.P., causing the White Nile to flood the sand dunes that had occupied its lower valley during the terminal Pleistocene. The Blue Nile also began to flood its lower valley very extensively at this time, for the climate of Ethiopia had now become very much warmer and wetter. The detailed history of lake level fluctuations investigated by F.Gasse & P.Rognon in the Afar and by F.A.Street in the Ethiopian Rift now enables us to reconstruct the history of the Nile from its headwaters to its outlet during the past 40 000 years. Once accurate radiometric dates extending beyond this range become widely available, we will be in a position to compare climatic and associated hydrological changes from the Equator to the Mediterranean during one complete interglacial-glacial cycle. Until then, our understanding of the effects and causes of long-term climatic changes will remain sketchy.

Pendant au moins deux mille ans, les savants et les voyageurs ont discuté entre eux du problème des sources du Nil et des relations entre le milieu climatique des hauts bassins du Nil et les crues estivales en Egypte. La vitesse annuelle de sédimentation fluviatile a attiré l'attention de l'historien grec Hérodote, ainsi que celle des ingénieurs de Napoléon vingt-deux siècles plus tard. Un problème qui nous préoccupe actuellement concerne l'époque à laquelle se sont amorcées les crues d'été, ainsi que les rapports entre ces crues et l'occupation préhistorique de la vallée du Nil.

M.A.J. et F.M.Williams donnent une esquisse de l'évolution géologique du bassin du Nil, et soulignent l'importance des évènements tectoniques en Ethiopie, en Uganda et au Soudan. L'influence des structures géologiques sur le réseau hydrographique du Nil à toutes les échelles spatiales est analysée en détail par D.A.Adamson et F.M.Williams. Parmi les conclusions à retenir de ces chapitres préliminaires, citons l'ancienneté et l'importance des structures NE-ENE et SE-SSE à travers le bassin du Nil, et le bon accord entre le volume total de matériel érodé par le Nil et ses affluents en Ethiopie, et celui qui a été déposé dans le grand cône du Nil. Le réseau hydrographique du Nil date du soulèvement tertiaire et du rifting en Afrique de l'Est, bien que les connexions fluviatiles entre les diverses parties du bassin aient beaucoup varié. Au cours des vingt derniers millions d'années, la partie ouest du bassin a été capturée et se déverse maintenant dans le bassin du Tchad, mais en Ethiopie et en Uganda le Nil a gagné des affluents importants.

K.W.Butzer fournit une étude approfondie des dépôts nilotiques et autochthones en Egypte méridionale. Il montre que les sédiments éthiopiens sont arrivés en Egypte dès le Pléistocène moyen. Au cours du Pléistocène supérieur, il y a en une alternance entre des épisodes de sédimentation par un Nil à forte crue et des périodes d'entaille pendant ou peu avant des phases plus arides où les dunes ont été actives et où les oueds ont cessé de couler.

Les crues tout à fait exceptionelles qui ont été datées de 12 000 à 11 500 B.P. en Haute Egypte ont été mises en évidence au Soudan, où M.A.J.Williams et D.A.Adamson ont réussi à obtenir des datations sur les hauts niveaux du Nil Bleu et du Nil Blanc au cours du Pléistocène supérieur et de l'Holocène. Des modèles palaeohydrologiques sont présentés ici pour le Nil Bleu holocène et

pléistocène. Fondés sur des reconstitutions des milieux quaternaires en Ethiopie, ces modèles se trouvent en très bon accord avec l'histoire de la sédimentation fluviatile au Soudan central.

Plus à l'ouest, à mi-chemin entre la vallée du Nil et le bassin du Tchad, le massif volcanique du Jebel Marra à une localisation assez originale entre la forêt et le désert, entre l'ouest et l'est, entre le Sahara et le Nil. Une mission de reconnaissance effectuée par M.A.J.Williams, D.A.Adamson et leur équipe montre que le climat a été beaucoup plus humide dans cette région au cours du Pléistocène inférieur ou moyen. Pendant le Pléistocène supérieur et l'Holocène inférieur des fleuves provenant du massif ont coulé vers le sud à travers les ergs fixés du Qoz Dango jusqu'au Bahr el Arab, affluent du Nil Blanc.

L'histoire des crues quaternaires du Nil devient plus claire lorsque nous passons en Ethiopie et dans les hauts bassins du Nil. En Uganda, comme le démontre D.A.Livingstone, une moindre pluviosité et des températures plus basses ont abouti à un remplacement des forêts par les graminées au cours du Pléistocène supérieur. Le niveau des lacs Victoria et Albert s'étant abaissé, ils sont devenus des bassins fermés. L'écoulement vers les marécages du Soudan méridional n'a recommencé que peu après 12 500 B.P. Le débit du Nil Blanc au cours du Pléistocène supérieur. Le Nil Bleu a inondé sa basse vallée à cette époque aussi, car le climat en Ethiopie était alors plus chaud et plus humide. L'histoire des oscillations lacustres en Ethiopie et dans le désert de l'Afar, presentée en détail par F.Gasse, P.Rognon et F.A.Street, est en parallèle avec celle du haut bassin du Nil. Elle permet donc de reconstituer l'histoire du Nil de l'amont à l'aval pour les derniers 40 000 ans. Dès que des datations radiométriques plus précises au delà de cette limite de 40 000 B.P. deviendront disponibles, nous pourrons faire des comparaisons entre les variations climatiques et hydrologiques le long d'un fuseau de longitude entre l'Equateur et la Méditerranée pendant un cycle complet glaciaire-interglaciaire. En attendant, notre compréhension des effets et des causes de variations climatiques à long terme reste encore insuffisante.

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9

Evolution of the Nile Basin

Evolution du Bassin du Nil

Ce chapitre retrace l'évolution géologique du Bassin du Nil. Celui ci s'étend depuis les bassins de réception du Nil Bleu et du Nil Blanc en Ethiopie et Ouganda, et se prolonge à travers le Soudan et l'Egypte, jusqu'au delta du Nil et la Méditerranée.

Le cours supérieur du Nil Bleu et de l'Atbara (un affluent majeur du Nil principal) trouve sa source dans les hauts plateaux d'Ethiopie, une région qui a été soumise depuis le Crétacé à un soulèvement d'au moins 2 000 m et depuis l'Oligocène à un volcanisme basaltique étendu et à des failles de rift. Les rivières du Nil Bleu et de l'Atbara doivent être plus jeunes que les roches volcaniques, oligocène supérieur – miocène inférieur, qu'elles entaillent et avoir connu sans aucun doute une histoire complexe de dérivation de l'écoulement due au volcanisme et à la tectonique, de même qu'un encaissement périodique en réponse à un soulèvement épisodique.

Le volume de roche érodé et enlevé des bassins supérieurs de ces deux rivières depuis l'Oligocène supérieur est estimé à 102 000 km^3 et le taux moyen annuel de l'abaissement de la surface de 0,015 mm durant les derniers 23 millions d'années. Un tel taux de dénudation implique de longues périodes de stabilité tectonique en alternance avec des intervalles plus courts de soulèvement.

Le soulèvement du bombement et la fracturation du rift s'initia au début du Tertiaire dans la région de l'Ouganda où se trouvent de nos jours les sources du Nil Blanc. Ce qui provoqua la dislocation d'un système de drainage probable coulant vers l'ouest. Le Lac Albert (L.Mobutu) se forma probablement au Mio-Pliocène et le Lac Victoria (avec un déversoir dans le Lac Albert) durant le Pléistocène. Une communication du drainage doit s'être établie entre le Lac Albert et le Soudan méridional à la fin du Cénozoïque.

Le Soudan connut aussi au milieu de l'époque tertiaire un volcanisme intermittent, des failles et la subsidence des principaux bassins sédimentaires, probablement reliés aux phénomènes de soulèvement et de bombement, de volcanisme et de fracturation existant en Ethiopie et en Afrique de l'Est. Au cours du Cénozoïque supérieur, alors que les rivières du Nil Bleu, du Dinder et du Rahad coulaient depuis les hauts plateaux éthiopiens jusque vers les basses plaines du Soudan oriental, un complexe de cônes alluviaux se forma, dont l'extrémité distale est représentée par la Formation Gezira. A cette époque il n'y avait pas de lien clairement discernable entre les bassins de drainage intérieurs du Soudan méridional (paléo-sudd) et le Nil principal, bien que au moins quelques cours d'eau secondaires éthiopiens puissent avoir atteint le Nil principal en traversant les plaines du Soudan oriental.

Des calcaires d'eau douce silicifiés et fossilifères ('Hudi Chert') indiquent qu'un lac, ou une série de lacs, existaient, dans ce qui est maintenant le désert de Nubie au Nord du Soudan, pendant les époques de l'Eocène supérieur et de l'Oligocène inférieur, ou plus tard, peut être alimentés par les eaux provenant du sud et de l'ouest. L'on ne sait pas avec certitude si le(s) lac(s) se déversai(en)t vers le nord à cette époque.

Au nord de la jonction des rivières du Nil

Bleu et du Nil Blanc à Khartoum, le Nil principal traverse par endroits en discordance les structures du socle, indiquant une surimposition à partir d'une couverture sédimentaire primitivement plus étendue de grès nubiens du Crétacé supérieur. Ceci implique un âge maximum crétacé supérieur pour le fleuve actuel de Nubie. L'on a des témoins de l'existence d'une rivière encore plus ancienne qui coula autrefois le long de l'axe de drainage du Nil actuel pendant et juste avant le dépôt des grès de Nubie.

La convergence de l'Afrique vers l'Europe au cours du Mésozoïque et du Tertiaire et l'abaissement du niveau de la mer correspondant à la rétension d'eau pour la formation des calottes glaciaires à la fin du Miocène provoca l'isolement de la Méditerranée. Celle-ci, soumise à une forte évaporation, devint un désert de sel de basse altitude. Le niveau de base du Nil fut alors radicalement abaissé avec le phénomène conséquent d'entaille du fleuve jusqu'à 570 m au dessous du niveau actuel de la mer près du Caire, et – 170 m près d'Aswan, à 700 km au Sud. Lorsque au Pliocène la Méditerranée se trouva à nouveau en communication avec la mer, il en résulta une pénétration de la mer dans les gorges de la vallée du Nil très loin au sud jusqu'à Aswan.

Une grande partie de la basse vallée du Nil, de même que les sources des Nils Bleu et Blanc, est controlée par des failles. L'érosion remontante le long des principales cassures et failles a sans aucun doute aidé à l'extension et à l'intégration du réseau de drainage depuis le début du Tertiaire jusqu'à l'époque actuelle.

Les analyses de pollens et de minéraux montrent que la connection entre les rivières éthiopiennes et le Nil principal se produisit au plus tard au début du Pléistocène, et que le régime hydrologique du Nil actuel était déjà établi vers la fin du Pléistocène moyen.

Des indications nettes de conditions hydrologiques plus anciennes sont rares ou absentes, de sorte qu'il faut trouver un mode de raisonnement plus indirect.

Le volume du delta du Nil est presque égal au volume estimé de matériaux enlevés par l'érosion des bassins du Nil Bleu et de l'Atbara-Tekezze dans les hauts plateaux éthiopiens. Ce qui suggère que le delta du Nil est en grande partie constitué de matériaux en provenance d'Ethiopie. La proportion de la charge sédimentaire actuelle apportée par le Nil Blanc au Nil principal est de moins de 2% de la charge en suspension annuelle totale, et il est peu vraisemblable qu'elle ait jamais été de façon signifiante plus élevée.

Les taux actuels d'érosion dans les hauts bassins du Nil sont au moins dix à vingt fois plus grands que le taux géologique moyen depuis la fin de l'Oligocène. Cette situation est sans doute due à l'érosion accélérée par l'action de l'Homme aussi bien qu'au soulèvement tectonique rapide des hauts plateaux éthiopiens durant le Pléistocène.

For over two thousand years scholars from many lands and cultures have wondered about the past and present behaviour of the Nile (see Biswas 1970; Harrington 1967). Eratosthenes of Alexandria (276-194/192 B.C.), Aristotle (384-322 B.C.) and Herodotus (484-425 B.C.) correctly attributed the annual summer floods in Lower Egypt to seasonal rainfall in the Nile headwaters. Leonardo da Vinci (1452-1519 A.D.) considered that the Nile headwaters issued from the Mountains of the Moon into three high lakes situated at about 2 000 m above sea-level, before flowing north across the desert to the sea. By 1613 a Portuguese Jesuit, Fr. Pedro Paez, had discovered the source of the Blue Nile upstream of Lake Tana. A century later Fr. Hieronimo Lobo, S.J., verified the discovery of Fr. Paez, and affirmed that the Egyptian floods stemmed from rainfall in Ethiopia (Moorehead 1972; Rzóska 1976).

Practical concern with annual variations in Nile flood levels is evidenced by the Roda Nilometer with its nearly continuous record of Nile flood levels from 641 A.D. until 1890 A.D., when the original Aswan Dam was completed (Bell 1970, 1975). Even more impressive, albeit more fragmentary, is the accurate

flood record engraved on the now broken stone Nilometer housed in Palermo Museum, which dates back to about 3 000-3 500 B.C.

Herodotus was aware, as were Napoleon's engineers 2 000 years later, that the Nile was expanding its delta and building up its floodplain at a measurable rate of roughly 1 cm a century below Cairo (Harrington 1967; Rzóska 1976). A legitimate scientific question posed by Herodotus, and by countless others since his pioneering observations of sedimentation in the Nile delta, concerns the age of the Nile as we now know it with its summer flood regime. Estimates vary from 12 000 years to over 50 000 years to possibly two million years. As always in scientific debate, argument is fuelled by inadequate information, so that interpretation of the available facts has sometimes seemed more a matter of personal preference than of reasoned evaluation of the data.

Fortunately, a great deal of new information is becoming available (see Chapters 11 and 12 in this volume), and some of the more sterile controversies are being abandoned. Detailed stratigraphic studies carried out over the past two decades in Kenya, Uganda and Ethiopia complement those from Egypt and Sudan. Geophysical work in the Kenyan, Afar and Ethiopian Rifts (Laughton 1966; Searle & Gouin 1972; Meyer et al. 1975) supplemented by geochronological and palaeoecological studies, throws new light on the age and evolution of the Blue Nile and Atbara basins, as do similar studies in Uganda (Bishop 1959, 1971) on the history of the White Nile. Deep-sea drilling and micro-fossil studies in the Mediterranean (Hsü et al. 1977), the Red Sea and the Gulf of Aden (Deuser et al. 1976) allow marine stratigraphic records to be used in conjunction with their admittedly often fragmentary terrestrial counterparts to clarify the geological history of the Nile.

The aim of this chapter is to trace the main stages in the evolution of the Nile Basin, starting with the Blue and White Nile headwaters in Ethiopia and Uganda, and proceeding seawards through Central Sudan and Nubia to Lower Egypt and the Eastern Mediterranean (see Figure 9.1).

9.1 ETHIOPIAN UPLIFT, VOLCANISM AND LAKE LEVEL FLUCTUATIONS

Table 9.1 is a preliminary attempt to summarise certain major trends in the Cenozoic volcanic and tectonic history of the Afar and Ethiopian Rifts and adjacent Red Sea. Published accounts are sometimes confusing and contradictory and interpretation of the data is in a state of flux, so that our table and the following summary are of necessity very provisional.

Before the development of the Ethiopian volcanic uplands and of the Afar and Ethiopian Rifts, the Ethiopian region consisted of Precambrian metasediments and granite intrusions capped by a relatively undisturbed horizontal sequence of mostly Mesozoic sandstones and limestones.

Uplift of the Ethiopia-Yemen region began during the Cretaceous, with the Afar forming a depression along the crest of the main swell (Mohr 1967). By Middle Tertiary time troughs had developed along the sites of the present Red Sea and Gulf of Aden (Hutchinson & Engels 1972; Mohr 1975). According to Girdler & Styles (1974) spreading of the Red Sea floor began in the Late

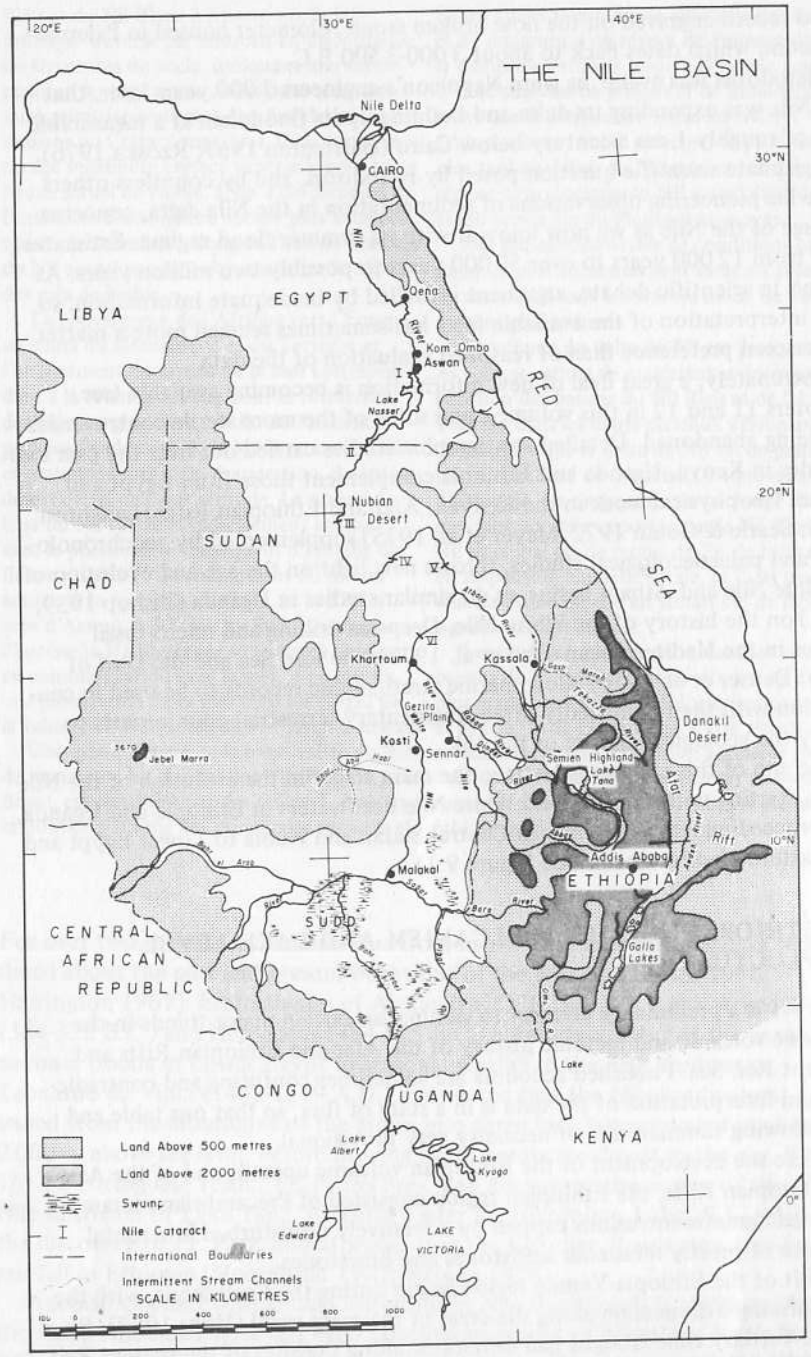
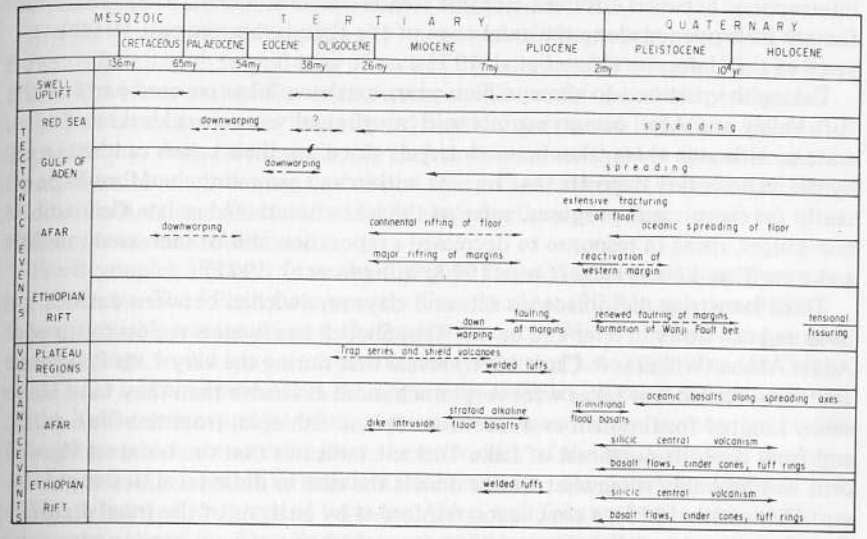


Figure 9.1 The Nile basin.

Table 9.1



Eocene, contemporaneously with a second major swell uplift, and may have occurred in two stages: the first from 41 m.y. to 34 m.y. ago, and the second from 4 m.y. to the present. Alternatively, the 41-34 m.y. age may be somewhat too old, and spreading may have continued intermittently over the past 25-30 m.y. (Gass 1977; Veevers 1977).

Major volcanism over the Ethiopia-Yemen swell began about 30 m.y. ago with the extrusion of flood basalts and related intermediate and silicic lavas (the Trap Series), the bulk of which were erupted between 25 m.y. and 19 m.y. ago (Rex et al. 1971; Jones 1976). A third phase of swell uplift and major rifting of the Afar margins began in the Early Miocene (Barberi et al. 1975). The Afar floor appears to have developed in two stages: an initial Miocene stage of continental rifting with crustal dilation, fracturing and dike injection, and a second Quaternary stage of sea-floor spreading along discrete axes (Barberi et al. 1975).

The Ethiopian proto-Rift originated as a narrow trough during the Late Miocene. The western Afar margin (or present eastern scarp of the Ethiopian highlands) seems to have developed progressively from north to south, eventually reaching the Ethiopian proto-Rift during the early Pliocene (Zanettin & Justin-Visentin 1975). Voluminous Early Pliocene ash flows erupted along the rift margins, overflowing both the proto-Rift and the adjacent plateaux (Mohr 1968).

Faulting of the Ethiopian Rift margins began in the Early Pliocene (Mohr 1975). A major episode of Rift margin and intra-Rift faulting during the latter half of the Pliocene coincided with a further phase of swell uplift, reactivation of the western margin of Afar, and a possible renewal of Red Sea floor spreading. Faulting continued intermittently throughout the Pleistocene, during which

large silicic central volcanoes formed in the Ethiopian Rift and Afar, usually at intersections between different tectonic trends (Mohr & Wood 1976). Tensional fissures have opened along the axial zone of the Rift during the past 10 000 years of the Holocene (Meyer et al. 1975).

During the past two to three million years extensive lakes covered parts of the Rift Valley and Afar, occupying tectonic troughs and volcanic calderas and craters. Although these lakes are now largely dried up, their basins can be traced by the sedimentary deposits that formed within and around them. More importantly for our present purposes, some of the lakes functioned as late Cenozoic rain-gauges, rising in response to decreased evaporation and/or increased rainfall and runoff, and conversely (Gasse 1977; Williams et al. 1977).

Thick lacustrine diatomaceous silts and clays sandwiched between dated lavas and ash flows in Afar and in the Webi Shebeli headwaters region south of Addis Ababa (Williams & Clark 1976) reveal that during the very Late Pliocene and Early Pleistocene lakes were very much more extensive than they have been since. Limited fossil pollen evidence from upland Ethiopia, from the Omo delta, and from deposits northeast of Lake Turkana indicates that the terminal Pliocene was probably somewhat wetter than is the case in those localities at present (Bonnefille 1977), a conclusion reinforced by analysis of the fossil diatom flora from the Afar lakes (Gasse 1975). It would be unwise to attach undue climatic significance to all of these early lakes, for in certain cases they may have come into being as a direct consequence of volcanic or tectonic ponding of existing drainage systems, and may have drained as a result of accelerated river erosion initiated by earth movements.

Returning to the origin of the Blue Nile and Atbara-Setit rivers, known respectively in Ethiopia as the Great Abbai and the Tekazze (see Figure 9.1), it is obvious that they must be younger than the youngest widespread rock formations into which they are entrenched, notably the Trap Series lavas of Late Oligocene to Early Miocene age. Superimposed from an extensive lava cover, rejuvenated intermittently by uplift of the Ethiopian highlands, and diverted by periodic volcanic flows and by river piracy, the Tertiary rivers of Ethiopia had a chequered history which we have barely begun to unravel. We cannot yet say when the Blue Nile gorge came into being, nor when the Tekazze became diverted around the breached and glaciated caldera of Ras Dashan and its flanking volcanic massifs, although a Miocene to Pliocene age seems possible. The age of the lava dam across Lake Tana is not yet known, nor is the precise age of its fault-bounded tectonic basin.

Between Lake Tana and the Sudan border the Blue Nile has cut a deep gorge across the Ethiopian highlands. The first 150 km of its course lie on lavas of the Tertiary Trap Series, after which the river flows through horizontal Mesozoic sediments until it reaches the Precambrian basement 330 km from Lake Tana. At this point a Mesozoic succession c. 1 000 thick capped by Trap Series basalts crops out in the side of the gorge. About 280 km below Lake Tana, the Addis Ababa - Debre Markos road crosses the gorge at 10°05′N, 38°10′E, exposing 250 m of Trap Series basalts. The basalts overlie at least 1 150 m of sedimentary rocks (limestone, marl, shale, gypsum and sandstone), the base of

which is not exposed. The gorge is 1 400 m deep and 20 km wide and is incised into a plateau of 2 600 m elevation (McDougall et al. 1975).

On the south side of the gorge the upper part of the section comprises three flows of basalt each several tens of metres thick and extending laterally for over 5 km. The lower part of the volcanic sequence is partly obscured by talus, but includes at least two more thick flows. Beneath the second flow from the top is a vertisol or dark cracking clay up to 3 m thick, developed in situ on weathered basalt and containing carbonised tree trunks and plant leaves of probable Middle Tertiary age. Diatomites locally underlie the upper flow, testifying to former lacustrine conditions.

Fresh samples of basalt from the top three flows yielded similar ages averaging 23.5 m.y. The fourth flow was significantly older (27.3 m.y.). Accepting these as reliable minimum ages, the basalts would be Middle to Late Oligocene, and the gorge would have a maximum possible age of Late Oligocene (McDougall et al. 1975). If we assume that the uppermost lavas which crop out in the gorges of the Tekazze river and its tributaries are of comparable age to those in the Blue Nile gorge, which seems valid given the proximity of the headwaters of the two catchments, it is possible to estimate the mean rate of regional denudation.

The volume of rock eroded from the Abbai and Tekazze basins in Ethiopia since extrusion of the Trap Series lavas may be estimated from a contour map at 71 000 km^3 for the Abbai basin and at 31 000 km^3 for the Tekazze basin, to within plus or minus 50 % accuracy. The planimetric area of the Abbai catchment above 1 000 m in upland Ethiopia is about 190 000 km^2, and that of the Tekazze is 85 000 km^2. Summing areas and volumes for the two basins gives a total loss of 102 000 km^3 of rock from a combined catchment area of 275 000 km^2. Mean denudation calculated by dividing the volume of rock eroded by the product of area and maximum basin age amounts to 15 $m^3 km^{-2} y^{-1}$, again to 50 % accuracy either way (McDougall et al. 1975).

A mean rate of surface lowering of only 0.015 mm y^{-1} for a tectonically active area of high relief seems remarkably low, and is more in keeping with modern rates from undisturbed tropical lowland forests (Gibbs 1967; Douglas 1969). The low value for geological erosion suggests episodic uplift with prolonged stable intervals. Merla (1963) has earlier suggested that uplift of the Ethiopian highlands took place in two stages, one in the Miocene, and the other in the Pliocene-Pleistocene, with the development of deep canyons, including the Blue Nile gorge. Faure (1975) has estimated the uplift of the Ethiopian highlands at 0.5 mm to 1.00 mm y^{-1} during the Late Pleistocene compared to a mean rate of only 0.1 mm y^{-1} since the Middle Tertiary. The rate of erosion would have been high during times of rapid uplift, and low for prolonged periods between accelerated uplift. A logical consequence of alternating phases of rapid and less rapid denudation in Ethiopia is that the pattern of sedimentation in Sudan and Egypt will also have varied, with intervals of coarse clastic sedimentation followed by intervals of much slower, more fine-grained deposition in both central Sudan and the Nile delta, always assuming of course that the main Nile was in receipt of water and sediment from Ethiopia.

To sum up so far, Ethiopia became updomed during Eocene-Oligocene and

Miocene-Pliocene times, with major volcanic eruptions between about 25 m.y. and 19 m.y. ago. Initial entrenchment of the Abbai-Blue Nile and Tekazze-Atbara river systems probably began during the Miocene or very Late Oligocene, and accelerated during Late Pliocene and Late Pleistocene times, with the eventual removal of some 100 000 km³ of basalt, sandstone, limestone and granite from their basins. Before attempting to follow the fate of this impressive volume of eroded debris, we will turn our attention to the headwaters of the White Nile basin in Uganda.

9.2 UGANDAN EARTH MOVEMENTS AND DRAINAGE DIVERSIONS

Geomorphic investigations in Uganda (Doornkamp & Temple 1966) suggest that before the Albert Rift came into being the original course of rivers like the Katonga in the north and the Kagera in the south was towards the west. Regional earth movements during the Early to Middle Tertiary resulted in swell uplift in eastern and southeastern Uganda and the development of a tectonic depression along the site of the present Albert Rift, which may not have been fault-bounded in its initial stages (Bishop 1971). Water and sediment accumulated in this proto-Rift, and the antecedent west-flowing rivers cut down into the uplands east of the proto-Lake Albert basin. Continued uplift during the Late Tertiary and Early Pleistocene eventually resulted in ponding of the west-flowing drainage, widespread alluviation and lake or swamp development, and the start of a strong eastward-flowing component of the upland drainage (Bishop 1971). It seems likely that a very extensive proto-Lake Victoria came into being at about this stage, although precisely when is still not known.

Fossil-bearing deposits southwest of Lake Albert indicate that during Miocene times fluvio-lacustrine sediments accumulated in a broad depression bounded by recent scarps drained by fast-flowing rivers. During the Early Pliocene deposition continued, with thick clays and subsidiary sands accumulating within a deep and permanent lake. Intermittent faulting along the Rift margins and deepening of the Rift itself resulted in Lake Pliocene cyclic sedimentation within the proto-Lake Albert rift (Bishop 1969, 1971). Up to 1 000 m of clays, silts and sands were rhythmically deposited within the lake in response to major movements and associated erosion along the faulted Rift margins. A final pulse of reactivation of the Rift boundary faults during Middle to Lake Pleistocene times caused drainage rejuvenation and further deposition of over 30 m of coarse fluvio-lacustrine sediments within the Lake Albert basin (Bishop 1971).

Irrespective of whether the Cenozoic depositional cycles within the Albert Rift were of tectonic or of climatic origin (a tectonic influence is not in doubt, but the role of climate remains to be demonstrated), it is fairly certain that ponded drainage from proto-Lake Victoria and the submerged Kyoga Valley would have flowed eventually into Lake Albert before evaporating or spilling over from that basin into southern Sudan. A Miocene drainage link between the Albert Rift and the foothills and swampy valleys of southern Sudan is thus not ruled out by the stratigraphic and tectonic evidence from Uganda (Berry & Whiteman 1968; Bishop 1971).

Doornkamp & Temple (1966) have described possible lake deposits up to 100 m above the present level of Lake Victoria which they consider were tilted and warped during two distinct intervals. Three untilted strand lines occur at elevations of 3, 12 and 18 m above the 1960 lake level (Temple 1964). The 3 m strand line is associated with charcoal dated at 3 720 years B.P. (Stuiver et al. 1960). Temple (in litt., 13.3.68) considered that the modern Lake Victoria basin is no older than late Middle Pleistocene on the grounds that it post-dates Miocene and Pliocene earth movements in the Kavirondo Gulf and in the Albert Rift, and contains sediments no older than the late Middle Pleistocene Nsongezi Series which have late Acheulian implements near the top of the sequence. Given that the Acheulian assemblage could be up to 0.7 m years old, and not 60 000 years, as Temple thought, a more cautious approach would be to regard Lake Victoria as Pleistocene, Lake Albert as Mio-Pliocene and Ugandan drainage through into southern Sudan as late Cenozoic. We will now examine the Cenozoic history of southern and central Sudan.

9.3 SUDANESE SUBSIDENCE AND ALLUVIATION

We have seen that in East Africa swell uplift during Middle and Late Tertiary times resulted in the development of the western and eastern Rifts and was accompanied by prolonged and widespread volcanism. Earth-movements, rifting, faulting and volcanism have continued intermittently in this region until the present day (Table 9.1). Uplift in Ethiopia, Kenya and Uganda seems to have been accompanied or followed not only by rifting within those countries, but also by probable downwarping and/or downfaulting in the adjacent lowlands of the Sudan. Precambrian Basement Complex rocks are up to 700 m lower west of the main western scarp bounding the Ethiopian uplands than they are in the uplands (Whiteman 1971). Whether the scarp has formed mainly by monoclinal flexuring or by faulting is still a matter for conjecture, but in eastern Sudan the Upper Cretaceous Gedaref-Nubian sandstone is extensively faulted, as are some of the Tertiary basalts which overlie the sandstone (Medani 1973; Chialvo 1975).

Medani & Vail (1974) proved that post-Cretaceous faults are far more common in the Sudan than has been appreciated, and Maley (1970) has shown that movement has taken place very recently along the Mirgissa fault near the second cataract. Many of the faults are intruded by basaltic and siliceous dykes, and near the Sudan-Ethiopian border in the Atbara-Setit basin, a basalt dyke within the Upper Cretaceous Gedaref Sandstone has been dated at 21 m.y., and younger lavas overlying the Sandstone at 10 m.y. (Chialvo 1975). Earlier ages reported from basalts near Gedaref and in the Red Sea Hills of 33 m.y. and 24 ± 5 m.y. respectively (Whiteman 1971) are inconclusive, and should be used with caution. Miocene to recent volcanism is also documented in the Bayuda volcanic field, in northern Darfur - southeastern Libya, and in the Jebel Marra region, where up to 8 000 km³ of rock have erupted during the past 20-30 m.y., a volume somewhat greater than the estimated original volume of Tibesti volcanic complex in the central Sahara (Francis et al. 1973).

In all probability the intermittent volcanism and faulting which took place during the Middle Tertiary in the Sudan is closely linked to the Middle Tertiary swell uplift and associated volcanism and rifting in East Africa. Concomitant with the uplifts in Ethiopia and Kenya-Uganda was the doubtless episodic subsidence of major sedimentary basins in south-central Sudan including the country over which the Blue and White Nile rivers now flow. Recent drilling and seismic exploration by Chevron Oil has revealed some 10-11 km of sediments beneath the present Sudd. North of the recently updomed Nuba Mountains the Late Cenozoic Umm Ruwaba deposits are over 300 m thick in places, and north of the Managil Ridge between the White and Blue Nile the Late Cenozoic Gezira Formation sands and clays are over 100 m thick. Most of the major rivers which flow to join the White Nile in southern Sudan flow across a broad synclinal basin, the axis of which runs from southeast to northwest in accordance with one of the major tectonic trends in the Sudan.

Where confined rivers emerge from uplands onto plains where they are no longer confined, they lose competence, deposit their load, and build up alluvial fans. These can be large or small, steep or gentle, depending on catchment size and lithology, river gradient and discharge and erosion within the catchment. The Cenozoic alluvial deposits within the Sudan are mostly alluvial fan deposits, characterised by rapid lateral and vertical facies changes, and by intermittent river rejuvenation and dissection of the older, proximal sectors of the fan, creating newer fans along the distal margins of the older ones. The Gezira Formation was laid down by proto-Blue Nile-Dinder-Rahad distributaries flowing across the eroded surface of the Nubian Sandstone and older rocks, just as the sands and gravels of the Nubian Sandstone were laid down by alluvial fan distributaries emerging from the uplands to the south and east and flowing north in Upper Cretaceous times, when uplift was already under way in Ethiopia. In the absence of known fossils and intercalated tuffs and lavas, about all we can now say about the Umm Ruwaba and Gezira fanglomerates and fluvio-lacustrine clays and sands is that they may range in age from Eocene or Oligocene near the base to Holocene at the surface. Erection of a more detailed stratigraphic sequence must await analysis of the discontinuous beds of pollen- and diatom-rich clays which current research has shown to exist within these deposits.

9.4 SUPERIMPOSED DRAINAGE AND STRUCTURAL CONTROL IN NUBIA

Central and southern Sudan has abundant depositional evidence of former fluvial activity, including the Gezira fan, the Khor Abu Habl fan, and the Sudd fan with its dry sandy ridges and swampy inter-ridge depressions. In the Nubian desert of arid Northern Sudan and southern Egypt, former Nile deposits are sparse and often dissected, so that we must also have recourse to the less persuasive erosional evidence of former Nile activity.

Rivers tend to follow the path of least resistance, and ancient rivers usually display a close adjustment to the detailed geological structures through which

they flow (see Chapter 10). The course of the main Nile at the sixth cataract, where it flows in a narrow gorge across an ancient ring-complex, or at the second cataract where it cuts discordantly across granites and dolerites, seems inexplicable unless we invoke a superimposition from a former cover of Nubian Sandstone, of which scattered remnants capping small mesas still remain. Maley (1969,1970) would extend the antiquity of the earliest Nile back still further, for the basal Nubian Sandstone gravels in the vicinity of the second cataract occupy a linear depression paralleling the axis of the modern Nile valley. For practical purposes, however, it seems best to regard the Nile as younger than the Upper Cretaceous continental and marine Nubian Sandstones into which it has entrenched its valley in Nubia and further north.

Fossiliferous silicified freshwater limestones, known as the Hudi Chert Formation, crop out in the Nile valley between Dongola and Khartoum, as well as between Wadi Howar and Wad el Melik in north-western Sudan. The Hudi Chert occupies depressions within the Nubian Sandstone and is in places capped by basalts of probable Tertiary age, as at Jebel Nakharu some 12 km north of Berber in northern Sudan. The rather nondescript fossil flora and mollusc fauna were regarded by Cox (1932) as being of probable Upper Eocene or Lower Oligocene age, although a more recent evaluation of the fauna is more non-committal and merely opts for a possible Tertiary age (Whiteman 1971). How long the Hudi Chert lake or lakes survived in northern Sudan is not known, but in all probability there was significant inflow into the lake from silica-rich waters from the south and west, possibly via the ancestral Atbara, Blue Nile and Wadi Howar. It is possible that the lake overflowed to the north, or it may have remained a closed basin until breached by headward-eroding drainage from Egypt. The lower Nile valley was deepened during the late Miocene, aggraded during the Middle and Upper Pliocene and was eroded anew during the Plio-Pleistocene low sea-level stages.

Following the deposition of the Upper Cretaceous Nubian Sandstone and possibly preceding the deposition of the Hudi Chert were two distinct periods of continental erosion and deposition, the oldest of which is represented by Tertiary continental deposits which became weathered and ferruginised prior to eruptions of Mio-Pliocene basalts. Maley (1970) equated these deposits with the 'Continental Terminal' deposits of Niger and Chad, and considered them to be of Mio-Pliocene age. The second phase of erosion resulted in deposition of the Plateau Formation conglomerates during (?)Plio-Pleistocene times. The conglomerates contain rolled pebbles of Nubian Sandstone and silicified wood, but no Hudi Chert pebbles, and occupy a broad depression running roughly parallel to the present Nile Valley.

Maley (1970) thought that the region around the second cataract had been a SW-NE trending drainage axis throughout much of its geological history, probably as a result of fault control. It seems likely that much of the post-Cretaceous faulting in the Sudan is broadly coeval with the various phases of rifting in East Africa. That significant stretches of the main Nile north of Khartoum, of the Atbara-Setit in eastern Sudan, and of the upper White Nile-Bahr el Gebel are fault-controlled is no longer in doubt. What is still unresolved is whether the Albert Rift structures continue north into Sudan and Egypt. It is possible

that future geophysical work in the Sudan will bring to light buried rift structures which may have had a considerable impact on sedimentation and drainage history.

9.5 THE NILE CONE AND THE MEDITERRANEAN SALINITY CRISIS

Much of Egypt was beneath the Tethys Sea during the early Eocene, but by late Eocene times the sea had retreated north of the Fayum; and the Oligocene ancestral Nile flowed into the sea somewhere north of the Fayum. The late Oligocene and Miocene earth movements of East Africa were paralleled in Egypt by upwarping, faulting and volcanism along the margins of the present Red Sea, and by more restricted movements within the Nile Valley, including downfaulting of the Kom Ombo graben north of Aswan (Butzer & Hansen 1968; Whiteman 1971). During early and middle Miocene times the Nile flowed north along its present drainage axis, entrenching through Nubian Sandstones and exhuming the irregular surface of the Basement Complex rocks. Three extensive rock-cut surfaces developed during this time, and the Nile lowered its valley by some 200 m.

Northward convergence of Africa upon Europe during the Mesozoic and Tertiary had a number of important side effects. Throughout the Jurassic and much of the Cretaceous the tropical Tethys Sea separated Europe from Africa. When Africa joined Europe in late Cretaceous time, a shallow shelf-sea still linked the Atlantic to the Indian Ocean. Disappearance of this sea and closure of the link to the Indian Ocean during late Early Miocene time some 20 m.y. ago – 'one of the major palaeobiological events of the Tertiary' according to Hsü and his colleagues (1977) – created the present pattern of land and sea. The Mediterranean remained linked to the eastern European Paratethys inland sea by a narrow seaway north of the Alps until the early Middle Miocene, when Alpine uplift began. Final separation of the Mediterranean and Paratethys inland seas some 14-15 m.y. ago had two effects: no saline seawater flowed from the Mediterranean to Paratethys, and there was no return flow of fresh-water from Paratethys to the Mediterranean.

A very sudden change took place in Late Miocene time with final isolation of the Mediterranean from the Atlantic some 6.5 m.y. ago. During the preceding one or two million years, widespread salt deposits up to 1 000 m thick accumulated throughout the Mediterranean basin, suggesting a continuous supply of brine and intense evaporation. Once the brine supply became cut off, possibly as a consequence of a world-wide drop in sea-level by 40 m as a result of expansion of the Antarctic ice cap at that time, the Mediterranean became a low-lying salt desert probably similar, though on a far grander scale, to the Dallol salt plains of the northern Afar desert. Rivers bordering the Mediterranean desert cut deep canyons along the continental margins, and redeposited some of the original salts. Several hundred metres of younger evaporites, mostly dolomite, gypsum, and anhydrite, were precipitated at this time (Hsü et al. 1977).

With its base-level thus drastically lowered, the Nile cone and delta became a subaerial alluvial fan in the distal sectors of which evaporites accumulated. The Nile cut down to 570 m below present sea-level at Cairo, and to –170 m at Aswan.

The salinity crisis ended as rapidly as it began. The West Antarctic ice melted, sea-level rose and overtopped the sill barring access from the Atlantic, and Pliocene marine flooding of the Mediterranean salt desert began. The deep, open Pliocene Sea submerged the late Miocene evaporites beneath 1 000-1 500 m of seawater. An arm of the Pliocene sea invaded the lower Nile canyon, and estuarine sediments accumulated in the drowned Nile valley, as far south as Aswan. The impact of this sudden change from desert to sea upon the climate of Egypt has yet to be evaluated in detail, but there is little doubt that late Pliocene Egypt was far wetter than it is today. Interestingly enough, the Indian Ocean link to the Red Sea across the Bab el Mandeb Straits was also restored some 3.5-4.0 m.y. ago, presumably as a result of glacio-eustatic rising sea-levels.

Plio-Pleistocene subsidence of the Nile cone and delta is doubtless related in part to the mass of overlying water, as well as to the weight of sediment itself. The Nile cone – 'one of the great submarine delta fans of the world' – is some 320 km wide, and extends out to depths of –2 800 m to the west and –1 600 m to the east. Drilling at DSDP site 131 at the far end of the western Nile cone revealed 272 m of interbedded Quaternary sands and clays. Clay mineral, heavy mineral and grain-size analyses show that the cone was built up by rapidly accumulating Nile sediments, at a rate of c. 0.55 mm y^{-1}. The absence of any significant changes in composition within the sedimentary column of the Nile cone (Emel'yanov 1972) encouraged Bartolini and colleagues (1975) to conclude that the connection between the White Nile, Blue Nile, Atbara, and Egyptian Nile took place not later than the Lower Pleistocene, a view advanced earlier by Rossignol (1961, 1962) on palynological grounds, and endorsed by Maley (1969, 1970) and by McDougall and co-workers (1975).

Owing to the fragmentary and weathered nature of the Early and Middle Pleistocene record of Nile sedimentation in southern Egypt and northern Sudan, it is not surprising that earlier workers like Butzer & Hansen (1968) were unable to find convincing proof of a drainage link between Ethiopia and Egypt much older than about 50 000 years. A recent re-appraisal by Hassan (1977) of the heavy mineral assemblage of Nile alluvium in Egypt now suggests that the modern Nile was well-established by at least the later part of the Middle Pleistocene (see also Butzer's reappraisal in Chapter 11).

The volume of the Nile cone is such that erosion rates would need to have been an order of magnitude higher than they have been for the past century (Hurst 1952) for the sediments in the Nile cone to have been laid down in the past 100 000 years, which was in fact not the case, for the cone stratigraphy and microfossil content demonstrate existence of the Nile cone during Miocene times. Harrison (1955) estimated the thickness and areal extent of Nile cone deposits from gravity anomaly data. Assuming no crustal sag the total volume of cone and delta would be about 95 000 km^3 but if we allow for the crustal sag that has undoubtedly taken place in late Cenozoic times, a more realistic estimate is obtained of c. 220 000 km^3. Emery and colleagues (1966) used

Harrison's contours to deduce a volume of 140 000 km³, a value they considered too high. Recent seismic investigations reported by Wong & Zarudski (1969) suggest that the submerged area of the Nile delta-cone complex is greater than previously thought, so that a sediment volume of 100 000 to 200 000 km³ seems plausible.

The volume of the Gezira Formation in central Sudan is a mere 1 800 km³, that of the Atbara fan probably about 600 km³, and the volume of Quaternary alluvium along the Nile is probably between 100 and 600 km³ (McDougall et al. 1975). We have already seen that some 100 000 km³ of rock have been eroded from the Ethiopian catchments of the Blue Nile and Atbara since extrusion of the Trap Series basalts there some 23.5-25.0 m.y. ago.

The concordance in the estimated volume of the Nile cone and the estimated volume of rock removed from Ethiopia suggests that the bulk of the Nile cone is made up of material of Ethiopian provenance. For the same unit discharge, the Blue Nile and Atbara now carry ten times more sediment than the White Nile. Despite a sizeable seasonal influx from the Sobat, the White Nile now provides less than 2% of the annual sediment load of the main Nile. The high proportion of Ethiopian volcanic minerals (Emel'yanov 1972) and of Ethiopian montane forest pollen and spores (Rossignol 1961, 1962) in early Pleistocene and younger Nile cone sediments show that a similar situation doubtless prevailed throughout Quaternary time.

9.6 GEOLOGICAL AND MODERN RATES OF EROSION IN THE NILE BASIN

If we assume that the bulk of the sediment in the Nile cone was derived from Ethiopia, the mean sediment yield since extrusion of the Trap Series may be estimated at between roughly 12 ± 6 m² km^{-2} y^{-1} for a cone volume of $150\,000 \pm 50\,000$ km³. This estimate compares well with the earlier estimate of 15 ± 7.5 m³ km^{-2} y^{-1} obtained by calculating the volume of rock eroded from the Blue Nile and Atbara headwater basins in Ethiopia, and allows for bulk density differences between bedrock and cone sediment, and for a possible 30% loss in solution from the highlands of Ethiopia (McDougall et al. 1975). The mean denudation rate over the past 23.5 m.y. would therefore amount to a net rate of surface lowering in upland Ethiopia of only 0.01 mm y^{-1}, or ten times less than the average rate of uplift since the Middle Tertiary (0.1 mm y^{-1}), which was itself up to ten times slower than the estimated rate of Late Pleistocene uplift of the Ethiopian plateau (0.5-1.0 mm y^{-1}).

Modern Nile erosion values are far higher. Shukri (1950) quoted a mean annual sediment load of 41 m tons for the Blue Nile, 14 m tons for the Atbara, and 57 m tons for the Nile at Cairo. More recent measurements give 120 m tons for the main Nile, and 50-100 m tons for the Blue Nile at Sennar before completion of the Roseires dam in 1965 reduced the sediment load at Khartoum to 40-70 m tons during 1967-1969 (El Badri 1972). Long-term measurements of Nile sediment load show a doubling in annual load during the 70 years preceding completion of the Aswan High Dam, despite the existence of sediment traps at the Sennar dam on the Blue Nile and at the Jebel Aulia dam on the White Nile.

Assuming an annual Nile sediment load of 50-100 m tons, of bulk density 1.5 g cm^{-3}, most of which comes from Ethiopia, gives a current rate of erosion in the Blue Nile and Atbara headwaters of 0.12-0.24 mm y^{-1}, which is ten to twenty times faster than the mean geological rate. Neil Munro of Hunting Technical Services (1976) has estimated that the present annual soil loss from the Ethiopian plateau areas west of the main eastern escarpment is almost four times greater than the estimates suggested above.

There can be little doubt that with rapid tectonic uplift in the Ethiopian highlands, reinforced by man-induced accelerated erosion, the life of the new reservoirs on the Atbara and Blue Nile will be quite short. Trapping of the bulk of the Nile sediment in Lake Nasser has already triggered off serious coastal erosion along the Nile delta, the long-term effect of which is now under review.

9.7 TOWARDS A SYNTHESIS OF NILE EVOLUTION

The Blue Nile and Atbara-Tekazze headwaters were superimposed from a cover of Oligo-Miocene basalts onto underlying Mesozoic sandstone and limestone and Precambrian granite and metamorphics. Rejuvenation of drainage through tectonic uplift during the Late Oligocene to Miocene, the Late Pliocene and the Late Pleistocene caused severe dissection in upland Ethiopia and the formation of very deep gorges.

Extensive alluvial fans were built up in southern and central Sudan at the outlet of major rivers issuing from the highlands of Ethiopia. Headwaters erosion is dominant in the Blue Nile and Atbara basins above an elevation of about 500-1 000 m, and fan aggradation is dominant below that height. Each fresh phase of renewed uplift in Ethiopia probably resulted in renewed fan construction in the subsiding sedimentary basins of south-central and western Sudan.

Drainage diversions in Uganda from Miocene times onwards caused ponding of water and sediment in the Albert basin, and overflow into Sudan may stem from those times. The emergence of Lake Victoria in its present form is a Pleistocene phenomenon, and may be younger than Early Pleistocene. The late Quaternary history of the White Nile headwaters is the subject of Chapter 14, and it is clear that overflow from Lakes Albert and Victoria into the upper White Nile will always have had a strong influence upon the White Nile regime.

Traces of a Late Cretaceous drainage link between Sudan and Egypt exist, but the first definite evidence of Nile flow from Ethiopia through Sudan to Egypt and the Mediterranean is so far only of Lower Quaternary age. Before then, the Miocene Nile excavated a very deep valley graded to a base-level formed by the dried out and saline Late Miocene Mediterranean desert. In Nubia, the post-Cretaceous Nile cut down through the Nubian Sandstone into the Precambrian Basement Complex rocks. During the Pliocene the Atlantic flooded the Mediterranean, and the Miocene Nile valley became a temporary

arm of the sea. Once the Pliocene estuary became infilled with estuarine and coarse fluviatile deposits the Nile began to prograde its delta anew.

Sea-level has risen and fallen through 100 m in response to Quaternary sea-level fluctuations. There were probably over 20 such oscillations in the past two million years, some of which may have influenced the Nile downstream of the first cataract. Upstream of the first cataract alternations in erosion and deposition reflect variations in river competence and in the ratio of Nile load to discharge, which are a complex and changing function of climatic, tectonic and volcanic events in Ethiopia, Uganda, Sudan and the Red Sea Hills, discussed in the next six chapters.

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10

Structural geology, tectonics and the control of drainage in the Nile basin

Géologie structurale, tectonique et leur rôle dans le drainage du bassin du Nil

La configuration du Bassin du Nil, les cours du Nil et de ses affluents ont été fortement influencés par des caractères structuraux et par des phénomènes tectoniques et volcaniques. Les structures géologiques en Afrique de l'Est suivent deux directions dominantes: NE à ENE et SE à SSE, d'après l'observation contrôlée sur le terrain des cartes topographiques, d'après celle des linéaments identifiés sur les photographies aériennes et sur les images établies d'après satellite. Il apparaît que ces orientations représentent d'anciennes lignes de faiblesse de la croûte, d'extension probablement continentale. Elles ont influencé, depuis le Précambrien, les directions des événements tectoniques, notamment les phénomènes de faille et de rift. Le drainage a été à son tour influencé par ces phénomènes tectoniques et volcaniques qui y sont associés, et même par les lignes de faiblesse structurale, car il exploite des parcours de moindre résistance.

Des changements sont intervenus sur les marges du Bassin du Nil dans quatre régions principales: le bassin du Turkana et de l'Omo, les bassins du Lac Victoria et du Lac Albert, la région du Jebel Marra et celle de la ligne de partage des eaux du Nil et du Tchad, et le réseau hydrographique éthiopien. Ces localités, ainsi que d'autres, ainsi qu'une grande partie de ce qui fait l'objet de ce chapitre, sont représentées sur la Figure 10.2.

Le Bassin du Turkana et de l'Omo s'est créé à la fin du Tertiaire lors de la formation des Rifts éthiopiens et est-africains. Il a été, pendant l'Holocène et de façon intermittente, en relation avec le Bassin du Nil en raison de conditions climatiques fluctuantes. Le canal de déversement depuis le Lac Turkana coïncide à un linéament satellite de direction ENE, le linéament du Lotigipi-Amar; et le drainage dans le sud-ouest de l'Ethiopie en direction de la rivière Sobat est fortement contrôlé par des failles de direction ENE et une linéation métamorphique de direction SSE dans les roches du socle précambrien.

Antérieurement au développement des rifts est-africains, le drainage dans le Kenya méridional et l'Ouganda se faisait vers l'ouest depuis une ligne continentale de partage des eaux à l'est de l'actuel Lac Victoria. Le bombement qui se développa avant la formation du rift arrêta ce drainage, les vallées furent ennoyées et formèrent le Lac Kyoga et le Lac Victoria. Le Lac Victoria occupe un bassin situé entre deux arches de voûte, celle du rift ouest et celle du rift Gregory. Il s'est déversé via les lacs Kyoga et Albert dans le Nil depuis 12 500 B.P., mais probablement jamais auparavant. Les modalités de formation des rifts et du drainage furent influencées par les structures géologiques de direction NE-ENE et SE-SSE. Le rôle de ces structures dans le drainage est bien illustré par la faille de décrochement Asua et les plissements secondaires associés qui ensemble ont contrôlé les cours de la rivière Asua et du Bahr el Jebel sur plus de 250 km.

Dans le Soudan occidental, la formation du volcan Jebel Marra au cours du Tertiaire provoqua une déviation marquée vers l'Est de la ligne de partage des eaux du Nil et du Tchad, et une inversion du drainage à l'ouest du volcan, ce qui eut pour résultat de supprimer quelque 60 000 km² du bassin du Nil. Dans

la région éthiopienne, antérieurement au rift, le drainage se faisait vers l'Est à partir d'une ligne de partage des eaux à l'ouest de l'actuel Lac Tana. Au Tertiaire, le soulèvement puis la formation du rift décapita et inversa le drainage. L'écoulement vers l'ouest, qui en résulta, de rivières comme le Nil Bleu et le Tekazze ajouta 180 000 km² au bassin versant du Nil. Les cours de ces rivières décrivent sur le plateau éthiopien des courbes dues au contournement de larges boucliers volcaniques.

Dans le Soudan méridional plusieurs affluents coulent à travers d'énormes cônes de déjection à faible pente situés sur la surface d'un grand fossé sédimentaire, le Fossé du Soudan méridional, qui apparaît limité par des failles de direction régionale SE-SSE et par des sédiments de déjection. En aval du Fossé, le Nil Blanc est confiné entre les pédiments des montagnes Nuba et la marge ouest des hauts plateaux éthiopiens. Le Nil Bleu inférieur en Ethiopie et près de Khartoum est parallèle aux failles et linéaments SE à SSE. La direction régionale ENE est suivie par le Nil principal lorsqu'il traverse le complexe annulaire du Sabaloka à la Sixième Cataracte, et des directions similaires apparaissent dans les dykes et les linéaments dans la région de Bayuda et à l'ouest vers Jebel Marra. La grande courbe du Nil au nord de Khartoum est due à une dérivation par soulèvement et activité volcanique de la région de Bayuda, et se trouve probablement contrôlée aussi par des structures de direction NE à ENE et SE à SSE. Un linéament satellite proéminent, le linéament d'Atbara, est co-linéaire avec la rivière Atbara et la partie du Nil principal qui comprend la Cinquième cataracte. Le parallélisme du Nil Bleu, de l'Atbara et du Nil principal reflète probablement ces structures SE à SSE.

Le cours du Nil en Egypte, dans sa majorité en direction du nord, est contrôlé par la bordure ouest de la voûte de la Mer Rouge, et dans ses détails par les orientations des failles et des diaclases, notamment dans les segments de direction SE à SSE. L'examen des orientations des affluents du Nil entre Aswan et Le Caire montre que ceux ci sont fortement contrôlés par des structures NE à ENE et SE à SSE.

Le système de drainage du Nil semble avoir existé, bien qu'avec des connections intermittentes, depuis l'époque tertiaire de soulèvement et de formation des rifts de l'Afrique de l'Est. Il semble aussi avoir été le résultat de ces phénomènes. Les anciennes lignes de faiblesse structurale qui contrôlaient les directions des rifts ont aussi exercé une influence directe sur l'orientation des fossés sédimentaires et sur tout le cours du Nil et de ses affluents.

10.1 INTRODUCTION

The Nile samples the geology of a considerable portion of Africa as it flows northwards across half the length of the continent. Africa is a mosaic of eroded Precambrian surfaces and sedimentary basins. Intercratonic mobile belts of metamorphic rocks, and the volcanic rocks and igneous ring complexes of Precambrian and Palaeozoic age are evidence of early tectonic disturbances. The rifting and vulcanism which have affected eastern Africa since early Tertiary times are the most recent of a series of disturbances which have fractured and deformed this ancient continent, but which have probably never broken it apart.

The southern headwaters of the Nile originate on rifted and uplifted Precambrian rocks in Kenya and Uganda, and on ancient eroded swells along the border of the Sudan with Zaire and the Central African Empire. To the west, the arched Precambrian basement and the Tertiary volcanic pile of Jebel Marra form the Nile-Chad watershed. The margins of the Red Sea and Ethiopian Rifts form the eastern extremity of the Nile basin. During its passage to the Mediterranean the Nile traverses an extensive, deep and probably still active intracontinental basin in the southern Sudan, then other smaller basins, extensive

areas of Precambrian basement, horizontal Mesozoic sediments of continental origin and Cenozoic volcanics as it flows northwards across the Sudan and Egypt. Near its mouth it crosses the nearly horizontal marine sediments which border the Mediterranean.

The present course of the Nile is largely a result of the Tertiary and Quaternary continental rifting and associated tectonic movements in eastern and north-eastern Africa (Figure 10.1). It rises in the tectonically active highlands of East Africa and Ethiopia, flows parallel to the western uplifted margin of the Red Sea Rift and empties into the Mediterranean basin, an active collision zone between the African and European continental masses. In turn, the Tertiary and Quaternary tectonic events themselves bear a close relationship to older geological trends, some of which are of continental extent. These trends also exert a direct influence on the Nile drainage as it crosses basement surfaces and their sedimentary cover.

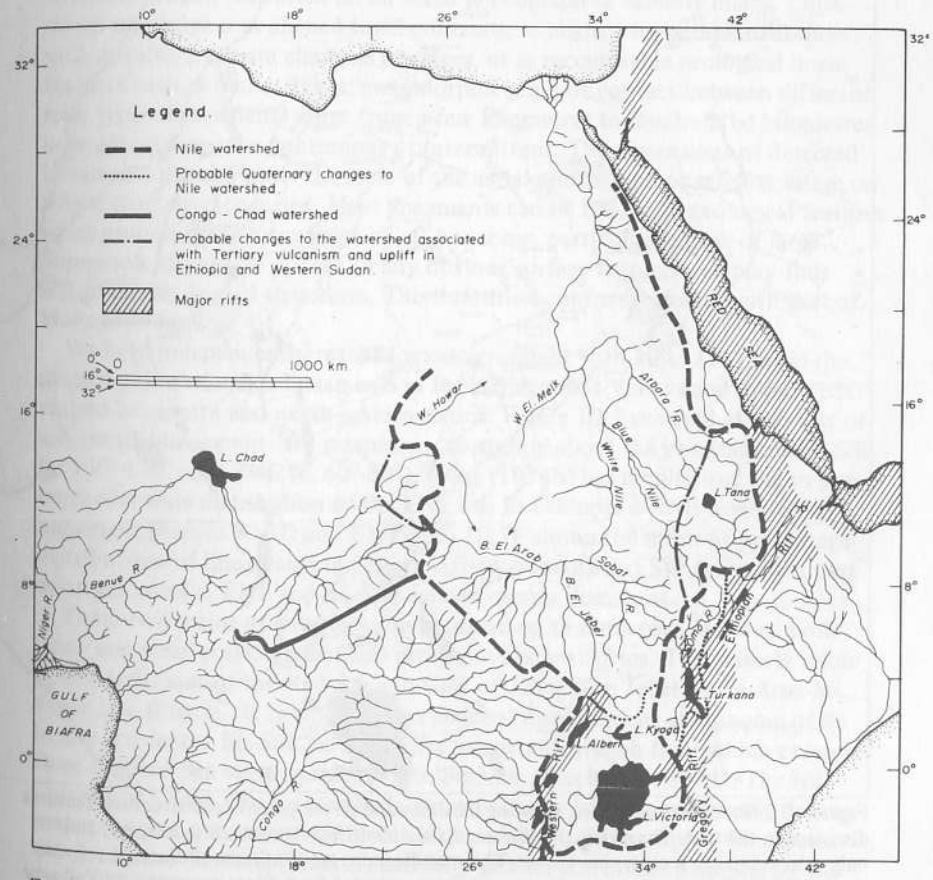


Figure 10.1 Drainage patterns in north-eastern and central Africa showing the present and probable former limits to the Nile basin.

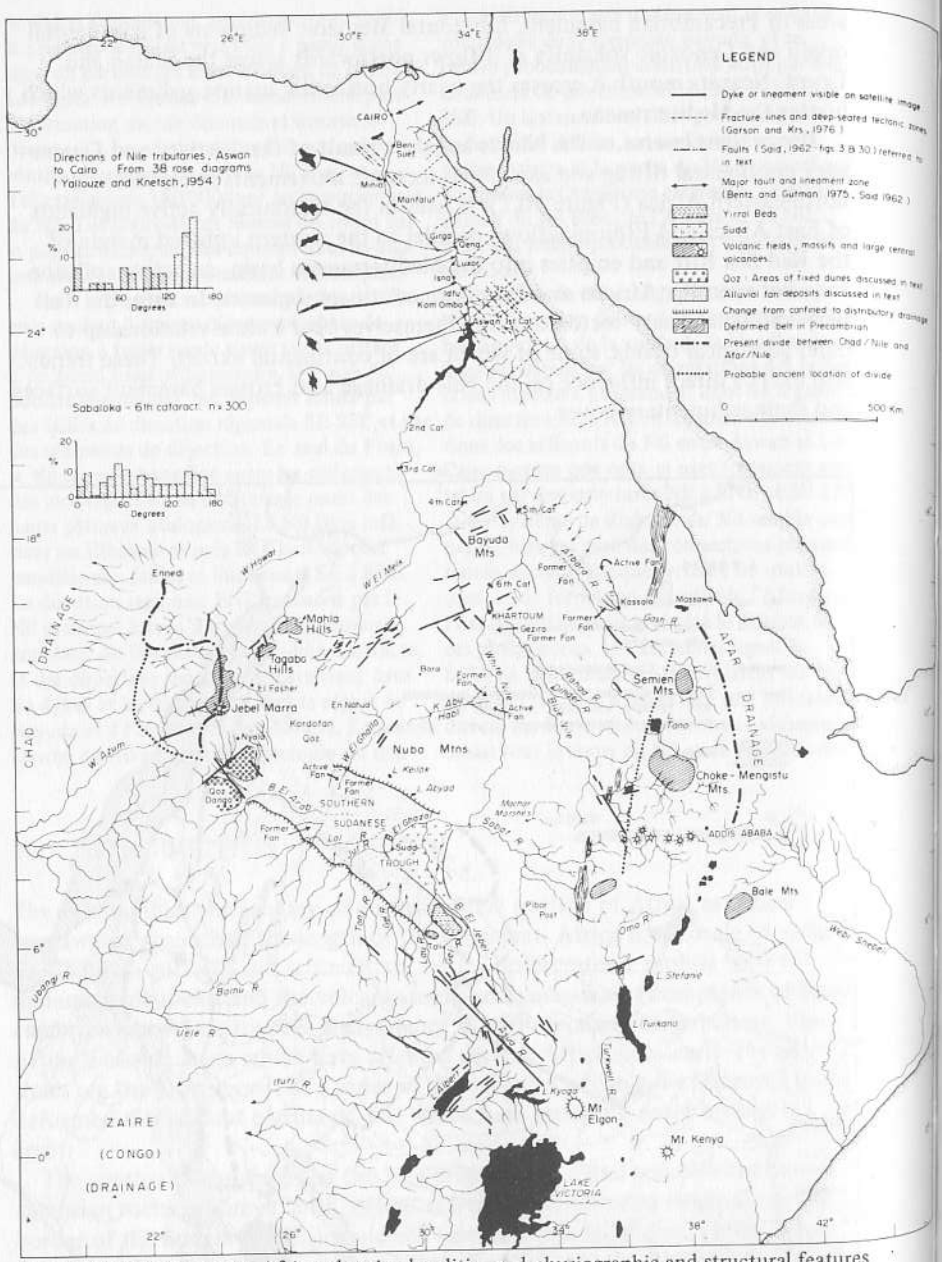


Figure 10.2 North-eastern Africa, showing localities and physiographic and structural features discussed in the text. The dykes and lineaments are identified from satellite imagery, and only selected major features are shown. The rose diagrams are syntheses of drainage orientations of Nile tributaries between Aswan and Cairo, selected from those presented by Yallouze & Knetsch (1954). The upper histogram summarises these drainage orientations. The lower histogram summarises orientations of major joints and air photo lineaments at the Sixth Cataract, measured from Whiteman (1971: Fig. 12).

The overall aim of this chapter is to combine new data with published information in a preliminary account of the influence of tectonic events and structural features on the drainage patterns in the Nile basin. Much of the detailed information discussed is summarised in Figure 10.2. Our data have been drawn from field-based geological studies, aerial photographs and mosaics, and satellite imagery. In certain cases a combination of several scales of observation by more than one worker or group of workers has been available to confirm the reality of structural features. The source of our evidence is given in each case.

10.2 LINEAMENTS AND STRUCTURAL TRENDS IN EASTERN AFRICA

We define a lineament as a linear feature which is presumed to be natural and of structural origin, identified on an aerial photograph or satellite image. Lineaments may appear as aligned tonal contrasts, as aligned topographic features such as valleys, stream channels or ridges, or as recognisable geological linear features such as faults, dykes, metamorphic grain or contact between different rock types. Lineaments range from a few kilometres to hundreds of kilometres in length and may be continuous or intermittent. The dimensions of detected lineaments depend upon the scale of the aerial photograph or satellite image on which they are recognised. Most lineaments can be related to geological features when ground-based knowledge exists but some, particularly those of large dimension, cannot be related to any obvious surface features and may thus reflect deeply buried structures. This definition conforms closely with that of Mohr (1974a).

We have independently reached good agreement with Mohr (1974a) in the identification of major lineaments in the African Rift Valleys and associated regions of eastern and north-eastern Africa. Figure 10.3 shows that two sets of sub-parallel lineaments are prominent, clustering about the orientations SE-SSE (c. 150°-170°) and ENE (c. 60°-80°). Mohr (1974b) has emphasised the importance and wide distribution of the ENE set. In Ethiopia a NNE trend is also important (Figure 10.3D and E). Figure 10.3F shows the mean of percentage distributions of lineaments in eastern Africa, Somalia and SW Arabia; the two orientations of c. ENE and SE-SSE remain clearly dominant.

These two major orientations can be matched to numerous features, both large- and small-scale, ancient and recent, in eastern Africa. They clearly relate to the directions of the Red Sea and Gulf of Aden. The Jebel Marra-Asua-Mt. Elgon line (Figure 10.2) which shows sinistral displacement along some of its length is oriented SE-SSE, as is another important wrench fault which extends from the Red Sea western margin into Somalia (Black et al. 1974). The Nile-Congo and Congo-Chad watersheds are remarkably straight and match the two major regional orientations (Figures 10.1 and 10.2). In the upper Omo basin north of Lake Turkana (Rudolf) carefully ground-controlled mapping by the Omo River Project (1973-1976) has revealed an intense network of faults and lineaments whose orientation frequencies are shown in Figure 10.4 A-E. The ENE and SSE trends are evident and the NNE trend, which parallels the Wonji

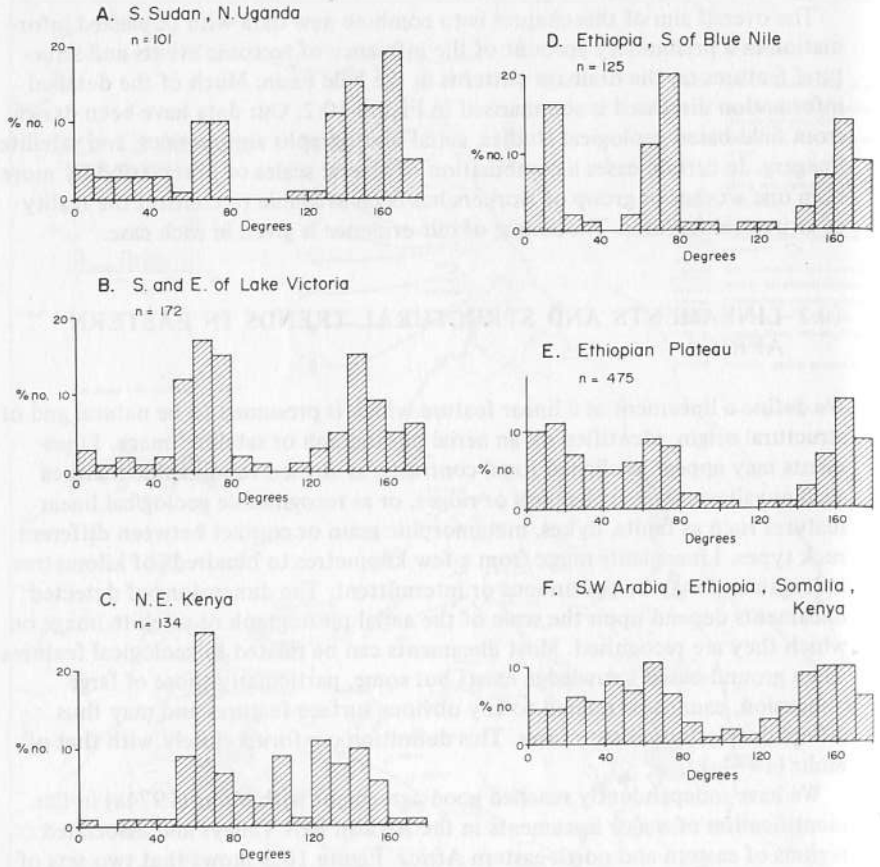


Figure 10.3 Histograms showing orientations of satellite lineaments in selected areas of eastern Africa. A, B, D and E are compiled from the maps presented by Mohr (1974a). C is compiled from the maps of Miller (1977), which include ground-based surveys. F shows the average of percentage distributions of satellite lineament orientations for eastern Africa (A, B, C and E above), south-west Arabia, and Somalia (no account being taken of possible rotation of Arabia with respect to Africa). The Arabian (n = 354) and Somali (n = 142) lineaments were measured from the maps of Mohr (1974a).
For histograms A, B, D and E the areas analysed were:
A: 4°N to 7°N by 31°E to 34°E;
B: 3°S to 7°S by 31°E to 34°E; 2°S to 3°S by 33°E to 34°E; 1°N to 3°S by 34°E to 35°E;
D: 7°N to 10°N by 34°E to 37°E;
E: 7°N to 12°N by 34°E to 37°E; 10°N to 12°N by 37°E to 39°E, 12°N to 13°N by 38°E to 39°E; 13°N to 14°N by 36°E to 39°E.

Fault Belt of the Ethiopian Rift (Mohr 1971:168), is also apparent here. Precambrian dykes between Lakes Turkana and Stefanie (Chew Bahir) show clustering about an ENE (c. 70°) orientation (Figure 10.4G-H), whereas Tertiary dykes show a very marked NNE trend.

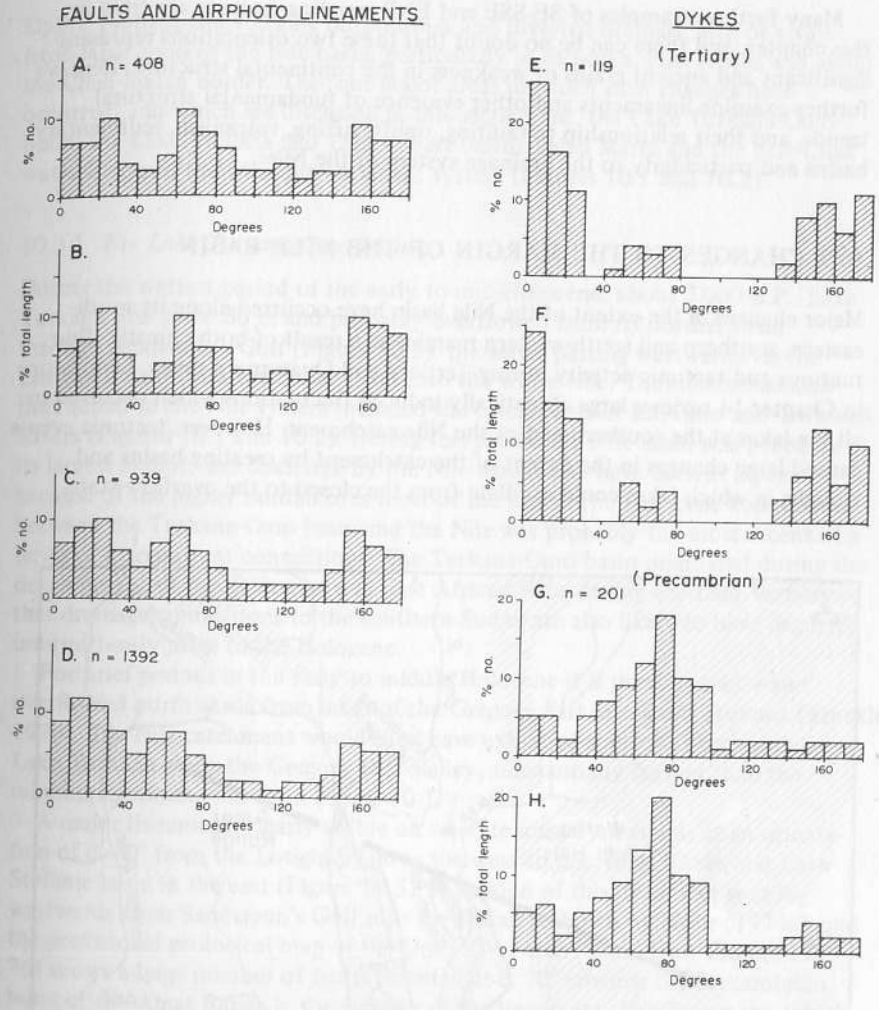


Figure 10.4 Histograms showing the orientations of faults, air photo lineaments and dykes in south-western Ethiopia. Measurements were made from the maps of the Omo River Project (1973-76). Histograms A and B were compiled from the northern half of the NW map sheet, C from the whole of the NW map sheet, and D from the NW map sheet and including the western side of the Rift margins. Histograms E and F (Tertiary dykes) were compiled from the NW map sheet, and G and H (Precambrian dykes) from the SE map sheet. Similar frequency distributions were obtained by analysing either length or number of these geological features with respect to orientation.

Many further examples of SE-SSE and ENE trending features are cited in this chapter, and there can be no doubt that these two orientations represent significant and ancient grains of weakness in the continental structure. Here we further examine lineaments and other evidence of fundamental structural trends, and their relationship to faulting, uplift, rifting, vulcanism, sedimentary basins and particularly to the drainage system of the Nile.

10.3 CHANGES TO THE MARGIN OF THE NILE BASIN

Major changes in the extent of the Nile basin have occurred along its south-eastern, southern and south-western margins as a result of both climatic fluctuations and tectonic activity during Tertiary and Quaternary times. Livingstone in Chapter 14 reviews large climatically induced fluctuations which occurred in all the lakes at the southern end of the Nile catchment. However, tectonic events caused large changes in the extent of the catchment by creating basins and troughs in which lakes could oscillate from the closed to the overflow state.

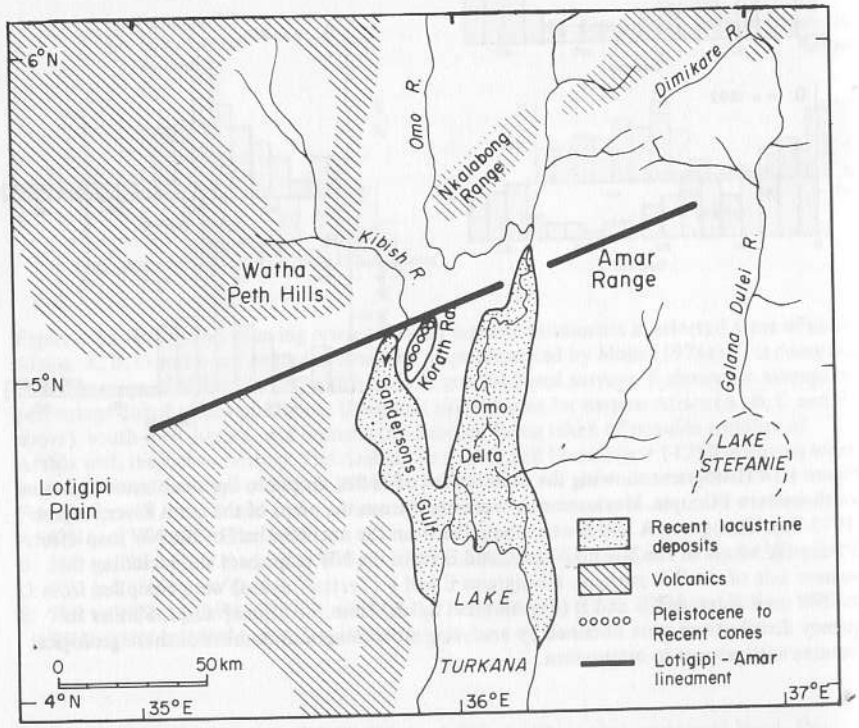


Figure 10.5 The northern end of Lake Turkana showing the relationship between the Lotigipi-Amar lineament, the Korath volcanics, the Lake Turkana overflow, and drainage. The Lotigipi-Amar lineament was identified on satellite imagery.

Uplift, faulting and volcanic outpourings also diverted drainage into or away from large areas of the Nile basin, particularly in Ethiopia, East Africa and along the Chad-Sudan border. The four major areas in which such changes have occurred, and which are discussed in this section are: the Lake Turkana-Omo basin; the Lake Victoria and Lake Albert basins; Jebel Marra and the Nile-Chad watershed; and the Ethiopian drainage system (Figures 10.1 and 10.2).

10.3.1 *The Lake Turkana-Omo basin*

During the wettest period of the early to mid-Holocene, about 7 000 B.P., Lake Turkana rose some 80 m and probably overflowed from its northern end through Sanderson's Gulf (Figure 10.5), the water passing westwards via the Lotigipi Swamp and the Sobat River into the White Nile. The substantial area thus added to the Nile system included the catchments of the Omo and Turkwell Rivers (Figures 10.1 and 10.2). During this period the Nile basin was probably at its largest extent, and discharge by the Nile would also have been at a peak because of the higher rainfall over most of the basin. The Holocene connection between the Turkana-Omo basin and the Nile was probably the most recent of a series of intermittent connections. The Turkana-Omo basin originated during the development of the Ethiopian and East African Rifts during the Late Tertiary so that drainage connections to the southern Sudan are also likely to have occurred intermittently prior to the Holocene.

For brief periods in the early to middle Holocene it is possible that water overflowed northwards from lakes of the Gregory Rift into Lake Turkana (Truckle 1976). The Nile catchment would then have extended some 300 km south of Lake Turkana along the Gregory Rift Valley, substantially further than the minimum estimate shown in Figure 10.1.

A major lineament, clearly visible on satellite imagery, extends at an orientation of c. 70° from the Lotigipi Plain in the west to the Amar Range and Lake Stefanie basin in the east (Figure 10.5). A portion of this lineament running westwards from Sanderson's Gulf into the Sudan is shown by Mohr (1974a), and the provisional geological map of the Omo River area (Omo River Project 1973-76) shows a large number of faults oriented at c. 70° crossing the Precambrian horst of the Amar Range in the vicinity of the lineament. This lineament, which we refer to as the Lotigipi-Amar lineament, coincides with the Holocene overflow channel from Lake Turkana. It separates the volcanics to the west of Lake Turkana from those associated with the Kibish River; it forms the northern limit to the linear array of some eight late Quaternary volcanic cones which form the Korath Range within the Omo Rift; it crosses the Omo River between, and parallel to, two remarkable angular bends in the river as it flows over late Tertiary and Quaternary sediments; and finally, it crosses the Precambrian Amar Range where it is expressed as drainage channels and faults (Omo River Project 1973-76). Granitoid dykes within the Amar horst are oriented parallel to the faults and the lineament (Figure 10.4G and H). The Lotigipi-Amar lineament undoubtedly reflects an ancient structure which has influenced dyke and fault orientations since Precambrian times and, more recently, has influenced drainage patterns in the lower Omo valley.

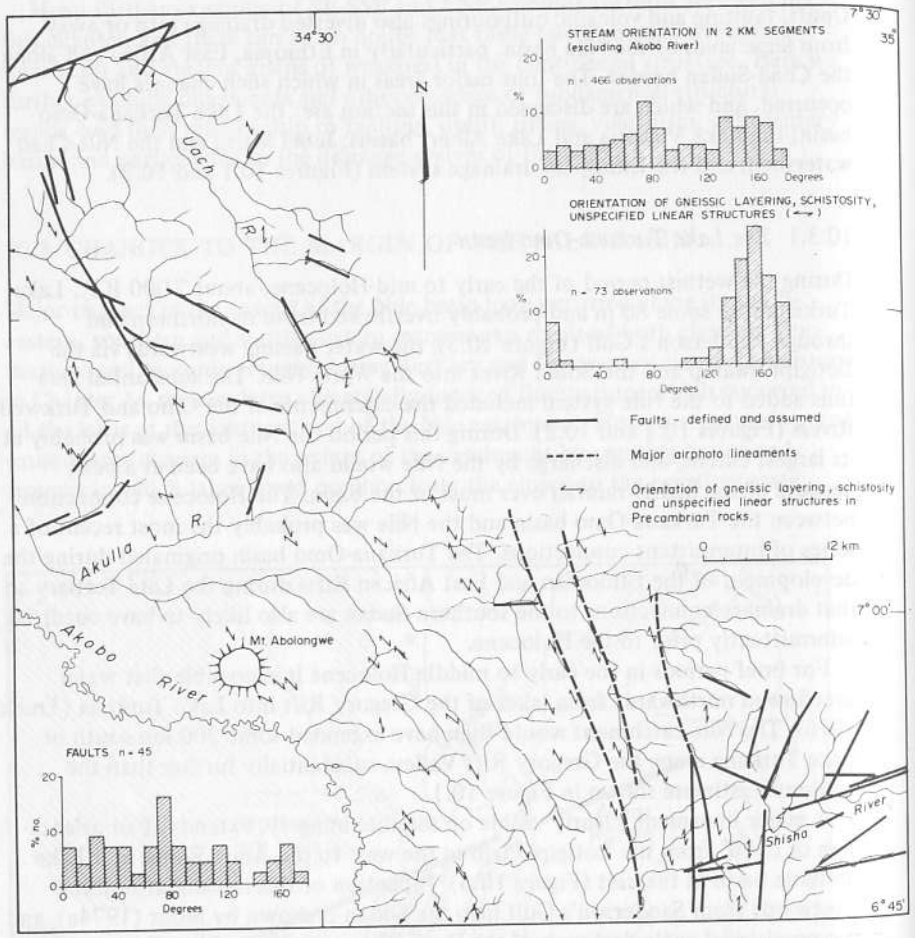


Figure 10.6 South-western Ethiopia, showing part of the drainage across Precambrian rocks towards the Sobat River, adapted from the maps of the Omo River Project (1973-76). The histograms summarise the orientations of streams, structures in the Precambrian basement, and faults. It can be seen that the prominent ENE component of stream orientation is controlled by faulting in the Precambrian rocks whereas the prominent SSE component is controlled by the basement grain. The Akobo River was excluded from the analysis of stream orientations because it occupies a flood plain.

The ground-controlled geological map produced by the Omo River Project (1973-76) provides an excellent example of stream control by underlying geological structure. Figure 10.6 is adapted from part of this map and shows streams draining from Precambrian rocks of SW Ethiopia towards the Sobat River. Our calculated frequency distribution of stream orientations shows two major directions, one at c. 70° and the other at 130°-170°. The orientation of basement

grain has a peak between 130° and 180°, whereas faults are preferentially oriented at c. 70°. There can be little doubt that here the non-random orientation of streams can be accounted for by their exploitation of two ancient structural trends: metamorphic grain and faulting in the Precambrian rocks, which match the two major orientations identified earlier.

10.3.2 *The Lake Victoria and Lake Albert basins*

The addition of the Lake Victoria basin to the Nile system at about 12 500 B.P. is described by Livingstone in Chapter 14. This event revolutionised the hydrology of the Nile basin by greatly extending the area of permanent swamps in the southern Sudan and by greatly increasing discharge during the dry season, thus ensuring perennial flow of the White Nile and the main Nile to the Mediterranean (Williams & Adamson 1974; Adamson et al., in press). As with the Lake Turkana-Omo basin the immediate cause of northward overflow from Lake Victoria and the lakes of the Western Rift was a rise in lake levels following a major climatic change. Evidence from the Lake Victoria basin itself does not yet indicate how long before 12 500 B.P. the lake was closed or, at least, did not supply water to the Nile. The presence of extensive evaporites along the White Nile (Williams & Adamson 1974) now dated to between c. 25 000 B.P. and at least 40 000 B.P. (Adamson et al., in press) suggests that major contributions of water from the East African lakes may have been rare in the late Pleistocene. It is possible that Lake Victoria itself had never supplied water to the Nile prior to 12 500 B.P. The important problem of possible earlier outflows from Lake Victoria should be tackled by further study of the White Nile sediments, by study of alluvial fan deposits such as those in and beneath the Sudd of central Sudan, by deeper coring in Lake Victoria and by a careful assessment of the possibility of southerly outflow from Lake Victoria.

The direction of eventual discharge from the Western Rift and Lake Victoria into the Nile was largely determined by tectonic events. The pre-Rift drainage pattern in East Africa has been discussed by Cooke (1958) who agreed with earlier suggestions that the Kafu, Katonga and Kagera Rivers flowed westwards across Uganda and the present positions of Lakes Victoria and Albert into the Zaire drainage system and ultimately into the Atlantic Ocean. The development of the Western Rift contemporaneously with, or subsequent to, that of the Gregory Rift disrupted the drainage. Figure 10.7 shows the present distribution of reversed drainage, drowned valleys and obvious lineaments in the area between Lake Victoria and southern Sudan. Using the terminology of Veevers (1977) the westerly flowing rivers were blocked by the arch whose crest subsequently downfaulted to produce the Western Rift. A similar arch developed to the east and down-faulted to produce the Gregory Rift. The inter-arch basin between these two rifted arches developed into the Lake Victoria and Lake Kyoga basins.

The effect of the Western Rift arch was to behead the Kibali River and to generate rivers such as the Ituri whose headwaters flow parallel to the long axis of the Rift before turning westwards into the Zaire basin. The westward flow of the Kafu River was slowed down and finally blocked, leading to the drowning of the Kafu and its tributary valleys in sediments and swamps. Similar

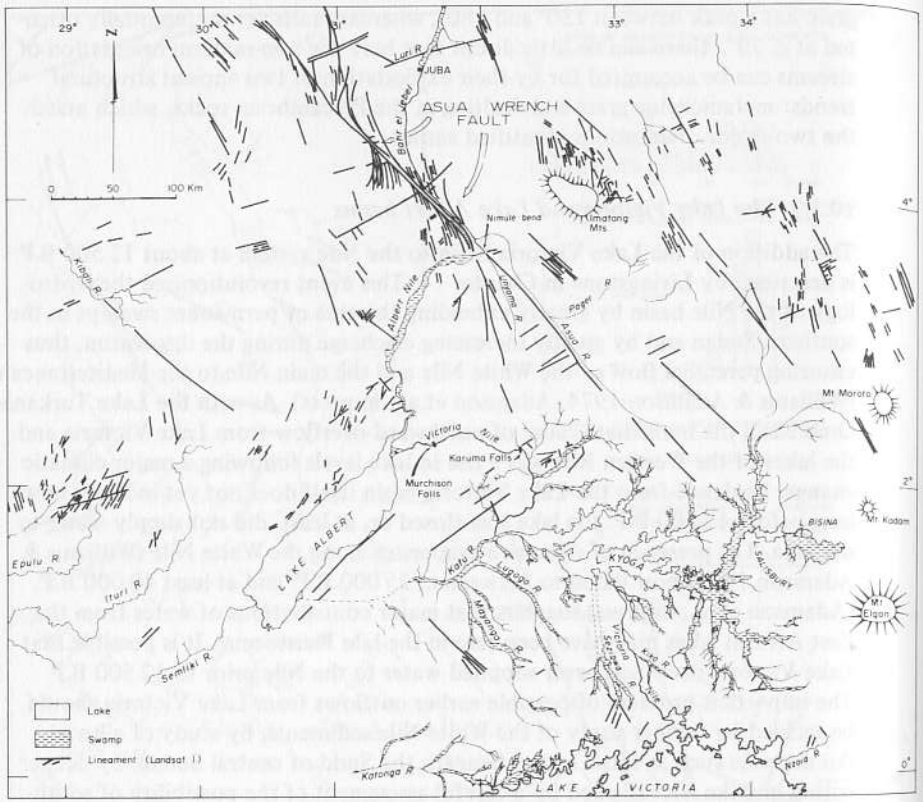


Figure 10.7 Relationship between satellite lineaments and drainage in the Lake Victoria and Lake Albert basins. The map was constructed from satellite imagery. The dashed streams indicate uncertainty as to their precise location, due to cloud cover.

events affected the Katonga and Kagera Rivers. Overflow from Lake Victoria into the Kafu system increased the swampiness and contributed to the size and stability of Lake Kyoga. Overflow from Lake Victoria caused Lake Kyoga to overflow into the Western Rift valley which was at substantially lower elevation than the inter-arch basin.

After leaving Lake Kyoga the present Victoria Nile flows north-east and then north along a valley in which the flow was previously in the opposite direction when the Kafu was an active westward-draining river. The Victoria Nile eventually breaches the eastern rim of the Western Rift near the Karuma Falls. The location of the overflow north-west of Lake Kyoga is probably due to differential uplift of the eastern rim. Consistent with this interpretation is the appearance of the Victoria Nile upstream and downstream of the vicinity of Karuma Falls. Upstream the river occupies broad and virtually horizontal sediment-filled valleys of the Kafu-Kyoga network, in contrast to the active incision and narrower channel of the stream on the downstream side.

Pallister (quoted by Temple 1967) interpreted the Victoria Nile as an overdeveloped tributary of the Kiko River. If this is the case, the Victoria Nile certainly assumed dominance over the parent stream subsequent to its tapping of the overflow from Lake Victoria c. 12 500 B.P. The dominance of the Victoria Nile over the Kiko may have been helped by the presence of two 25 km long fracture zones oriented at 167° and 140-145° which the Victoria Nile has exploited as it leaves Lake Victoria.

As with the Lake Turkana-Omo basin, many of the lineaments shown in Figure 10.7 undoubtedly pre-date the Tertiary arching and rifting and represent structures which have influenced both the rifting itself and pre- and post-Rift drainage patterns. Two main lineament orientations are evident in Figure 10.7: NE-ENE (c. 70°) and SE-SSE (c. 150°-170°), corresponding to the two major regional orientations described earlier. That the lineaments pre-date rifting is indicated by the continuity of both sets on either side of the Western Rift and by the pre-rift drainage pattern.

The importance and extent of the two sets of lineaments in the vicinity of the Lake Victoria basin can be gauged by analysing the frequency distribution of orientations of lineaments mapped by Mohr (1974a). Figures 10.3A and B show our analysis of the frequency distributions of all lineaments mapped by Mohr in southern Sudan, northern Uganda, and to the south and west of Lake Victoria in Kenya and Tanzania. The ENE and SSE orientations are strongly dominant in this sample of 273 measurements. Temple (1967: Figure 2) adapts unpublished field data of Pallister to show the orientation of geological structures which have controlled the outflow from Lake Victoria and the courses of adjacent streams. Although the sample size is small (21 measurements of orientation), the NE-ENE and SE-SSE trends are evident. This ground-based study provides evidence of the reality of the structural trends derived from Mohr's and our own examination of satellite imagery.

The influence of ENE and SSE structures on the present drainage pattern is clearly shown in Figure 10.7. The Mayanga, Lugogo, Sezibwa and other rivers to the west of the Victoria Nile, the Victoria Nile itself with its affluent the Kiko River, and some of the rivers to the east show a strong component of SE-SSE orientation in their courses. Prominent NE-trending lineaments run subparallel to the eastern rim of the Western Rift and to segments of the Kafu River and the Victoria Nile. The northern arms of Lake Kyoga and parts of the Kafu River show an ENE trend, and the SE-SSE trend is apparent in the vicinity of Lake Salisbury along the line of the Asua wrench fault. NE-ENE structures control the orientations of the Kavirondo and Speke Gulfs on Lake Victoria.

The Asua wrench fault provides an excellent example of the control of stream orientation by a major geological structure. Figure 10.7 shows this wrench fault and associated structures in more detail than has previously been available. The fault itself follows an orientation of about 140° over a distance of some 500 km through Uganda and southern Sudan. Numerous drag folds are evident on both sides of the fault, and their orientation shows that displacement along the fault was sinistral. The Asua River follows the fault for some 180 km and its continuation, the Bahr el Jebel, continues along the fault for a further 70 km before curving northwards towards Juba, following precisely the curva-

ture of the drag folds. The course of the Unyama River to the south of the fault also follows the direction of drag folds. The breach in the rim of the Western Rift exploited by the Victoria Nile near Karuma Falls corresponds to the intersection of NE-trending lineaments with a series of SSE-trending lineaments which extend toward the Asua wrench fault at the junction of the Albert Nile and Bahr el Jebel. These SSE-trending lineaments may also bear some relation to drag folds of the Asua fault system. The Asua fault appears to be an ancient structure which has also had an important effect on rifting in that it terminates, and has apparently blocked, the northward extent of the Western Rift.

Other major fault zones parallel to the Asua fault, and thus to the major SE-SSE structural trend, are shown in Figure 10.7. The Kibali River, a tributary of the Zaire River, appears to follow closely a major lineament of similar orientation in the Zaire basin. The SE-trending wrench fault north of the Imatong Mountains in southern Sudan is also clearly sinistral, as indicated by dragfold orientations. A number of major fault zones of similar orientation in northern Uganda have been reported by ground-based surveys (W.H.Morton, personal communication). Between Juba and the Sudd swamps the Bahr el Jebel curves to the NNW, probably following drag folds on the southern side of extensions of these Ugandan fault zones into southern Sudan. Its tributary the Gwir (Figure 10.10) probably also follows drag folds. The course of the Bahr el Jebel from its junction with the Albert Nile downstream into the Sudd has the form of an opened-out Z, probably reflecting the influence of drag folds associated with the two major parallel wrench fault zones. The Luri River north of Juba is a clear example of a tributary which follows the ENE structural trend rather than a drag fold.

Finally, it is interesting to note how the overflow from each of the three basins: Lake Victoria, Lake Kyoga and Lake Albert, is associated with a sharp change in the gradient of the Nile and youthful incision downstream of the overflow. The Lake Victoria basin, an inter-arch basin, overflows at the Rippon Falls and cascades into the ponded and virtually defunct Kafu-Kyoga drainage system. The Lake Kyoga basin overflows at its north-western edge by breaching the rim of the Western Rift, and the Victoria Nile flows via rapids and waterfalls into the Rift. The Western Rift is also breached at its northern end and the Albert Nile waters cascade down to the lower level of the Sudan over rapids at Nimule. The northerly outlet from each of these three lakes can be explained by a reduction in the amount of arching (uplift) northwards along the Western Rift. No outlet was possible to the east or north east because the ancient continental divide between the Indian and Atlantic Oceans lay to the east of Lakes Victoria and Kyoga (Cooke 1958) and because the volcanic massif of Mt. Elgon and the mountains to the north effectively increased the elevation of the eastern rim of the inter-arch basin.

10.3.3 *Jebel Marra and the Nile-Chad watershed*

There is evidence from the western Sudan that a major change in the western margin of the Nile Basin occurred as a result of Tertiary and Quaternary vulcanism. The eruption of the Jebel Marra volcanic complex which commenced in

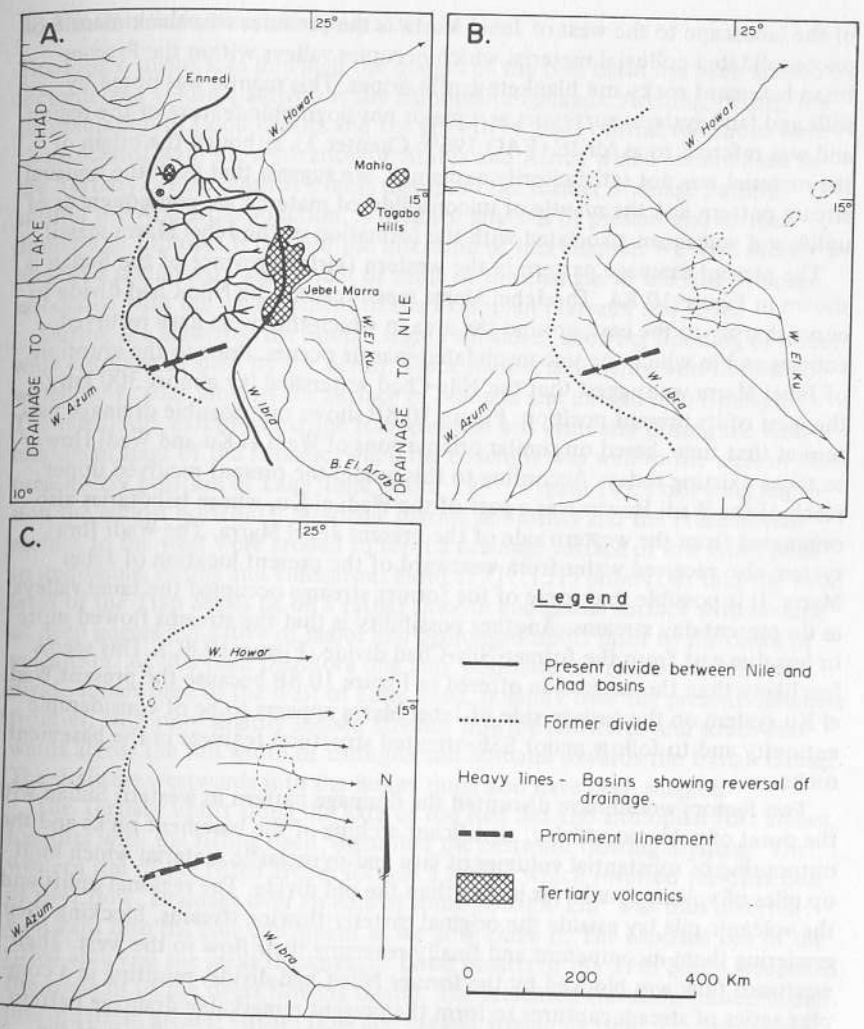


Figure 10.8 A: The present drainage system in the Jebel Marra region of western Sudan. B and C: Two possible drainage patterns prior to uplift and volcanism, as discussed in the text. The prominent lineament was identified on satellite imagery.

the Miocene resulted, in our view, in a westward diversion to Chad of previously eastward-flowing drainage (Figures 10.1, 10.2 and 10.8). A catchment of more than 60 000 km^2 was thus deleted from the Nile basin. The geology and importance of the Jebel Marra area is discussed in chapter 13, and in this section we concentrate on the probable effect of the vulcanism on drainage.

The area to the west of Jebel Marra is notable for the shape of the streams in the upper parts of the Wadi Azum and Wadi Howar systems (Figure 10.8). These streams show a remarkable degree of recurvature. A second conspicuous feature

of the landscape to the west of Jebel Marra is the presence of a thick mantle of unconsolidated colluvial material which occupies valleys within the Precambrian basement rocks and blankets gentle slopes. This mantle was noted by soils and land systems surveyors as a major physiographic feature of the region and was referred to as 'drift' (FAO 1969: Chapter 3), although the origin of the material was not satisfactorily explained. We suggest that both the unusual stream pattern and the mantle of unconsolidated material are consequences of uplift and vulcanism associated with the formation of the Jebel Marra massif.

The present drainage pattern in the western Darfur Province of the Sudan is shown in Figure 10.8A. The Jebel Marra massif causes the Nile-Chad divide to curve sharply to the east, around the area in which the rivers have recurved courses and in which the unconsolidated mantle occurs. Prior to the eruption of Jebel Marra we suggest that the Nile-Chad watershed lay almost 300 km to the west of its present position. Figure 10.8B shows one possible drainage pattern at that time, based on similar orientations of Wadi el Ku and Wadi Howar to those existing today. According to this model the present recurved upper reach of the Wadi Howar was a part of the Wadi el Ku, whose tributaries also originated from the western side of the present Jebel Marra. The Wadi Ibra system also received water from westward of the present location of Jebel Marra. It is possible that some of the former streams occupied the same valleys as do present-day streams. Another possibility is that the streams flowed more or less due east from the former Nile-Chad divide (Figure 10.8C). This seems less likely than the suggestion offered in Figure 10.8B because the present Wadi el Ku system on the eastern side of Jebel Marra appears to be of considerable antiquity and to follow major SSE-oriented structural features in the basement rocks.

Two factors would have disrupted the drainage pattern in western Sudan with the onset of volcanic activity: significant arching of the basement rocks and the outpouring of substantial volumes of lava and pyroclastic material which built up piles of volcanic rocks far higher than the old divide. The regional uplift and the volcanic pile lay astride the original easterly-flowing streams, blocking them, rendering them incompetent and finally reversing their flow to the west. Their westward flow was blocked by the former Nile-Chad divide, resulting in a complex series of stream captures to form the present remarkable drainage pattern of the Wadi Azum system. The Wadi Azum exploited the lowest part of the former divide in order to reach the Chad basin. This breach in the former divide corresponds to a major ENE lineament which is prominent on satellite imagery as it crosses the Precambrian basement (Figure 10.8). To the north west of Jebel Marra, one reversed stream was captured by the Wadi Howar and remained within the Nile basin.

During the process of drainage reversal there would have been a long period during which streams had very low or even zero grade. Slopewash would then have mantled the gentle lower slopes and choked valleys with deep accumulations of debris eroded from the Precambrian basement surface, thus producing the drift mantle referred to above. These accumulations are further described in Chapter 13, and we presently favour a tectonic rather than a climatic explanation for their origin. They are currently being eroded.

10.3.4 *The Ethiopian drainage system*

The fourth major area in which the margin of the Nile basin has been altered by tectonic and volcanic activity is the Ethiopian highlands. Arching, rifting, the accumulation of flood basalts and the growth of great central volcanoes were all associated with the separation of Arabia and Africa which commenced in the Tertiary. These gigantic events disrupted the former drainage pattern around the Afar triple junction. A detailed analysis of present and former drainage in Ethiopia is beyond the intention of this chapter. We wish merely to present a preliminary assessment of some of the changes to the Nile drainage associated with the development of the Ethiopian Plateaux and Rifts.

During the Mesozoic the Somali region subsided, allowing flooding of a very wide continental shelf by the ocean. Thick marine sediments were deposited which now cover most of the surface of Somalia and extend into Ethiopia. The maximum extent of marine transgression was evidently during the Kimmeridgian stage of the Jurassic, when the coastline was well to the west of the present-day position of Lake Tana (Mohr 1971: Figure 10). Following regression the almost horizontal Mesozoic marine sediments and the Precambrian surface to the west were eroded to form a drainage surface of low relief prior to updoming, rifting and vulcanism. Mohr (1971:151) points out that the basal lavas of the Trap Series lie on a rather smooth and gentle surface with no sign of deep gorges indicative of major and prolonged uplift prior to the onset of vulcanism. At this time therefore one may postulate the existence of a low divide somewhere to the west of Lake Tana, possibly near the present Sudanese frontier, with only slightly incised streams flowing eastwards and south-eastwards across the full width of Ethiopia and Somalia towards the Indian Ocean. The drainage westwards into the Sudan must also have been sluggish.

The Tertiary uplift along the axes of the Red Sea and Ethiopian Rift arches, together with the rifting itself, disrupted the eastward flowing drainage. The western rim of the rifted arches formed a barrier which reversed the direction of river flow. Drainage over an area of some 180 000 km^2 was thus diverted westward into the Nile catchment as we now know it. The elevated rim of the rifted arch and the great thickness of flood basalts of the Trap Series steepened the gradient of the rivers flowing inland. The increased elevation caused higher precipitation, greater stream flow and greater stream incision. On the eastern side of the Ethiopian rift a similar process occurred so that the rivers flowing towards the Indian Ocean, although severely beheaded, were rejuvenated by the increased gradient and precipitation. Incision such as we now see in the gorges of the Webi Shebeli River and its tributaries resulted.

A major difference is clear between the stream patterns to the east and to the west of the Ethiopian Rift (Figure 10.2). On the eastern side the rivers generally flow fairly directly to the south-east, towards the Somali lowlands. The upper course of the Webi Shebeli River, more or less parallel to the Rift, is a notable exception due to diversion of the river by the Bale volcanic massif. On the western plateau it is the rule rather than the exception that the rivers follow a strongly recurved course across the plateau before escaping north-westwards to the Sudanese lowlands. As with the upper Webi Shebeli the explanation lies

largely with the Miocene eruption of central shield volcanoes, superimposed on the surface of the Trap flood basalts. The Semien and Choke-Mengistu Mountains are two major examples of such volcanoes (Figure 10.2). Dainelli (1970) considers that erosion affected the surface of the flood basalts before the Choke-Mengistu volcanics were erupted, suggesting a substantial time gap between flood and central vulcanism. He noted the occurrence of lacustrine and fluvial sediments probably extending beneath the products of this shield volcano, and our own observations of aerial photographs and satellite imagery have revealed a wide distribution of similar sediments over the surface of the Trap basalts. This implies a well-established Miocene-Pliocene drainage system. With the formation of the shield volcanoes, drainage from the Ethiopian plateau, although forced ultimately westwards, had to find its way around the huge volcanic piles, thus contributing to the remarkable recurvature of rivers such as the Abbai (Blue Nile) and the Tekazze (Atbara). Shorter rivers such as the Rahad and Dinder which flow directly off the western edge of the Ethiopian plateau have straight courses like most of those flowing off the Somali plateau.

The addition of the huge catchment of the Ethiopian highlands to the Nile system resulted in the vast input of water and sediment which now characterises the annual Nile flood. McDougall et al. (1975) calculated that the volume of the Nile cone in the Mediterranean is consistent with the volume of material eroded from Ethiopia since Oligocene times. The present Nile regime of annual flooding due to the Blue Nile-Ethiopian contribution must thus have been established during the late Tertiary and persisted throughout the Quaternary as suggested by the drainage patterns analysed above.

10.4 THE SOUTHERN SUDANESE TROUGH

In the southern Sudan, all rivers converge to form the White Nile (Figure 10.2). The main area of convergence is the Sudd which receives water from the East African lakes via the Bahr el Jebel, from the Nile-Zaire watershed, from the Nuba mountains and, in principle at least, from the Nile-Chad watershed although the amount of water now received from this last region is probably negligible. The drainage from south-western Ethiopia and the border regions of Kenya reach the White Nile via the Sobat River, downstream of the Sudd. The White Nile headwaters all traverse basement or volcanic surfaces in which they are incised to varying degrees in confined channels, and emerge onto the vast plains of the southern Sudan, a complex of overlapping alluvial fans of very gentle slope. Stream flow changes from confined to distributary forms as the streams spread out across their fans, add more sediment and migrate laterally. Figure 10.2 shows part of the area of low-angle fans, but makes no attempt to show the full extent of fans, particularly in the Sobat River system. The physiography of this whole region requires study.

The Sudd occupies part of an immense sedimentary trough, some 300 to 400 km in width and almost 1 000 km in length, which stretches south-eastwards from Darfur Province in western Sudan towards Kenya and Uganda (Figure 10.2). The surface of this trough is covered by active and abandoned

alluvial fans, by swamp deposits, by active distributary streams and by prior stream channels. Figure 10.7 shows a remarkable example of both an active and an abandoned low-angle fan of the Wadi el Ghalla where it emerges from its confined channel. This feature was drawn to our attention by D. Parry of Hunting Technical Services (personal communication) who has mapped it in some detail.

The thickness of sediment within the trough is great, estimates of the order of 10 km being given as a result of seismic traverses by Chevron Oil exploration parties (lecture given at Geology Department, University of Khartoum). The sediments have been ascribed to the Tertiary Umm Ruwaba Formation by the Sudan Geological Survey (Whiteman 1971a: Figure 6) but we feel that this nomenclature is misleading on account of the difficulties of correlation between individual sedimentary basins. This trough, which we refer to as the Southern Sudanese Trough, is a major structural feature of the Nile basin and bears clear relationships to ancient faulting and to more recent tectonic and volcanic activity.

The margins of the Southern Sudanese Trough can be defined clearly on satellite imagery and mosaics by the boundary between confined and distributary drainage (Figure 10.2); that is, by the boundary between a dissected ironstone plateau and aggraded sediments. The edge of the ironstone is shown on the Sudan Geological Survey 1:2 000 000 map, part of which is reproduced by Whiteman (1971a: Figure 6). The south-western margin of the Trough parallels the Asua and other wrench faults in northern Uganda and southern Sudan. It is also strikingly clear from satellite imagery that the south-western margin of the permanently flooded Sudd also follows this SE to SSE orientation. The correspondence between the south-western boundary of the Trough and the fault zones is a strong indication that this side of the trough is fault-bounded. At its north-western end, the south-western edge of the Trough matches the edge of the Qoz Dango sand field and a prominent lineament visible on satellite imagery. Further to the north-west on the Chad side of Jebel Marra the same orientation is adopted by many of the branches of the Wadi Azum stream system and by many of the faults and fracture zones shown by Vail (1974) and Medani & Vail (1974). As Vail (1972) and Whiteman (1971a:99) have pointed out, there is a good evidence of a major zone of weakness extending from Mount Elgon via the Asua wrench fault to, and probably beyond, Jebel Marra. The south-western side of the Southern Sudanese Trough follows this alignment, which is also one of the important regional trends (SE-SSE) noted previously.

The region of the north-eastern edge of the Southern Sudanese Trough is poorly known, since there have been no geological or physiographic field studies on the southern side of the Nuba Mountains. Figure 10.2 shows, in a generalised way, the SE-trending boundary between confined and distributary drainage in this region, and more detail of the physiography is given in Figure 10.9. The orientation of this boundary roughly parallels that of the south-western margin of the Trough and matches several faults or fracture zones shown by Vail (1974) which cross the Wadi el Ghalla. It also matches approximately the boundary between Precambrian rocks and deposits mapped as Tertiary Umm Ruwaba Formation on the Geological Map of Africa (1973:

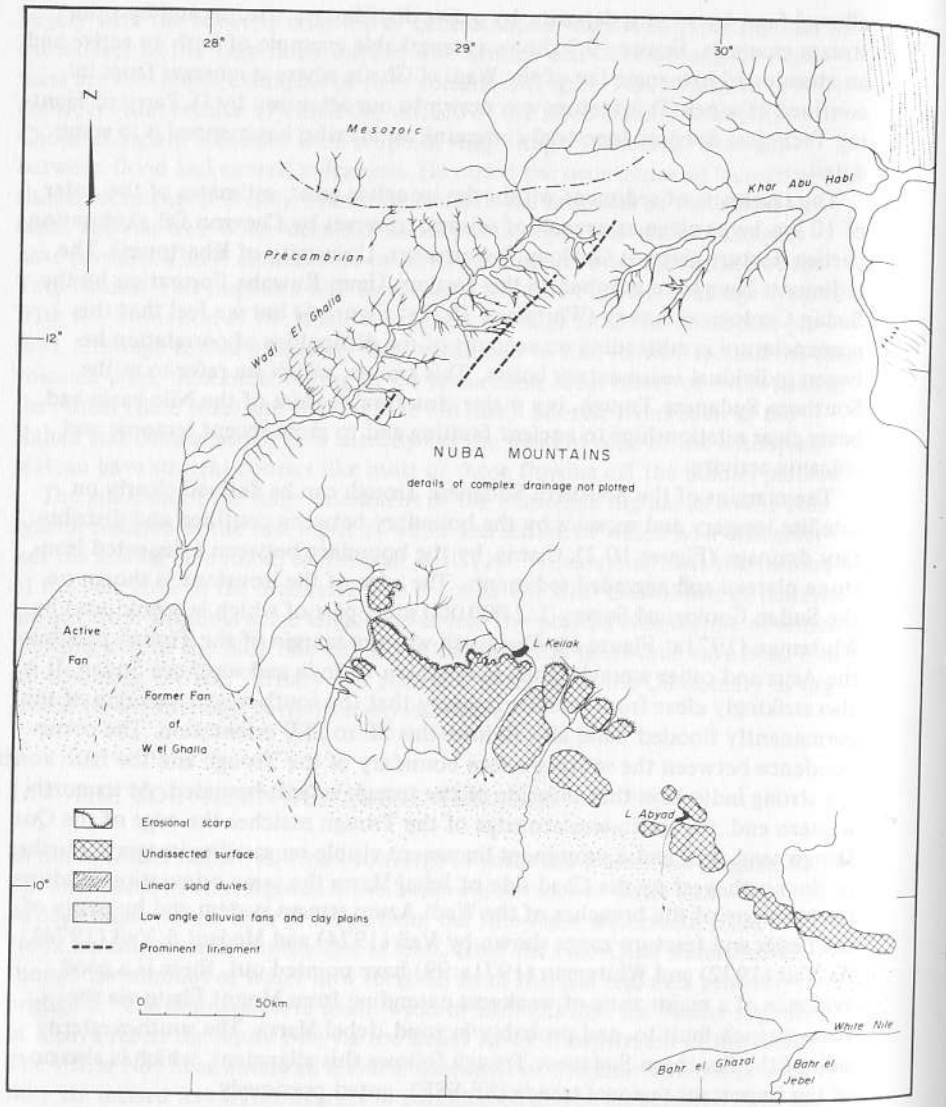


Figure 10.9 The northern margin of the Southern Sudanese Trough and the rectilinear drainage pattern of the Wadi el Ghalla, mapped from satellite imagery. The undissected surface with its northern erosional scarp is clearly visible on satellite imagery. It probably corresponds, at least at its southern end, with an ironstone surface.

Sheet 5). It appears to be a down-warped and possibly down-faulted margin, partially apparent as an erosional scarp abutting the Precambrian Nuba Mountains but largely obliterated by low-angle alluvial fans and trough sediments. The undissected surface appears to be analogous to a series of extremely low-angle cuestas.

The 1:250 000 Lake No Sheet of the Sudan Survey (1936) shows an ironstone escarpment of low relief oriented roughly SE at about 30 km north of the Bahr el Jebel-White Nile confluence. The ironstone surface undoubtedly corresponds to the undissected surface visible on satellite imagery (Figure 10.9), and may be analogous to the ironstone surface on the Zaire side of the Trough. The absence of an obvious erosional scarp on the northern side of the undissected surface at its south-eastern end could be due to minimal downwarping. In this region the White Nile flows east-west, has a very low gradient and is flanked by outcrops of Precambrian basement rocks within 50 km on both sides of the river. It thus appears that sediment depth is relatively shallow here, indicating a lesser degree of downwarping than to the north - west within the main Trough. The outcrops of basement rock also account for the relatively confined course of the river as it flows out of the lower end of the Sudd, in striking contrast to the immense spread of water across the low-angle fans and swamps upstream.

Figure 10.9 shows the drainage pattern of the Wadi el Ghalla as it crosses Precambrian basement west of the Nuba Mountains. The remarkably rectilinear pattern matches the orientations of prominent lineaments visible on satellite imagery. Vail (1974) maps a fault-fracture zone with similar orientation, and the structural control of drainage in this region has been confirmed by El Rabaa (personal communication). Major branches of the Khor Abu Habl have the same north-east orientation (Figure 10.2). Minor wadis along the lower course of the Wadi el Ghalla are oriented SE-SSE, matching the orientation of a second set of faults (Vail 1974) and the northern edge of the Trough.

The geology and physiography of the Yirol area (Figure 10.10) are also suggestive of a faulted margin along the south-western edge of the Southern Sudanese Trough. Between Yirol and the Bahr el Jebel is a block (the Yirol Block), obvious on satellite imagery, of slightly elevated ironstone country which is crossed by relict drainage channels and which diverts the streams flowing northwards towards the Sudd. The Lau River, and the Lau tributary which flows into Lake Anyl and thence to Lake Yirol, are both diverted around the Yirol Block and a smaller block to the south-west. Water is ponded in Lake Yirol and Lake Anyl against the western edge of the Yirol Block. The two long edges of the Yirol Block parallel the south-west margin of the Southern Sudanese Trough, the course of the Bahr el Jebel, and the south-west margin of the Sudd. Little is known of the sub-surface geology. Despite some similarity Andrew (1948) considered it doubtful to identify the Yirol beds with the Cretaceous Nubian Series and recognized that they could have been deposited at any time over a very long interval. The Yirol beds have subsequently been included in geological maps as Mesozoic (Geological Map of Africa 1963; Whiteman 1971a:75; Vail 1974) but we agree with Andrew that there is no good evidence as to their age.

In our view the Yirol Block is a remnant of widespread deposits which are now buried beneath younger sediments of the Trough. The Block may also contain Precambrian rocks according to Vail (1974). It has probably been preserved at the surface by block-faulting which has orientations parallel to the SE-SSE and NE-NNE lineaments and the faults evident further south (Figures 10.2, 10.5 and 10.10). The Yirol Block, according to this interpretation, would form part of the faulted south-western edge of the Southern Sudanese Trough.

The present focus of drainage within the Trough is well to the west of the outflow of the White Nile and is centred on the Bahr el Ghazal (Figure 10.2). Lateral stream diversion on an aggrading alluvial fan has probably contributed to the westward diversion of water flowing down the Bahr et Jebel. Subsidence

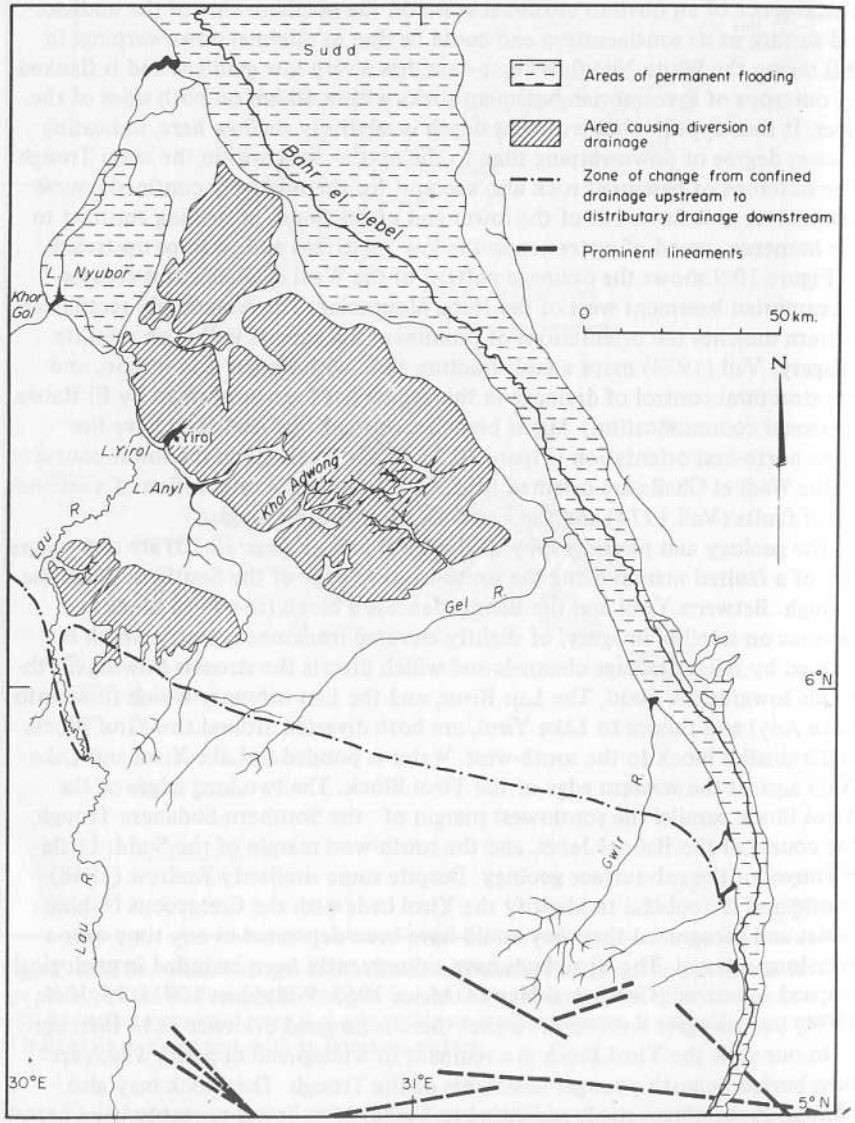


Figure 10.10 Drainage patterns around the Yirol Block, southern Sudan, mapped from satellite imagery. The boundary between confined and distributary drainage is generalised south of the Yirol Block. The satellite lineaments form part of the group shown at the northern margin of Figure 10.7.

and compaction may also have contributed to the location of the drainage focus. Subsidence of the Trough and fault movements are probably still active, judging from reports of minor but common earth tremors in southern Sudan (Whiteman 1971a, b).

10.5 CENTRAL SUDAN AND BAYUDA

Downstream of its junction with the Sobat River, the White Nile flows northwards in an almost horizontal gutter between the pediment of the Nuba Mountains and the Ethiopian foothills. Outcrops of basement rock impinge occasionally on the river. Sedimentary basins such as the Umm Ruwaba and Gezira basins are relatively shallow compared with the Southern Sudanese Trough, and their surfaces are now blanketed by low-angle fans from the Khor Abu Habl and the Blue Nile respectively (Figure 10.2). The bulk of sediment in these basins is likely to be of fluvial origin with minor lacustrine components (Whiteman 1971a:89; Boushi & Abdel Salam, in press), representing mainly the accumulation of successive fan deposits. The orientation of these basins does not match the north-south orientation of the White Nile. For example, Vail (1974) shows major SW-orientated faults between the Khor Abu Habl and Bara, presumably associated with the Umm Ruwaba basin. The overall impression is of the White Nile flowing northward from the enormous southern catchments in a channel confined between the updomed and faulted western margin of the Ethiopian highlands and the Nuba Mountains.

The Blue Nile in the Sudan is oriented at about 150°-160°, matching the direction of prominent lineaments in Precambrian rocks in Ethiopia. The geology of the lower Blue Nile in Ethiopia is virtually unknown but satellite imagery shows lineaments (Figure 10.2) and the map of Merla et al. (1973) shows faults similar in direction to the river. Figure 10.2 also shows that similarly oriented lineaments and wadis occur north, west and north-west of Khartoum. Mula (1972), Vail (1974) and Medani & Vail (1974) have mapped faults and fracture zones in the vicinity of Khartoum which match this orientation. The orientation of the Blue Nile, the Rahad and Dinder Rivers, and of the Gezira sedimentary basin, are undoubtedly influenced by these similarly oriented geological structures which are evident at both the upstream and downstream ends of the Blue Nile.

The presence along the lower Blue Nile of numerous thick deposits of pure volcanic glass of fluvial provenance shows that volcanic eruptions have blanketed the headwaters of at least part of the Nile system as recently as between 20 000 and 30 000 B.P. (Adamson et al., in press). The ash blanket was sufficiently substantial to choke and fill stream channels on the Gezira fan. The origin of the ashes is unknown but is most probably Ethiopian, thus indicating the direct and recent effect of vulcanism in Ethiopia on the Nile in the Sudan. The presence of volcanic ash deposits along the White Nile (Adamson et al., in press) suggests that ash may also have blanketed part of the south-western Ethiopian plateau. Quaternary volcanic activity along ENE alignments of cones

and craters is shown in this region by the survey carried out by the Omo River Project (1973-1976).

North of Khartoum the main Nile is closely confined by Precambrian basement, by Mesozoic Nubian Sandstones and by volcanic rocks. The Sixth Cataract of the Nile occurs where the river cuts a deep, narrow gorge through the Sabaloka ring complex. The river is superimposed, having cut through a covering of Nubian Sandstone before exploiting major joints in the basement. Figure 10.2 shows the frequency distribution of the joints and air-photo lineaments in the ring complex, calculated from the map prepared by Almond (Whiteman 1971a: Figure 12). There is a wide spread of orientations, as would be expected of a ring complex, but a preferential 50°-70° trend is evident, together with less well marked trends at c. 20° and 140-170°. Because of the fairly large sample of features measured, these trends are likely to be real. The main orientation of the Nile gorge across the ring complex is c. 70°, matching the regional ENE trend. In our view there is no conflict between superposition of the Nile and its exploitation of major lines of weakness within the underlying basement.

The course of the Nile north of Khartoum is notable for the gigantic bends as it flows towards Egypt (Figure 10.2). We suggest that the great bend immediately north of the Sixth Cataract was necessitated by updoming and volcanic activity in the Bayuda area. The Bayuda area within this great bend of the Nile is a Precambrian surface dotted with ring complexes, volcanic flows and vol-

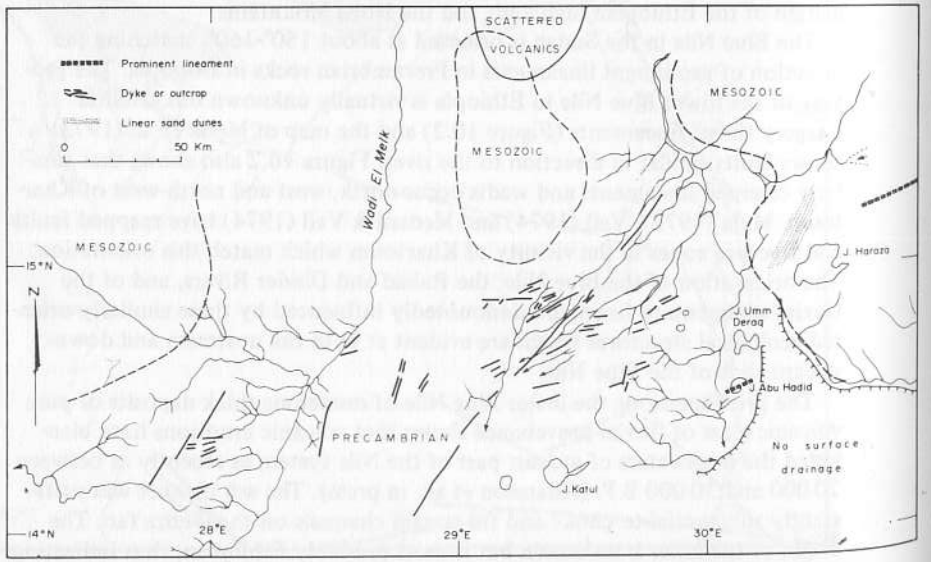


Figure 10.11. The headwaters of the Wadi el Melk, showing the relationship between dyke orientations and drainage, mapped from satellite imagery. Approximate geological boundaries are taken from Vail (1974). The 180 km lineament discussed in the text and shown also on Figure 10.2 appears at the eastern side of the map.

canic cones, some of which appear to be quite recent (Vail 1974). This situation indicates updoming of the Bayuda area preceding or accompanying the onset of vulcanism, followed by erosion of most of the overlying Nubian Sandstone. The eroded sand entered the Nile system or was carried short distances by local streams, dumped and then redistributed by wind. This could account for the major system of linear sand dunes to the south of the Bayuda area some 100 km NNW of the Sixth Cataract. Updoming and volcanic activity may also have caused ponding of the Nile near the Fifth Cataract, downstream of its junction with the Atbara River. Whiteman (1971a:96) draws attention to the possibility of ponding in the vicinity of the Atbara-Nile junction.

The Bayuda area also has prominent dykes and lineaments corresponding closely to the two major directions of ENE and SSE. The correspondence between these orientations and the direction taken by the Nile as it bends around the Bayuda dome is unlikely to be accidental. Whiteman (1971b) rejects fault control of the Nile in this region, but its detailed course is undoubtedly controlled by other structural features of the Precambrian basement and its former Nubian Sandstone cover.

It has been recognised previously that the Bayuda volcanic field and Jebel Marra, together with the Tagabo and Mahla volcanics, lie on a major zone of structural weakness which crosses Africa from the Gulf of Guinea (Vail 1972). The area between Jebel Marra and the main Nile north of Khartoum is also traversed by numerous prominent NE-ENE trending dykes and lineaments (Figures 10.2 and 10.11). Two sets of dykes, oriented at c. 40° and c. 70°, exert a strong influence over the drainage on the Precambrian basement in the headwaters of the Wadi el Melk and its tributaries (Figure 10.11). The 40° orientation is probably related to that in the Wadi el Ghalla region further south, while 70° is one of the dominant orientations noted throughout this chapter. One particularly prominent 70° lineament to the west of Khartoum can be traced for at least 180 km and appears to continue on the eastern side of the main Nile.

Near the border with Ethiopia a major lineament conspicuous on satellite imagery forms a SSE extension of the course of the Atbara River and can be traced south of the Tekazze River into Ethiopia (Figure 10.2). This lineament, which we refer to as the Atbara lineament, has not been represented on geological maps, but it corresponds to the boundary between a large area of volcanic rocks to the west and Precambrian rocks to the east (Vail 1974). The Atbara lineament, the main length of the Atbara River and the sector of the main Nile containing the Fifth Cataract are all co-linear, suggestive of structural control of the Atbara basin and part of the course of the Nile. This suggestion is reinforced by the remarkably parallel courses of the Atbara and Blue Nile in the Sudan, both rivers apparently being influenced by structures having SSE trends. Whiteman (1971a:167) considered that some overall structural control, such as a synclinal axis, was involved. North of the Third Cataract the Nile flows over Precambrian basement, and the angular course of the river suggests that it is continuing to exploit structural weaknesses.

10.6 THE LOWER NILE

Structural and tectonic control of the Nile and its tributaries is evident in Egypt. As in the south, the Nile is directed northwards in its overall course by the western rim of the Red Sea arch, and major segments of its course are controlled by fault and joint orientations. Said (1962) draws attention to the several sets of faults which traverse Egypt and which are particularly well exposed to the north-east and east of the country. He identifies them with a Red Sea (Erythrean) trend oriented SE, a N-S trend which he identifies with the East African metamorphic grain, and an approximately E-W (Tethyan) trend. These fault orientations are shown in his simplified tectonic map of Egypt which shows remarkable parallelism between SE-SSE faults and the Nile north of the Qena bend (Said 1962: Figure 3). These faults are shown in Figure 10.2, and match the orientation of the fracture lines and deep-seated tectonic zones mapped by Garson & Krs (1976) further south. Thus from Cairo to well south of Aswan the orientation of one major set of faults and zones of weakness corresponds to the SE-SSE orientation of substantial segments of the Nile and of the Red Sea. These features are frequently evident on satellite imagery. Bentz & Gutman (1975) conclude that the course of the Nile near Cairo is largely fault controlled and that these faults influenced the development of a gigantic erosional gorge some 3 000 m deep formed by the Nile at the end of the Miocene, presumably when the Mediterranean was an arid saline basin (Hsü et al. 1973).

A second major set of faults is oriented NE-ENE (Said 1962; Bentz & Gutman 1975). Garson & Krs (1976) show a large number of ENE fracture lines southwards along the western side of the Red Sea, some of which run inland to the Nile. They also extend offshore into the Red Sea and occur in Arabia, and according to Garson & Krs may have been important in guiding the direction of Red Sea spreading.

Yallouze & Knetsch (1954) analysed by means of 120 rose diagrams the orientations of a very large number of tributaries of the Nile between Aswan and Cairo. A selection of their rose diagrams in which the sample size was large is reproduced on Figure 10.2. This study shows how drainage follows orientations which bear a clear relation to some of the major structural directions and which are presumed to be joint controlled. Figure 10.2 also shows a histogram, compiled from the 38 largest samples of Yallouze & Knetsch, of the frequency of orientation of tributary streams. Their dominant orientation as they cross sandstone or limestone is SSE, conforming to the most prominent direction of weakness in the Precambrian basement and its sedimentary cover. Yallouze & Knetsch emphasise that geological structures in the basement are clearly expressed in the overlying sedimentary blanket. In this way, a river such as the Nile which may be superimposed from a sedimentary cover onto basement rocks can follow basement trends and structures with the need for only minor alterations of direction.

10.7 CONCLUSION

There is no doubt that the Nile basin and the detailed courses of its rivers have been strongly influenced by structural features and tectonic events. This chapter has described major changes to the margin of the basin resulting from Tertiary and Quaternary uplift and volcanic eruptions, as well as the occurrence of a major fault-bounded sedimentary trough which is the focus of drainage in the southern Sudan. The detailed courses of rivers such as the Bahr el Jebel, the Blue Nile, the Atbara, the main Nile and numerous tributaries are seen to be influenced strongly by important linear structures including dykes, joints, faults and geological contacts. The great bend in the main Nile north of Khartoum is probably due to diversion by vulcanism in the Bayuda area.

The geological lineaments which have exerted so strong an influence over the Nile basin and its drainage patterns have been shown to cluster about two preferred orientations: c. NE-NNE and c. SE-SSE, which bear a striking resemblance to the orientations of the Red Sea and the Gulf of Aden. We do not attempt here to assess the regional geological significance of these preferred orientations, nor do we wish to speculate about their origins. It is clear however from the evidence presented in this chapter that we are dealing with geological structures of great antiquity and of continental dimensions, which have guided both regional tectonics such as rifting, vulcanism and faulting, and the detailed courses of the Nile and its tributaries.

The evidence from this chapter is consistent with a considerable age for the Nile drainage system, without implying a continuous connection from southern Sudan to the Mediterranean. Climatic and tectonic events may have interrupted the connection, but there is little doubt in our view that the Nile basin is as old as the Tertiary rifting of Africa.

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11

Pleistocene history of the Nile Valley in Egypt and Lower Nubia

Histoire de la vallée du Nil en Egypte et en Basse Nubie au Pleistocène

La série du Cénozoïque supérieur de la Vallée du Nil en Egypte et Basse Nubie comprend une suite complexe d'alluvions nilotiques et autochtones, en partie interdigitées mais pas nécessairement en phase, de même que des paléosols qui leur sont liés et des formes d'érosion.

Cette série ne peut être interprétée sans des modèles géomorphologiques modernes, et sans s'appuyer sur une recherche cartographique détaillée, des analyses micro-stratigraphiques et des études sédimentologiques. En dépit de quelques lacunes, c'est l'une des plus complètes et des plus informatives disponibles pour le Sahara, et la seule qui démontre clairement l'interférence des tendances paléoclimatiques subméditerranéennes et subsahariennes.

La première moitié du Miocène fut caractérisée par le découpage de surfaces d'érosion étendues sous des conditions semiarides. La sédimentation deltaïque et l'effondrement des couches en Basse Egypte, accompagnés du basculement des blocs dans le Graben de Kom Ombo furent suivis par le soulèvement en forme de voûte des couches de la plateforme stable d'Egypte et par le surcreusement de la Vallée du Nil qui s'approfondit (568 m au dessous du niveau de la mer au Caire, 172 m au dessous du niveau de la mer à Aswan) en réponse à l'assèchement du Bassin méditerranéen vers 8 à 5 millions d'années B.P. Le Pliocène commença par une transgression marine, comprenant des schistes glauconitiques de faciès d'estuaire ou de lagune jusqu'au Sud d'Aswan (de −172 à −35 m). L'absence d'abondants dépôts détritiques bruts implique un climat subhumide. Le reste du Pliocène vit une accumulation de faciès lagunaires, lacustres et fluviaux grossiers, suggérant des conditions subarides, s'élevant de 120 à 130 m, comprenant des *Ostrea, Pecten et Anancus* dans le nord. Ils furent suivis, en Haute Egypte, de conglomérats massifs s'élevant jusqu'à 180 m.

La série de la première moitié du Pléistocène comprend 5 phases majeures d'alluvionnement provenant du Nil et des oueds locaux, sables mêlés de graviers ou graviers bruts tous d'origine locale, indiquant un environnement semi-aride. Les phases d'alluvionnement comprennent: 1) l'étage de Gallaba (3 sous unités, 60-74 m au dessus de la plaine d'inondation actuelle avec des plateformes fluviales associées), 2) l'étage de l'oued Allaqui (+50 −55 m, avec une pédimentation de bord de vallée et plus de 100 m de dépôts, localement), 3) les sous-étages de Dihmit et d'Adindan (+40 −48 m, +40 −42 m, le premier avec une pédimentation étendue de bord de vallée; le second avec de l'Acheuléen tardif *in situ*), 4) l'étage de Dakka (+30 −35 m, avec 120 m de dépôts dont la base est à 10 m au dessus du niveau de la mer; pédimentation de bord de vallée; Acheuléen *in situ*), et 5) l'étage de l'oued Korosko (2 sous-unités, +23 −25 m, +12 −15 m); comprend des faciès de silts – Formation de Dandara – avec des composants minéralogiques éthiopiens de même que de l'Acheuléen *in situ*. Des intervalles de creusement du Nil majeur (25-200 m d'amplitude) dans des remblais plus anciens, séparent ces unités alluviales, et au moins 2 paléosols majeurs inter-

médiaires, indiquant un climat subaride à subhumide, peuvent être identifiés: un Paleargid typique qui suit l'alluvionnement d'Adindan et un Haplargid typique subséquent à l'étage de l'oued Korosko et de Dandara.

Le Pléistocène supérieur semble commencer par les alluvions de conglomérats d'oueds en Nubie et à l'oued Kurkur, à une époque ou la plaine d'inondation du Nil était plus basse qu'actuellement. Après une nouvelle dissection, une calcification ou un concressionnement ferrugineux, l'alluviation de la Formation du Korosko inférieur commença bien avant 40 000 ans B.P. Une plaine d'inondation sableuse, en partie marécageuse, reflétait une activité d'oued accélérée, avec le complément d'un fort apport des eaux d'inondation éthiopiennes. Les dépôts de source correspondants à Kurkur semblent être contemporains du peuplement atérien. La formation de Korosko se déposa ensuite, après un creusement du Nil d'au moins 10 m, et représenta la plaine d'inondation enfoncée (+34 m en Nubie, +20 m à Kom Ombo) d'une rivière sableuse au réseau anastomosé avec des faciès mélangés du Wadi et du Nil; l'âge estimé est supérieur à 32 000-27 000 ans B.P. environ, avec des industries du Paléolithique moyen le long du Nil, et une occupation atérienne à l'oued Kurkur.

Les épisodes semi-arides du Korosko furent suivis par un climat hyperaride, l'invasion de la vallée par les dunes, et 34 m ou plus d'enfoncement du Nil. La formation suivante de Masmas représente une masse épaisse de silts d'inondation éthiopiens ayant atteint un remplissage de +33 m en Nubie mais seulement de +8 m près du Caire. C'est à la fois l'enregistrement de l'activité minimale de l'oued et les dunes interdigitiées qui impliquent un climat hyperaride en Egypte, mais la pente accusée, les chenaux de sable fréquents et le débordement sur une plaine d'inondation exceptionnellement large impliquent un substantiel débit de pointe du Nil. L'intervalle de temps estimé de 25 000-18 000 ans B.P. coïncide avec le peuplement de Khor Musan et d'Halfan (Paléolithique supérieur) en Nubie. Par la suite, les industries de la fin du Paléolithique ont proliféré sur la surface du sol stabilisée (Torrert vertisol), antérieurement à un enfoncement d'au moins 28 m ainsi qu'à l'invasion des dunes.

L'unité suivante, le Membre Darau de la Formation de Gebel Silsila représente une plaine d'inondation nilotique à 22,5 m en Nubie, à +13 m à Kom Ombo, +5 – 7,5 m à Esna-Quéna, et –5 m dans le nord de l'Egypte. Le gradient trop fort de la pente, l'apport du Soudan central de graviers de silex noir de Hudi, l'érosion des roches saines du socle à l'endroit des cataractes, les dépôts de la charge solide en relief, et les chenaux à déplacement et à bifurcation rapides, tous apportent des arguments en faveur d'inondations d'été vigoureuses et d'une grande efficacité. Un premier étage élevé, vers 17 000 ans B.P., fut accompagné d'un dépôt local accéléré et suivi par une récession mineure et une invasion de dunes ou formation vertisol. Ensuite, les sous-étages du haut-Nil à 14 500-12 500 ans B.P. coincidèrent avec un dépôt d'oued renouvelé, alors modéré. Un Nil 'sauvage', avec des inondations aberrantes d'une ampleur phénoménale, est indiqué vers 12 000-11 500 ans B.P., de multiples industries de la fin du Paléolithique, situées le long de la plaine d'inondation, furent dispersées à cette époque. Une brêve phase hyperaride suivit vers 11 500 ans B.P., avec au moins 20 m d'enfoncement du Nil, le dessèchement total de la Dépression du Fayum, et la formation du sol 'Paleorthid' calcaire.

Deux sous intervalles d'un nouvel alluvionnement nilotique à 11 200-7 700 ans B.P. et 7 300-6 000 ans B.P. représentent le Membre Arminna, Formation de Gebel Silsila, avec à nouveau une pente accusée (+15 m en Nubie, –8 m à Fayum), mais une absence dans le lit de faciès primaires et grossiers, comme pour le Nil actuel. L'activité accélérée des oueds en hiver, principalement à 11 000-8 000 ans B.P., n'était pas en phase avec les inondations d'été du Nil. Le peuplement épi-paléolithique se concentra sur la plaine d'inondation du Nil, plutôt que sur celles des oueds où un paléosol 'camborthid' subséquent indique des conditions subarides.

Après au moins 15 m d'enfoncement du Nil vers 6 000 ans B.P., la dernière plaine d'inondation non-fonctionnelle fut comblée durant les 5e et 4e millénaires avant J.C., c'est-à-dire pendant les époques Fayum 'A', Prédynastique et Groupe A. C'est le Membre Kibdi, Formation de Gebel Silsila, à +6 –7 m en Nubie, –8 m dans le Fayum. L'alluvionnement accéléré du Nil en été fut à nouveau saisonnièrement en opposition de phase avec l'activité accélérée des oueds en hiver.

11.1 INTRODUCTION

The Quaternary record of Egypt was first systematically studied by Max Blanckenhorn (1901) during many years of field work. This early framework was superseded by the comprehensive survey of K.S.Sandford for the University of Chicago Oriental Institute (Sandford & Arkell 1929, 1933, 1939; Sandford 1934). Despite a number of local studies between 1933 and 1960, and several attempts at revision of Sandford's schema of uniform geomorphic stages along the length of the Nile, a new era of fieldwork was predicated on the massive surge of research funding set into motion by the Nubian Monuments Campaign. The Nile Valley (Figure 11.1) from the Sudanese border to the Kom Ombo Plain was mapped in detail and comprehensively published by Butzer & Hansen (1968). The record of Sudanese Lower Nubia was examined by De Heinzelin (1968), while that of the Esna, Dendera and Dishna sectors of Upper Egypt, and of the northern Sudan was explored in the archaeological investigations of Wendorf & Schild (1976). Finally, the subsurface geology of the Nile and its delta has been partly elucidated as a result of deep borings related to dam construction, and water or oil exploration (see Chumakov 1967; Said 1975).

11.2 THE TERTIARY GEOMORPHIC SETTING

The extensive sedimentary plains, hill complexes, and tablelands of Egypt and the Libyan Desert owe their origin to continental, littoral and marine sedimentation of late Cretaceous to early Miocene age (Said 1962; Whiteman 1971), followed by extensive subaerial denudation during most of the Tertiary (Butzer & Hansen 1968:431ff.). The Tethys Sea covered Egypt during the early Eocene, but had receded northward to the latitude of the Fayum by late Eocene times. During the Oligocene, an ancestral Nile flowed across parts of the structural-erosional Libyan Tableland to empty into the Tethys north of the Fayum. Upwarping and faulting of the Red Sea perimeter was preceded or accompanied by widespread but localized vulcanism, probably in terminal Oligocene times. The major Kom Ombo Graben was first downfaulted at about this time, with further block tilting during the late Miocene; gravity breccias of Eocene limestone rest on or within steeply-dipping Esna Shales but are older than horizontal Pliocene strata (Butzer & Hansen 1968:23ff.; Sandford & Arkell 1933:10f.).

During the early and mid-Miocene, the ancestral Nile flowed along its present axis and extensive, coalescent pediment plains were cut across both the Nubian Sandstone and Basement Complex through much of Nubia, fingering into the Libyan Desert and Red Sea Hills. Three major stages, the Kurkur, Ballana and Aswan Pediplains, can be recognized, during which the land surface was reduced almost 200 m (Butzer & Hansen 1968:29ff., 210ff., 350ff.). Long intervals of semi-arid climate are implied (Table 11.1).

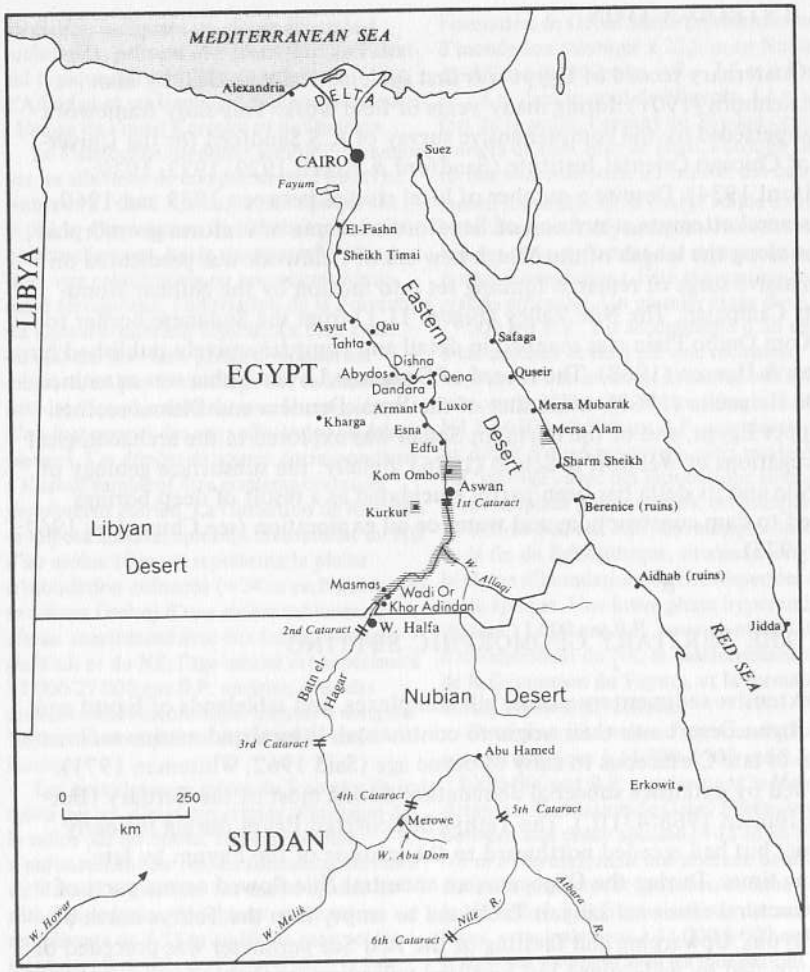


Figure 11.1 Location map of Egypt.

11.3 THE MIO-PLIOCENE OVERDEEPENED VALLEY

The Mediterranean Basin was separated from the world ocean during the late Miocene, and extensive evaporites indicate that there was no Mediterranean Sea ca. 8 to 5 million years ago (Hsü et al. 1973). Anhydrites were even deposited in parts of the Delta zone of subsidence (Said 1975). This interval saw entrenchment of the Nile into bedrock, to 568 m below modern sea level near Cairo (Said 1975) and 172 m below sea level near Aswan (Chumakov 1967). Although facilitated by fracture zones, and affected by epeirogenic impulses, this downcutting was pre-eminently a fluvial response to a phenomenally low base level.

A reconstituted Pliocene sea invaded the overdeepened Nile trench, depositing a 135 m suite of montmorillonitic clays, interbedded with sands, and rich in organic detritus, glauconite and zeolite, preserved at −172 to −35 m elevation as far south as Aswan (Chumakov 1967). The rare ostracods here suggest brackish water and estuarine conditions, with no evidence of arid zone, torrential run-off.

These early Pliocene beds are followed at Aswan by 110 m or more of thin-bedded sands, interbedded with gravels or clay lenticles (Chumakov 1967) and, near Kom Ombo, by at least 40 m of sands and gravelly sands, or shales with gypsum intercalations (Butzer & Hansen 1968:33ff). In the limestone segments of the Nile Valley between Luxor and the Fayum, there are over 60 m of calcreted quartz sands, marls with gypsum or gravelly interbeds, and chert or limestone conglomerates, showing complex horizontal as well as vertical, lenticular facies changes (Sandford & Arkell, 1933:6ff.; Sandford 1934:18ff.; Chumakov 1967). These beds, which lack fauna, include common gravity breccias or local tufa complexes adjacent to the Eocene limestones, and are best preserved within embayments of the Miocene Nile trench. Chumakov (1967) argues that the upper conglomeratic and breccioid units of the Valley of the Kings (the 'Issawia Formation' of Said 1962, 1975) which attain 180 m elevation, compared with a maximum of 120-130 m for Pliocene deposits at Cairo or Kom Ombo, may be younger than the sand unit at Aswan. However, the lowest part of this sequence ('Armant Formation' Said 1975) certainly represents a late Pliocene facies complex and must be considered coeval with the well-known marine *Ostrea-Pecten* beds, exposed northwest and southwest of Cairo to 121 m (Blackenhorn 1901; Sandford & Arkell 1939:13ff.). Of some interest is the Pliocene mastodon *Anancus osiris* recovered from the Giza Pliocene (Arambourg 1947). Overall, these late Pliocene beds suggest a degree of torrential runoff as well as abundant moisture in Egypt.

The Plateau Tufas of Kurkur and Kharga (Butzer & Hansen 1968:355ff., 515ff.) probably represent Libyan Tableland counterparts of the late Pliocene valley-margin tufas. At Kurkur they include two stratigraphic units (over 45 m), with basal clastic interbeds and occasional organic tufas in a thick body of travertine-like, laminated freshwater limestones. Deposited adjacent to a former drainage line, there are impressions of *Ficus* leaves, and a wide range of pollen, particularly of several palms and of acacia. Abundant water and a subarid or subhumid climate is suggested by all criteria.

11.4 EARLY TO MID-PLEISTOCENE ALLUVIAL HISTORY

11.4.1 *Introduction*

The Egyptian Nile alternately aggraded coarse gravels and cut down its bed into older, unconsolidated sediments during most of the Pleistocene. Similar sequences of aggradation and dissection can be verified for the larger tributary wadis, resulting in frequent development of suites of Nile or wadi terraces or both. Sandford (1934; Sandford & Arkell 1929, 1933, 1939) argued for the existence

Table 11.1 Miocene to mid-Pleistocene geomorphic evolution of the Nile Valley
(Tertiary chronostratigraphy after Berggren 1972; Pleistocene after Butzer 1974a)

Stratigraphy	Phase	Phenomena
	18	Nile dissection and wadi downcutting (at least 15 m).
	17	Pedogenesis, a red soil (typic Haplargid) with 1 m solum. Climate subarid.
	16	Nile and Wadi aggradation; Wadi Korosko substages at 23-25 m and 12-15 m above modern floodplain; includes Dandara Formation silt facies, with first Ethiopian summer-flood heavy minerals. Acheulian in situ. Climate semiarid.
	15	Nile and wadi dissection (at least 25 m).
	14	Nile and wadi aggradation (locally 120 m thick at Aswan), valley-margin pedimentation (Upper Egypt and Nubia); Dakka stage, 30-35 m above floodplain. Acheulian in situ. Climate semiarid.
	13	Major Nile downcutting (by some 135 m) to 10 m above sea level (Aswan).
	12	Major pedogenesis, a deep red soil (typic Paleargid) with 1-1.5 m B2 horizon and partial decomposition of igneous gravel to 6 m depth. Climate subhumid.
	11	Nile and wadi gravel aggradation, valley-margin pedimentation; Dihmit stage, 44-48 m above flood plain. After minor dissection, Adindan aggradation in southern Nubia at +40 to +42 m. Late Acheulian in situ. Climate semiarid.
	10	Nile and wadi dissection (at least 30 m).
	9	Nile and wadi gravel aggradation (locally 100 m) and valley-margin pedimentation; Wadi Allaqi stage, 50-55 m above floodplain, with substages. Climate semiarid.
	8	Major downcutting of Nile (by some 200 m or more) to 55 m below sea level (Aswan).
	7	Nile and Red Sea Hill wadis aggrade Gallaba gravels, 3 substages, 60-74 m above modern floodplain (Upper Egypt), or cut fluvial platforms (Nubia). Climate semiarid.
	6	Marine regression in Nile trench, with sands, gypsum shales and conglomeratic marls of fluvial, lagoonal or lacustrine facies (130 m in south), superposed by massive conglomerates, in part gravity breccias (180 m); Plateau Tufas (at Kurkur and Kharga); *Ostrea-Pecten* beds, with *Anancus* (120 m, in north). Climate subarid.
	5	Marine transgression into Nile trench, with glauconitic shales, of estuarine or lagoonal facies as far south as Aswan (−35 m and below). No torrential runoff; climate subhumid.
	4	Desiccation of Mediterranean Basin; uparching of Egyptian stable shelf; cutting of overdeepened Nile Valley (−568 m Cairo, −172 m Aswan).
	3	Deltaic sedimentation and downfaulting (Lower Egypt); block-tilting (Kom Ombo Graben); cutting of Aswan Pediplain (at 180-210 m) in Lower Nubia and Upper Egypt. Climate semiarid.
	2	Cutting of Ballana Pediplain (at 230-260 m) (Pediment II at Kurkur Oasis) in Lower Nubia. Climate semiarid.
	1	Cutting of Kurkur Pediplain (at 300-360 m) (pediment I at Kurkur Oasis) in Lower Nubia; fluvial or estuarine El-Khashab Red Beds (west of Cairo). Climate semiarid.
		Local vulcanism; upwarping (Red Sea Hills); downfaulting (Kom Ombo).

Pleistocene: Middle Pleistocene (0.13-0.7 x 10^6 yr); Lower Pleistocene (0.7-1.8 x 10^6 yr)

Pliocene: Late (1.8-4 x 10^6 yr); Early (4-5 x 10^6 yr)

Miocene: Late Upper (5-8 x 10^6 yr); Early Upper (8-10.5 x 10^6 yr); Middle (10.5-16.5 x 10^6 yr); Lower (16.5-22.5 x 10^6 yr)

of a repetitive terrace sequence of essentially constant gradient throughout Egypt and Lower Nubia. The three highest, at relative elevations of 80-100, 60-75 and 45-50 m, were believed to be Plio-Pleistocene and pre-Paleolithic. Two further terraces at 30 and 15 m, and a discontinuous feature at 22 m, were shown to include Acheulian artifacts. Several younger and lower features from 9 m above to well below modern floodplain were attributed to the time span represented by the Middle and Late Palaeolithic. Sandford attributed these supposedly synchronous terrace units to readjustments of the Nile River in response to eustatic fluctuations of Mediterranean base level. Subsequent work has shown that at least the older terraces north of the Asyut area cannot be directly linked with those in Upper Egypt and Nubia (Butzer 1959). Furthermore, even in southern Egypt the scheme does not stand up in detail in any one area nor in terms of its coherence (Butzer & Hansen 1968), although Sandford's field observations were basically sound.

11.4.2 *Lower Nubia*

The Pleistocene deposits and erosional features of a 277 km long, 3 km wide stretch of Egyptian Nubia has been mapped at 1:41 500 (Butzer & Hansen 1968: Figures K1-K10), and a generalized, 1:300 000 map is available for the adjacent Sudanese sector, north of the Second Cataract (L.Daels in De Heinzelin 1968).

Fluvial platforms, partly mantled by sheets of gravel, are well developed along more open stretches of the valley. These platforms are frequently continued, after a marked inflection, by inclined pediment surfaces of ferricreted sandstone, veneered with lateral wash. The major wadis of the east bank commonly have thick alluvial deposits along their lower courses. Deposits range from quartz sands with fine to medium-grade quartz pebbles (Nile facies upstream of major wadi confluences), to sandstone and ferricrete sandstone rubbles (near west bank wadis), to coarse-to-cobble-grade igneous, metamorphic and quartz gravel (downstream of and within major east bank wadis). This complex of wadi and autochthonous Nile gravels represents a bed-load facies lacking in suspended sediments, and for the most part moderately weathered. It is not surprising that subsaharan components are difficult to trace. Nonetheless fluvial platforms and conglomerates can be followed across the Basement Complex rocks of the Batn el-Hagar (Maley 1969, 1970; also satellite photography), well into Upper Nubia.

The Nile and the major wadis are not visibly overdeepened south of about Kalabsha. Episodes of downcutting did in fact involve a degree of bedrock incision, while terrace aggradation was accompanied by extensive bedrock planation. The resulting erosional forms are developed with some regularity and assist in linking isolated gravel exposures. Furthermore, the existing structural framework of Nubia (Butzer & Hansen 1968:20ff., Figure 5-1) does not influence terrace elevations in longitudinal profile. These features assist in geomorphic correlation of the alluvial sequences from one sector of the river to the next.

However, the alluvial components show more horizontal than vertical diffe-

rentiation; paleosols, although prominent, are little differentiated; and alluvial terraces are almost generally eroded or deflated, if not veneered with wash or eolian sands. Finally, there is no fauna whatsoever. These difficulties in dealing with the early to mid-Pleistocene record apply to all of Egypt, and render intraregional correlation difficult and any external correlations tenuous.

Bearing these caveats in mind, the following sequence of alluvial stages can be recognized in Egyptian Nubia (Butzer & Hansen 1968: chapter 5 and maps) (Figure 11.2):

1. Wadi Allaqi stage, +50 – 55 m, probably with two substages. Major lateral pedimentation; deep (B2 horizons 1-1.5 m), red paleosol – a typic Paleargid (according to Soil Survey Staff 1975 classification);
2. Dihmit stage, + 44 – 48 m. Major lateral pedimentation; deep, red paleosol (Paleargid);
3. Adindan stage, +40 – 42 m. Poorly represented in tributaries and absent north of Dakka; deep, red paleosol (Paleargid);
4. Dakka stage, +30 – 35 m, with possible lower substage. Moderate (B2 + B3 horizons 1 m) red paleosol – a typic Haplargid;
5. Wadi Korosko stage, +23 – 25 m, with lower substages recorded by several extensive Nile-cut platforms or localized wadi gravels; bedrock cutting of auxiliary Nile channels; moderate, red paleosol (Haplargid).

A datum to this sequence is provided by the Wadi Floor Conglomerate, a unit of up to 6 m of fine-to-cobble grade, cemented gravels that postdates weathering of the previous gravels as well as long-term subsequent dissection. It is projected to below modern floodplain, providing a convenient mid/late Pleistocene boundary in southern Nubia (Butzer & Hansen 1968:282ff.).

Sandford & Arkell (1933:26, 31) recovered Acheulian artifacts from Dakka stage gravels at Tumas and from a 15 m wadi gravel north of Wadi Halfa. Kleindienst (1972) describes evolved Acheulian found in situ within the Adindan-stage Nile gravels at the mouth of Wadi Or, but records no Acheulian surface sites on top of deposits of the Dakka and Wadi Korosko stages. Finally, Chmielewski (1968) excavated two rich, late Acheulian sites from wadisediments probably projected to the Wadi Korosko-stage Nile floodplain, at Arkin, in the northernmost Sudan.

Two or three major gravel stages are found west of the Nile in Sudanese Lower Nubia, but these have not been differentiated by De Heinzelin (1968; see also comments by Maley 1970), who labels them 'Pre-Nile Group' or 'Dabarosa Formation'. Although zigzag faults bound several pedimented sandstone blocks along the Egyptian-Sudanese border, in at least one instance gravel terraces traverse such a fault without evidence of disturbance (Butzer & Hansen 1968:232ff.). Nonetheless, faulting has affected the oldest conglomerates south of the Second Cataract (Maley 1970).

11.4.3 *Aswan, Kom Ombo Plain and Edfu*

An excellent sequence of thick alluvial gravels, partly exposed by deep bores around the Aswan Dam, is present near the southern end of the Miocene Nile trench. The oldest deposits post-dating the late Pliocene fluvio-lagoonal beds

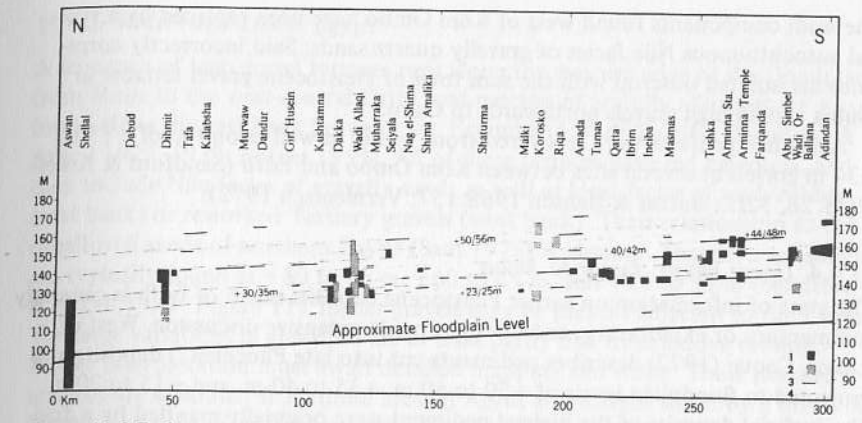


Figure 11.2 Early to mid-Pleistocene Nile and related Wadi gravels in southern Egypt. 1:autochthonous Nile gravels; 2: wadi gravels; 3: rock-cut fluvial platforms; 4: longitudinal profiles of major stages. After Butzer & Hansen (1968: Fig. 5-9), with permission of the University of Wisconsin Press (copyright).

are those of the Gallaba stage. Three fluvial substages are represented at +60 to 74 m (163 m maximum elevation) in a huge sweep of wadi gravels emanating from the Red Sea Hills via a series of braided channels (Butzer & Hansen 1968: chapter 2). This is the 'Villafranchian' 'Kubaniya suite' of Chumakov (1967), which cannot be readily correlated with the substantially higher Issawia gravels and breccias in the Luxor area. Subsequently, the Nile re-excavated its old trench to –55 m, and then deposited at least 75 m of fresh gravelly sand with clayey lenticles, the early Pleistocene 'Kundi suite' of Chumakov (1967).

The subsequent gravel terrace sequence of the Kom Ombo Plain has been mapped at 1:100 000 (Butzer & Hansen 1968: Figure 2-12) and can be correlated with that of Nubia by gradient projection: HT (High Terrace) I, +51 to 54 m, multiple Nile channels, Paleargid soil, Adindan stage; HT II, +40 to 43 m, multiple Nile channels, Paleargid soil, Dihmit stage; MT (Middle Terrace), +34 m, Haplargid soil, Dakka stage; and LT (Low Terrace) I and II, +22 m and +15 m, Haplargid soil, Wadi Korosko substages (Butzer & Hansen 1968: Table 2-2 and p. 265). Elevations of gravels and rock-cut platforms on the bedrock margins and within the graben are at identical levels, precluding Pleistocene faulting or downwarping. At Shellal, an alternative Nile bedrock channel is filled with 120 m of Dakka-stage gravelly sands (Chumakov 1967), indicating a major period of downcutting almost to sea level between the Dihmit and Dakka stages. This long erosional interval may or may not coincide with the protracted period of intensive biochemical weathering that significantly altered the Adindan and Dihmit gravels (Butzer & Hansen 1968:52ff., 252ff., 490ff.).

East of Edfu, Wadi Abbad has several prominent alluvial terraces: deeply weathered 'High Terraces' at +52 to 54 m and +42 m and a moderately weathered 'Middle Terrace' at +34 m; typical 'Low Terraces' are only preserved upstream (Butzer & Hansen 1968:63f.). Said (1975) describes a section from a late substage of the Gallaba gravels ('Idfu Formation'), south of Edfu, where

the wadi components found west of Kom Ombo have been replaced by a typical autochthonous Nile facies of gravelly quartz sands; Said incorrectly correlates his isolated outcrop with the sum total of Pleistocene gravel terraces in Nubia and all high gravels northwards to Cairo.

Acheulian artifacts were recovered from within as well as on top of +15 to +34 m gravels at several sites between Kom Ombo and Edfu (Sandford & Arkell 1933:28, 32ff.; Butzer & Hansen 1968:157; Vermeersch 1972).

11.4.4 *Upper Egypt: Luxor to Asyut*

The state of information on earlier Pleistocene deposits north of Edfu is generally rudimentary or exploratory, and does not merit extensive discussion. West of Luxor, Coque (1972) describes pediments cut into late Pliocene(?) deposits and projected to floodplain levels of +50 to 60 m, +35 to 40 m, and +15 to 20 m. The surficial deposits of the highest pediment were originally mantled by a duricrust of pink, calcareous silt embedding local rubble (brocatelli), in effect a calcreted red paleosol. The lowest of these pediments, which shows moderate reddish weathering, has alluvial counterparts in the wadis east of Luxor (Butzer 1959).

At the mouth of Wadi Qena there are extensive alluvial terraces of gravelly, well-stratified sands at +34 m and +23 m, as well as fragments of higher wadi floodplains at +70 m and +51 m (Butzer & Hansen 1968:64f.). Sections in a Nile counterpart of the +23 m wadi terrace at Dandara have been studied by C.V.Haynes (in Wendorf & Schild 1976:95ff.). This is a sand-silt, in part marly, over 20 m thick and with a moderate red paleosol (? Haplargid) on top, under gravelly wash or compact sands with Acheulian artifacts. An interbedded terminal tufa has a C^{14} date of greater than 39 000 B.P. Defined as the Dandara Formation, this unit can be readily correlated with the Wadi Korosko stage further south. It is clearly distinct from the similar facies of the Upper Pleistocene Korosko Formation (Butzer & Hansen 1968) by virtue of its minimum radiocarbon age, its paleosol, its Acheulian context, and its clay minerals (contrast F.A.Hassan, in Wendorf & Schild 1976: Figure E-1, with Butzer & Hansen 1968: Figure D-1), although its pyroxene-epidote index is comparable (Hassan 1976). The Dandara Formation is a valid stratigraphic unit of variable facies and lithology that could be used to define the Wadi Korosko stage. However, Said (1975) indiscriminately applies the name to thick (250-1 000 m or more), suballuvial sands in northern Egypt and beneath the Delta, which in fact have a different mineralogy (see Hassan 1976: Appendix 2). In this connection, there is as yet no valid 'Qena Formation' (a small body of surface sands embanked against the Dandara Formation in the type area, see Wendorf & Schild 1976: Figure 53). A similar sequence to that at Dandara, but with better exposures, is currently being studied by Vermeersch et al. (in press). An important, although secondary Acheulian industry is found in a +10 m rubefied wadi terrace resting on both thick sands and nilotic silts.

Alluvial terraces are well developed in the mouth of Wadi Asyut, and along the floodplain margins northwest and southeast of that city. Former floodplain levels at +70 m, +44 to 52 m, +25 to 30 m, and +12 to 15 m can be identified (Butzer 1959).

11.4.5 *Middle and Lower Egypt*

A sequence of high gravel terraces runs along the western edge of the floodplain from Minia to the west-central Delta, and patches of gravelly alluvium are also found along the east bank between the Fayum and Wadi Tumilat (Sandford & Arkell 1929, 1939; Butzer 1959). All of these terraces have red paleosols, and they include Nile facies of gravelly sands as well as local facies of wadi rubble (east bank) or reworked Tertiary gravels (west bank). Their relationship to the suballuvial sands of northern Egypt (Said 1975) is obscure. These terrace suites are typically found at +80 to 95 m, +60 to 65 m, and +25 to 35 m (Sandford & Arkell 1939: Figure 11); higher gravels may be present adjacent to the Fayum. The large variations in elevation are at least partly due to extensive erosion. Proper interpretation must await detailed mapping and study. These northern terraces are separated from those around Asyut and further south by a break of 80 km, and they may well be unrelated. A glacial-eustatic framework (see Butzer 1960) is possible, but not demonstrated, in that relative level of the +25 to 35 m terrace complex appears to decrease upstream, where terrace subdivisions at +22 to 32 m and +10 to 18 m can be identified south of the Fayum.

11.4.6 *Discussion*

The early to mid-Pleistocene evolution of the Nile Valley in Upper Egypt and Lower Nubia is summarized in Table 11.1. No attempt is made to incorporate the gravel terraces and suballuvial sands of northern Egypt into this scheme. The Adindan, Dakka and Dandara (Wadi Korosko) stages are all associated with evolved Acheulian artifacts, which in subsaharan Africa are older than 200 000 but probably younger than 500 000 years (see Butzer & Cooke, in press); this is the basis for assigning a Middle Pleistocene age for geomorphic phases 10 to 18 (Table 11.1). By exclusion, phases 7 to 9 represent the Lower Pleistocene.

The protracted periods of bedrock planation and long-distance, high-competence transport of coarse bed-load deposits recorded by the successive periods of aggradation (see Butzer 1976c: section 8-6) are interpreted to represent a substantially wetter, but seasonal and semiarid climate (Butzer & Hansen 1968:78ff., 226ff., 439ff.). The major red paleosol has argillic subsurface horizons with over 35% clay fraction, with kaolinite dominant, and is of rotlehm type, qualifying as a Paleargid. It implies a degree of geomorphic stability and a subhumid climate. The later red paleosol has montmorillonitic clays and an argillic horizon with intermediate clay levels and qualifies as an Haplargid. A subarid climate is suggested.

Almost all of the Pleistocene gravel-sand units can be attributed to regional runoff from the Red Sea Hills, feeding the Nile via a series of major east bank wadis. As late as the Dakka stage, these bed-load deposits essentially lack the pyroxenes characteristic of heavy mineral suites derived from Ethiopia by the modern, summer flood regime (see Chumakov 1967; Hassan 1976). The Dandara Formation provides the first evidence for large-scale influx of subsaharan, nilotic suspended sediment into Egypt (Hassan 1976). This does not preclude earlier summer floods from Ethiopia (Butzer & Hansen 1968:79, 435), but it does indicate that regional runoff was decreasing in significance, and that subsaharan

discharge had for the first time assumed relative prominence in Egypt. Such an interpretation finds support in the presence of Ethiopian pollen (*Podocarpus gracilior;* tropical Ericaceae; Acanthaceae; Pedaliaceae) and spores (tropical ferns) in Calabrian marine deposits downcurrent of the Nile (Maley 1969).

11.5 LATE PLEISTOCENE TO HOLOCENE NILOTIC HISTORY

11.5.1 *General*

The geomorphic evolution of the Nile Valley until the late Middle Pleistocene was dominated by local hydrographic dynamism, with major wadis supplying the bulk of the run-off and sediment redistribution by the Nile. The Dandara Formation records the beginning of a gradual shift to the more familiar summer-flood regime, probably no later than 200 000 B.P. An arbitrary but convenient datum for the base of the Upper Pleistocene is provided in southern Lower Nubia by the Wadi Floor Conglomerate, which predates three major lithostratigraphic units that serve as distinctive markers through most of southern Egypt (Figure 11.3).

11.5.2 *Lower Nubia and the Kom Ombo Plain*

11.5.2.1 *Wadi Floor Conglomerate.* Some 5 or 6 m of well-rounded cobble conglomerates may overlie the potholed, bedrock floors of Nubian wadis. They imply a local base level at or below modern floodplain, and record a last episode of high wadi competence in valleys now transporting little coarser than sand-grade particles. This Wadi Floor Conglomerate was indurated by calcareous or ferruginous cements, but not rubefied, prior to renewed erosion (potholing) and accumulation of the quasi-nilotic Korosko formation (Butzer & Hansen 1968: 282ff.). In the Kom Ombo region, the Wadi Floor Conglomerate may be present well below modern floodplain.

11.5.2.2 *Korosko Formation.* Resting on top of the Wadi Floor Conglomerate is a complex of white to light brownish grey marls, sands and sandy gravels, extensively discoloured by limonitic mottling (Butzer & Hansen 1968:87ff., 266ff.). Facies range from valley-margin, subaqueous lime muds, intercalated with wadi sands or gravels, to fluvial, calcareous sands. Locally, root casts and rootlet impressions are conspicuous, recording a floodplain vegetation of grasses and shrubs. Evaporite interbeds (halite) are common near the eastern edge of the Kom Ombo Plain. In the mouths of the smaller wadis, local stream detritus normally interdigitates sharply with marly nilotic materials, indicating winter wadi discharge onto a dry floodplain, although a few ponds persisted where wadi sands were washed into standing waters. The overall facies arrangement suggests a braided stream complex along the Nile axis. An abundance of sorted sands along the west bank (Butzer & Hansen 1968:241, Figure 6-10) further indicates fluvial reworking of eolian sands (occasionally identified as dunes by De Heinzelin 1968, in default of sediment and clay mineral analyses).

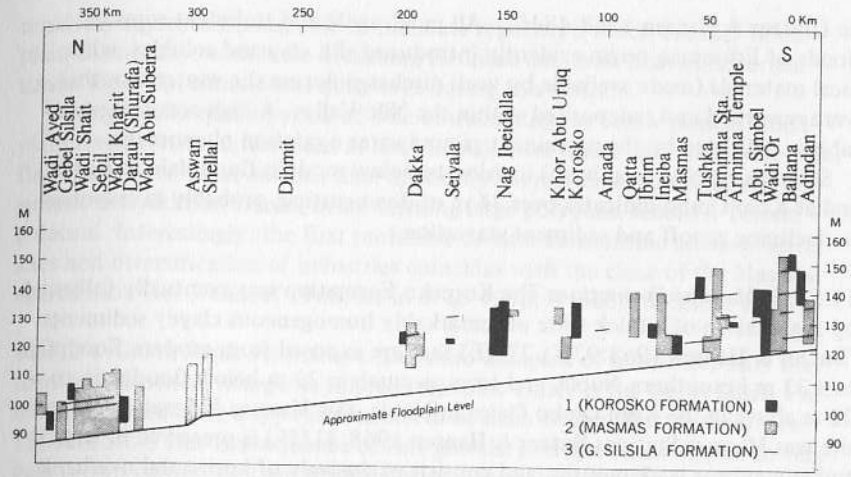


Figure 11.3 Late Pleistocene to Holocene nilotic deposits in southern Egypt. Vertical range of sediments is shown for the Korosko and Masmas formations, but maximum outcrop elevations (only) are shown for the several members of the Gebel Silsila Formation. After Butzer & Hansen (1968: Fig. 6-1), with permission of the University of Wisconsin Press (copyright).

The Korosko Formation (type area at New Korosko near Kom Ombo; Butzer & Hansen 1968:124f.), culminates as a graded floodplain deposit, dropping from +34 m near the Sudanese border to +20 m on the Kom Ombo Plain. Its base is everywhere found below modern floodplain. Two members, separated by considerable downcutting, can be verified in Wadi Or (Butzer & Hansen 1968:271, 296ff), where the lower, silty unit attains +11 m (top eroded) and was dissected to bedrock prior to accumulation of the upper, sandy unit to +22 m (top eroded). This upper member, generally represented in Nubia and at Kom Ombo, has a minimum radiocarbon date of 27 250 B.P. Aggradation of perhaps 50 m of deposit, separated by at least 10 m of erosion, presumably required tens of millennia overall. An early Upper Pleistocene age range seems indicated.

Mammalian faunas are absent from the Korosko Formation, but mollusca are found in marly, low-energy deposits of the Kom Ombo Plain. Most common are *Planorbis, Valvata* and *Bulinus,* all snails preferring stagnant or slowly-moving waters, with occasional *Lymnaea* and *Corbicula* (Butzer & Hansen 1968: 510). Artifacts are rare, but some large and unpatinated flakes in situ in Wadi Or may imply penecontemporaneous Middle Paleolithic occupation of the area (Butzer & Hansen 1968:272, 301).

The heavy minerals of the Korosko Formation have high pyroxene counts, and pyroxene/epidote ratios only slightly lower than those of modern Blue Nile-Atbara flood silts (Butzer & Hansen 1968:467ff.; Hassan 1976). The clay mineralogy is pre-eminently that of montmorillonite and interlayered illite/mica, with secondary but distinct maxima of kaolinite; the latter may indicate a higher component of White Nile drainage than subsequent nilotic formations

do (Butzer & Hansen 1968:484ff.). All in all, swift and turbulent summer floods of Ethiopian origin evidently introduced silt, clay and solubles, while local materials (made available by wadi discharge during the winter months) were reworked and redeposited within the Nile Valley. A high seasonal water-table is indicated by the prominent groundwater oxidation phenomena.

Subsequent Nile (and wadi) incision to below modern floodplain in Nubia and at Kom Ombo indicates over 34 m of downcutting, probably in response to declining runoff and sediment starvation.

11.5.2.3 *Masmas Formation.* The Korosko Formation was eventually followed by aggradation of a thick suite of remarkably homogeneous clayey sediments (Butzer & Hansen 1968:97ff., 272ff.) that are exposed from modern floodplain to +33 m in southern Nubia, and from as much as 33 m below floodplain to 22 m above in the Kom Ombo Plain. In Nubia, this Masmas Formation (type site was Masmas Station; Butzer & Hansen 1968:311ff.) is preserved in large embayments or wadi mouths, and consists exclusively of horizontal overbank deposits, i.e. flood silts and local sand splays, varying in texture from clayey sand to clayey silt, with carbonates increasing away from the river. In the Kom Ombo Plain the Masmas Formation is prominently developed and ranges in facies from marly beds or massive, slickensided clayey silts to sandy deposits in clearly defined channel fills. Colours range from brown to dark greyish brown, and structure is strong, blocky to prismatic, depending on clay content. Terminal networks of deep (1.5 m) polygonal cracks, filled with younger wash or evaporites, are characteristic and indicate a floodplain vertisol (Torrert). Intercalated wadi deposits are rare and reflect minimal discharge from the Egyptian tributaries.

The Masmas Formation represents a continuous sequence of periodic Nile aggradations, over 50 m thick. Excellent channel sections near Kom Ombo indicate meandering primary and secondary channels, with coarse levee deposits and root drip, interdigitated with extensive sand splays. Flood silts are the dominant facies, however, with reducing backswamps verified at the eastern end of the plain by sulfide-rich silts with *Planorbis, Valvata* and *Bulinus.* In Sudanese Nubia the Masmas Formation is identical with the Dibeira-Jer (ex-Khor Musa) Formation (De Heinzelin 1968), which has a (revised) radiocarbon date of 20 900 B.P. (WSU-203) in its uppermost part and underlies younger deposits with a basal date of 18 800 B.P. Terminal dates of 18 300 and 17 000 B.P. obtained on marls of the Kom Ombo Plain are probably contaminated by younger carbonates and too young. A mid-Upper Pleistocene date of ca. 25 000-18 000 B.P. seems a reasonable estimate on available evidence.

There is next to no mammalian fauna in the Masmas unit, and archeological associations are rare and essentially confined to Sudanese Nubia. They include the Levalloisian flake industry known as Khor Musan (see Wendorf 1968) as well as the first of several microlithic, blade industries of Late Palaeolithic type, the Halfan, found in terminal Masmas beds (Irwin et al. 1968).

The heavy minerals and clays indicate that the Masmas deposits are typical summer flood residues, perhaps with a slightly greater White Nile component (Butzer & Hansen 1968:470f., 484ff.; Hassan 1976). They record a period of

relatively vigorous floods, able to inundate regularly a much broader floodplain than today, with levee-breaching far more common than in historical times. Egyptian climate was quite arid during this episode.

During a subsequent period of Nile downcutting (to below present floodplain level, vertical differential at least 28 m), local wadis dissected these older floodplain silts. At about this time or shortly thereafter slickensides and epigenetic dehydration cracks, often forming large polygons, record a Torrert paleosol. Interestingly, the first profusion of Late Palaeolithic archaeological sites and diversification of industries coincides with the close of the Masmas aggradation (see Wendorf 1968; Irwin et al. 1968; Wendorf & Schild 1976).

11.5.2.4 *Gebel Silsila Formation.* The third complex of nilotic deposits that form a convenient, mappable lithostratigraphic entity is the Gebel Silsila Formation, named after a type section north of Kom Ombo (Butzer & Hansen 1968:132ff.). This is a sequence of fine gravels, silts and sands of pale to very pale brown colour, that are readily distinguished from the Masmas Formation; they are lighter, sandier, rarely clayey, poorly structured, and often lenticular, with gravelly interbeds. This episode includes three major phases of nilotic aggradation, separated by effective downcutting, so that subdivisions, the Darau (oldest), Arminna, and Kibdi (youngest) members, are necessary. The facies of these members are more or less identical, so that field mapping must be based on ancillary geomorphic criteria. For these reasons, a single formation is maintained by the rules of stratigraphic nomenclature, which considers formations as lithostratigraphic units suitable for extensive field mapping. The disposition of the members is as follows:

a. Darau Member. These deposits exceed 18 m in thickness, and attain +22.5 m in southern Nubia, +13 m at Kom Ombo, with an oversteepened gradient of 1.17 in 10 000 (compared with 0.94 today). Due to this gradient, the younger members are mainly suballuvial north of about Kalabsha, and several channel stages of the Darau Member only are recorded on the Kom Ombo Plain: +11 to 13 m (ca. 17 000-14 500 B.P., 4 radiocarbon dates), +9 to 10 m (ca. 14 500-13 000 B.P., 10 radiocarbon dates), and +8 m (ca. 12 500 B.P., 1 date). Finally, there was an episode of at least several centuries, shortly after 12 000 B.P., during which Nile floods sporadically attained +22 m at Kom Ombo and +30 m at the Sudanese frontier, i.e. 8 to 9 m above the general floodplain of the time. No terraces were created, but clayey flood silts (up to 3 m maximum thickness) were laid down in sheltered areas beyond the active floodplain. This dramatic episode of a 'wild' Nile must reflect unusual climatic anomalies in subsaharan Africa. Post-Darau floodplain dissection amounted to at least 7 m in Nubia and 9 m near Kom Ombo.

b. Arminna Member. These deposits are at +15 m in southern Nubia, where they date to 11 200-8 000 B.P., but at only +4 m year Edfu ('El-Kab Formation'; Vermeersch 1972, 1976), where they date to ca. 8 400-7 700 B.P. There are fewer bed-load deposits in the Arminna than in the Darau Member, except where Darau beds have been eroded and reworked. Maximum thickness recorded is 12 m, and subsequent dissection was at least 15 m.

c. Kibdi Member. Related deposits at +6 to 7 m in southern Nubia are poorly dated but culminated in the 4th millennium B.C. They comprise flood silts or gravel lags reworked from older beds, and were dissected when flood levels declined significantly at the beginning of the Dynastic era (Bell 1970).

The Darau and Arminna-Kibdi members of Butzer & Hansen (1968) compare reasonably well with the Sahaba and Arkin formations of De Heinzelin (1968) and must be considered as equivalent and essentially interchangeable units on either side of the Egyptian-Sudanese boundary (despite revisionist views expressed by Wendorf & Schild 1976:273ff.). Within the Sahaba, De Heinzelin (1968) additionally recognizes a minor recession accompanied by vertisol formation. His inter-formational 'regressional' units, the Ballana and Birbet 'formations', are eolian deposits that valuably complement the nilotic record along the wind-sensitive western margins of the valley. They evidently provide different information than the multiple fluvial units interdigitated along the wadi-sensitive eastern margins, as described further below.

The Darau Member at Kom Ombo, and the Darau-Sahaba and Arminna-Arkin in Southern Nubia include a host of Late Palaeolithic sites (see various authors in Wendorf 1968; Irwin et al. 1968; Smith 1968, 1976; Phillips & Butzer 1975). A-group materials are found in the Kibdi. The Darau unit has provided a considerable faunal inventory, generally associated with archaeological occurrences. A range of habitat-specific riverine, bush, and grassland mammals are represented, modern except for the buffalo *Homoioceras*, but conspicuously lacking certain Ethiopian forms: elephant, rhino and giraffe (Churcher 1972; Gautier 1968; C.A.Reed & P.F.Turnbull, unpublished). A remarkable avian fauna, including many seasonal migrants, is also present (Churcher 1972). The molluscan faunas of Sudanese Nubia are described by Martin (1968).

11.5.2.5 *Interpretation of the Gebel Silsila Formation.* The Darau Member of the Gebel Silsila Formation pertains to channel and levee environments of a rather more vigorous and competent Nile. Horizontal flood silts are rare; instead, former shoals of bed gravels or sands interfinger with laterally embanked topset and backset strata. Coarser grade bed loads and a striking incidence of shifting or braided channels indicate greater competence and rapid sedimentation rates. Relative proportions of clay minerals and heavy minerals are, for the first time, almost identical to those of today.

However, the gravels are marked by an influx of exotic flint, chert, chalcedony, agate, jasper and carnelian – most of which are totally absent from older deposits, and are derived in good part from the Hudi Chert outcrops in the central Sudan. Flushing of chalcedony, agate and carnelian pebbles through local Sudanese wadis into the Nile, and from there northwards along the length of the Egyptian Nile valley, requires not only abundant runoff in the central Sudan but an unusually great, if periodic, Nile flood competence – one that transports little coarser than pea-sized gravel today.

This image of a high-competence Nile is supported by the presence of abundant medium-grade pebbles of granite, aplitic feldspar and schist at Kom Ombo, that were derived from vigorous erosion of the Basement Complex rocks

between Aswan and Kalabsha. The argument is completed by the surge of unworn quartz sand grains that appears both at Kom Ombo and in Nubia simultaneously with the Hudi Chert gravels, indicating fresh erosion of the cataract floors (Butzer & Hansen 1968:111f., 330f., 478). The vigorous Darau floods remain difficult to explain in terms of the complex climatic zonation of the Nile Basin in Upper Nubia, Ethiopia, and the White Nile drainage components, on the one hand, and the question of peak discharge versus overall flood volume, on the other.

It is unlikely that fresh Sudanese gravel components were introduced to Egypt during the Arminna and Kibdi stages, when most gravel was deposited as lags or in shoals embanked against eroded Darau silts. This implies less vigorous floods than during the Darau substage. The brief periods of effective dissection before 11 200 and again after 7 900 B.P., like that after 3 000 B.C., can best be related to rapidly declining flood discharge and sharply reduced sediment load. However De Heinzelin's (1968: Figure 5) 'Nile high-water curve' does not provide an estimate of Nile discharge but, instead, records changing, absolute floodplain elevations.

11.5.3 *Upper Egypt: Edfu to Dishna*

The Masmas Formation, as a distinctive lithological entity, can be traced along the western margins of the Nile from 13 km south of Edfu (at +18 m, possibly overlying Korosko Formation; see Sandford & Arkell 1933:45f.), past Edfu-Hierakonpolis (+15 m; Butzer 1961) and Armant (+7.5 m, interbedded with eolian sand; Sandford & Arkell 1933:47) to south of Luxor (+6 m). Typical exposures of the Gebel Silsila Formation are not found in this area.

However, near Esna, Wendorf & Schild (1976:43ff., Table 15, Appendices) have developed an informative sequence of younger flood silts, pond deposits, and dunes of terminal Pleistocene age that are situated on top of typical Masmas outcrops, locally at +5 m. A massive unit of dunes is interbedded with the top of the heavy Masmas silts, with the earliest occupation on top of these dunes (Site E71K1) dated 18 020 B.P. At El-Saayda (El-Kilh), between Esna and Edfu, a series of occupations on top of the Masmas silts (here interbedded with eolian lenticles as at Armant) are dated 16 950-17 800 B.P. (Wendorf & Schild 1976:27ff.), leaving no doubt about a firm correlation of the Masmas litho units in this area with those at Kom Ombo and points further south. The dunes are not exactly dated: site E71K1 suggests they were blown up during the period of Nile dissection ca. 18 000-17 000 B.P., whereas at E71K9X a similar (identical?) dune rests on pond deposits dated at 16 830 B.P. that in turn rest on an eroded surface of Masmas silt. Since no geological mapping was undertaken by Wendorf & Schild (1976), and since the sum total of granulometric work consists of thirteen sand-sieve analyses (Appendices C and F), this stratigraphic problem must remain unresolved. It is possible, however, that E71K9X records seepage from a high Nile stand coeval with the earliest phase (Channel A) of the Darau Member.

Above a possible paleosol, a sequence of pond deposits with interesting diatom floras was laid down within the interdunal swales near Esna, in response

to lateral seepage, from Nile floods at some 7 m above modern floodplain (see Wendorf & Schild 1976: Figures 37 and 49), mainly prior to 12 690 B.P. Nilotic silts shortly thereafter overwhelmed the area to about +7.5 m. Correlation with the terminal units of the Darau Member at Kom Ombo is reasonable.

Further north, near Dandara, the post-Masmas dunes are represented under late Darau silts (+5 m) that have a basal date of 12 500 B.P. (C.V.Haynes in Wendorf & Schild 1976:102ff.). Across the river, near El-Makhadma, nilotic sands (+4 m) with mollusca are dated ca. 13 380 B.P. (Wendorf & Schild 1976: 113ff.) and rest on slope wash that locally mantles possible Masmas silts. Finally at Dishna there is an interesting sequence of interdigitated Nile silts (no elevation given), pond deposits, and wadi detritus, unfortunately lacking in radiocarbon dates (Wendorf & Schild 1976:121ff.). Potential parallels with interdigitated Darau silts and wadi formations at Kom Ombo remain to be explored.

The complex post-Masmas deposits recorded between Esna and Dishna complement the Darau time-stratigraphic record at Kom Ombo, but the lack of stratigraphic and radiometric precision at present limits their utility in defining useful subdivisions for the Darau. Most importantly, perhaps, the Esna-Dishna sector provides a sequence of Late Palaeolithic archaeological sites.

Recent work in northern Upper Egypt by Vermeersch et al. (1977) promises to fill major lacunae. At several sites near Abydos, Middle Palaeolithic industries with Levallois technique but very few retouched tools were recovered from wadi terraces or fans. At Nazlet Khatir, near Tahta, a mint workshop assemblage was located in mixed wadi-nilotic gravels that overlie calcareous silts recalling the Korosko Formation.

11.5.4 *Middle and Lower Egypt*

After another spatial break, the next deposits of late Pleistocene aspect downstream are found 5 m and more below the modern floodplain at Qau (with an interesting mammalian fauna), Sheikh Timai, and El-Fashn (Sandford 1934: 86ff., 95). The presence of agate pebbles in a gravelly sand facies suggests the Gebel Silsila Formation. The sporadic +7 to 9 m fine gravel terraces adjacent to the Fayum and near the head of the Nile Delta (Sandford & Arkell 1939: 54ff., 79f.; Caton-Thompson 1946) are difficult to relate to southern Egypt but are partially clarified within the Fayum Depression (see below). It is probable that the thick body of micaceous sands intercalated between the modern flood silts and the older gravelly sands beneath the Nile Delta (Butzer 1974b) relate to the Gebel Silsila Formation, and that they fill a deep delta valley cut in response to the maximum of the Last Glacial eustatic regression.

The nilotic component of the shelf and deep-sea sediments off the Nile Delta is difficult to interpret, since such off-shore accumulations are affected by base level changes, shoreline distance, alluvial gradients in Lower Egypt, nilotic sediment composition, mean Nile volume, and peak discharge. Stanley & Maldonado (1977) identify three late Pleistocene cyclothems dating ca. 58 000-28 000 B.P., 28 000-17 000 B.P., and 17 000 B.P. to present, in reasonably close analogy to the Korosko, Masmas, and Gebel Silsila formations. Maximum sedimentation rates along the submarine Nile cone, suggestive of above-average suspended sediment transport and summer flood discharge, are indicated ca. 28 000-23 000 B.P. and 17 000-5 700 B.P., coincident with the terminal Korosko or early Masmas on the one hand, and the Gebel Silsila on the other.

11.5.5 *Fayum Depression*

The Fayum Depression provides a low-level adjunct to the Nile Valley recording many late Pleistocene to Holocene events otherwise obscure in northern Egypt. The behaviour of the fluctuating lakes within the basin depends on Nile floodplain level and possible blocking sediment at the Nile-Fayum entrance.

A number of beaches developed along the eastern and south-eastern margins of the basin have artifacts, primarily worn, and can be correlated altimetrically with features in the adjacent Nile Valley. A beach at 34 m above sea (not lake) level matches the +8 m fine gravel terrace along the Nile, and both have Middle Palaeolithic implements (Sandford & Arkell 1929:37ff.; Sandford 1934:92ff.; Caton-Thompson, Gardner & Huzayyin 1937; Caton-Thompson 1946). Two lower beaches at 28 m and 22.5 m have Late Palaeolithic implements and may correlate with agate-pebble sands (Gebel Silsila Formation) below Nile floodplain. The related molluscan assemblage of the Idwa Bank has been described by Gardner (1932). These older features deserve further study.

The Holocene record of the northern Fayum has been substantially clarified by recent work (see Wendorf & Schild 1976:155ff.). Older diatomites and lacustrine sands, presumably related to the Idwa stage, were desiccated at some time prior to 8 100 B.P., when a Nile-fed lake was recreated and soon reached 17 m. After a recession to below 12 m another high lake phase attained 24 m about 7 140 B.P., then falling to below 9 m. Subsequent high stages of 17-20 m date in the main part to the 5th and 6th millennia B.C. and the early Old Kingdom. These lake fluctuations within the Fayum provide critical data on Nile behaviour during the late Arminna time span. In combination with Vermeersch's (1972, 1976) El-Kab dates in Upper Egypt, they infer two subdivisions of the Arminna, with high Nile levels ca. 11 200-7 700 and 7 300-6 000 B.P.

11.6 LATE PLEISTOCENE TO HOLOCENE WADI HISTORY

Although the late Pleistocene Nile was governed by hydrographic events in the Sudan and Ethiopia, the role of the Egyptian tributaries is critical to proper evaluation of the regional setting. Furthermore, since no systematic information is available on wadi behaviour north of the Kom Ombo Plain during this time span (see Butzer 1959), it is useful to draw in complementary information from Wadi Kurkur, to the west of Aswan, and from the Red Sea littoral, east of Edfu. These data allow a more representative picture to be presented by way of conclusion.

11.6.1 *Lower Nubia and the Kom Ombo Plain*

Subsequent to the Wadi Floor Conglomerate of Nubia, several phases of accele-

Table 11.2 Late Pleistocene and Holocene geomorphic evolution of the Nile Valley

Phase	Phenomena
14	Historical records of declining flood levels (with floodplain readjustment) 3 000-2 800 B.C., catastrophic low floods 2 250-1 950 B.C., repeated excessive floods 1 840-1 770 B.C., declining floods 1 180-1 130 B.C., increasing again A.D. 600-1000. Egyptian climate generally hyperarid.
13	Aggradation of Kibdi Member, Gebel Silsila Formation; +6 to +7 m in Nubia, suballuvial north of Aswan, 17-20 m lake in Fayum; mainly Ethiopian flood silts, indicating higher Nile sedimentation rates with steeper floodplain. Active slope denudation and accelerated wadi activity reflecting winter rains (Shaturma Formation, Member I); 5th and 4th millennia B.C. Fayum A, Predynastic and A-Group. Climate arid but slightly wetter.
12	Nile and wadi dissection (at least 15 m), ca. 5 000 B.C. (6 000 B.P.).
11	Aggradation of Arminna Member, Gebel Silsila Formation; +15 m in Nubia, +4 m at Edfu, suballuvial in north, and 17-24 m lake levels in Fayum. Two phases 11 200-7 700 B.P. and 7 300-6 000 B.P., separated by regression; mainly Ethiopian flood silts, indicating higher Nile sedimentation rates with steeper Nile floodplain. Accelerated wadi activity before 8 000 B.P. reflecting winter rains (Sinqari Member, Ineiba Formation); paleosol (Omda soil: Camborthid) later. Epi-Paleolithic settlement (Arkinian, Shamarkian). Climate arid to subarid.
10	Nile and wadi dissection (at least 20 m) and total desiccation of Fayum Depression ca. 11 500 B.P. Climate hyperarid.
9	Aggradation of Darau Member, Gebel Silsila Formation; +22.5 m in Nubia, +13 m at Kom Ombo, +7.5 m at Esna, +5 m at Dandara, suballuvial (−5 m) in Middle Egypt and under Delta, and 22.5-28 m lakes in Fayum. Oversteepened gradient, Ethiopian flood silts, influx of Hudi gravel from central Sudan, fresh bedrock erosion in cataract areas, prominent bed-load deposits and rapidly shifting, bifurcating channels, all indicate vigorous, high-competence summer floods. First high stage ca. 17 000 B.P. accompanied by accelerated wadi activity (Malki Member, Ineiba Formation); followed by minor Nile recession, with dune invasion of Esna floodplain, vertisol in Sudanese Nubia; several high substages 14 500-12 500 B.P. coeval with moderate wadi activity; culminated by 'wild' Nile ca. 12 000-11 500 B.P. and development of calcareous paleosol (Adda Soil: Paleorthid). Late Palaeolithic settlement (including Halfan, Idfuan, Sebilian, Affian, Sebekian, Qadan, Silsilian and Isnan). Climate mainly arid but slightly wetter.
8	Nile and wadi dissection at least 28 m, considerably more in northern Egypt); dune fields invade floodplain at Esna and in western Nubian valley; formation of vertisol (Torrert) on old floodplain. About 18 000-17 500 B.P. Late Paleolithic settlement (Khor Musan, Halfan, Idfuan, Fakhurian, Ballanan). Climate hyperarid.
7	Aggradation of Masmas Formation; +33 m Nubia, +22 m Kom Ombo, +18 m Edfu, +7.5 m Armant, probably +8 m Cairo and related 34 m Fayum lake. Mainly Ethiopian flood silts, inundating an unusually broad floodplain, with frequent sand splays and an oversteepened gradient in the south, all infer substantial Nile peak discharge. Minimal local wadi activity and interdigitated dunes in western valley. Estimated age 25 000-18 000 B.P. Late Palaeolithic settlement (Sudanese Nubia only: Khor Musan, Halfan). Climate hyperarid.
6	Nile and wadi dissection (at least 34 m); dunes in western Nubian valley. Climate hyperarid.
5	Aggradation of Korosko Formation, upper member; +34 m Nubia, +20 m Kom Ombo, not yet verified north of Edfu, indicating oversteepened Nile gradient. Strong Ethiopian flood component; braided channel, sandy, in part ponded floodplain margins; much accelerated activity of high-competence local wadis, declining later. Wadi Tufa IV at Kurkur. Estimated age >32 000-27 000 B.P. Middle Palaeolithic (Nubia), Aterian (Kurkur) settlement. Climate semiarid.
4	Nile and wadi dissection (at least 10 m).
3	Aggradation of Korosko Formation, lower member; strong influx of Ethiopian flood waters; sandy, in part ponded floodplain; accelerated wadi activity. Wadi IIIc at Kurkur (Aterian settlement?). Age >40 000 B.P. Climate arid.
2	Wadi dissection (at least 6 m), followed or preceded by calcification or ferricretion.
1	Aggradation of Wadi Floor Conglomerate (Nubia) and Wadi Tufa IIIa/b (Kurkur). Nile below modern floodplain. Climate semiarid to subarid.

Table 11.2 (continued)

rated wadi activity can be recognized in southern Egypt (see Butzer & Hansen 1968: chapters 3 and 6):

a) The upper member of the Korosko Formation is everywhere interdigitated with gravels or sands reflecting active wadi discharge. On the Kom Ombo Plain, where only the upper two-thirds of this unit appear to be exposed, there is a systematic upward fining from sandy gravel at the base, to gravelly marl, to marl at the top, arguing for a diminution of wadi activity with time. In Nubia, where basal contacts are better preserved, the initial deposits rarely include gravel, but a major influx of wadi clasts can be localized in the second quarter of the unit, with a gradual decrease in wadi competence thereafter The mixed nilotic-wadi deposits of the Korosko Formation in fact grade upstream into well-defined alluvial terraces, e.g. in Wadi Or, that appear to be related to extensive mantles of alluvial or colluvial wash on pediments and piedmonts adjacent to the wadi floors. These observations consequently allow stratigraphic definition of a significant 'pluvial' event in the hill country of southern Egypt.

b) The Masmas Formation and the preceding interval of Nile dissection provide minimal evidence for wadi activity. Runoff in the desert hills was no greater than it is today.

c) The Gebel Silsila Formation, a nilotic unit, is matched by a significant body of variable wadi deposits, that has been described, defined and mapped as the Ineiba (two members, Malki and Sinqari; ca. 17 500-8 000 B.P.) and Shaturma (two members, the second being subrecent wash; late prehistoric to historic) formations.

The Malki unit is broadly coeval with the Darau substage, with which it interfingers in Nubia. However, a single radiocarbon date of 17 400 B.P. at Kom Ombo, where alluviation was not a response to oscillations of local base level, suggests that wadi aggradation may have even begun at the eastern margin of the old Masmas silt plain a few centuries before the branches of the Darau Nile had built up a new, broader floodplain to the west. The Malki Member at Kom Ombo consists of a light brown, laminated clayey silt, with prismatic tendencies and frequent slickensides, local evaporites, and abundant rootlet impressions. Thickness exceeds 9 m. Now forming a +4 to 6 m wadi terrace, these deposits represent suspended sediment carried to the edge of the Kom Ombo Plain by the largest watercourses of the Red Sea Hills. Local detritus is confined to lenses near the base of the sequence, and indicates little rainfall within the Nile Valley proper. In the smaller Nubian wadis the lithostratigraphic equivalent

comprises local sands with basal gravel intercalations, also suggesting maximum runoff early in this phase. Aggradation at Kom Ombo had ceased prior to the 'wild' Nile interval after 12 000 B.P., deposits of which are not overlapped by Malki silts east of Kom Ombo. At approximately this time, calcification of the Malki deposits indicates pedogenesis, a semidesert soil of Paleorthid type (Adda Soil Zone). The wadi interbeds at Dishna (see Wendorf & Schild 1968: 121ff.) appear to be equivalent to the Malki unit.

After some 4-12 m of wadi cutting east of Kom Ombo, a light yellowish brown, well stratified, partly current-bedded, silty fine sand or coarse sand was deposited with interbeds of coarse gravel or silt, and a maximum thickness of 8-11 m. Large vertical and horizontal root drip is common and suggests shrub growth and some trees, while proliferations of *Zootecus insularis* and *Pupoides coenopictus* snails imply abundant vegetation. This is the Sinqari Member, and it argues for a period of frequent winter rains. A similar impression obtains in Nubia, where it is interdigitated with the Arminna Member in Khor Abindan (Butzer & Hansen 1968: Figure 6-9) and Wadi Or. The equivalent Nubian facies comprises sand with thick basal gravels and *Zootecus* proliferations. The latter, from the upper half of this fill, provided a date of 8 890 B.P. and indicate correlation with the first half of the Arminna substage. Subsequently, partial decalcification, rubefaction, and kaolinitic clay formation record the 30-100 cm cambic horizon of a Camborthid paleosol (Omda Soil Zone). These reddish semidesert soil profiles provide useful stratigraphic markers. They also indicate a period of subarid conditions with biochemical weathering and repeated, fairly gentle rains. This pedogenesis must be younger than 8 000 B.P. but older than the Shaturma Formation; it may be coeval with the late Arminna stage ca. 7 000 B.P.

The Shaturma Formation, Member I, was deposited following 1-6 m of dissection. These are light brown, well stratified silty sands or sandy silts, interbedded with gravel lenses and averaging less than 2 m thick east of Kom Ombo. Laterally these beds grade into sheets of coarse piedmont colluvium that are ubiquitous in the wadi systems of the eastern deserts. In fact, in Nubia this unit is mainly represented by such colluvial mantles, which rest on top of the Omda Soil, or grade directly into shallow rubble terraces. Organic vestiges are rare, but abundant late prehistoric occupation in Wadi Kharit immediately postdates most of the Shaturma sands. A related date of 4 660 B.P. suggests termination by about 3 100 B.C., i.e. a broad contemporaneity with the Kibdi substage. Member II of the Shaturma Formation represents a minor wadi infilling, probably of Islamic age, e.g. in Wadi Qena, where an 11th century A.D. date is available (Butzer 1974c).

In general, greater Nile discharge of Ethiopian origin coincided with accelerated wadi activity in the Egyptian deserts between 17 500 and 4 600 B.P. Particularly informative is a section in Khor Adindan that shows dark Nile flood silts of the Kibdi unit interdigitated – but along sharp, minor disconformities – with reddish sands of the Shaturma Formation (Butzer & Hansen 1968: Figure 6-7 and 288ff.): local winter spates and summer Nile floods were seasonally out of phase. An identical interdigitation of Arminna flood silts and Ineiba (Sinqari) wadi sands is verified 300 m upstream (Butzer & Hansen 1968: Figure

6-8 and 6-9). In other words, accelerated late Pleistocene to Holocene wadi activity in Egypt can be largely, if not entirely, attributed to winter rains, and not to a simple, northward extension of the sporadic summer shower activity evident in Sudanese Nubia today. Nonetheless, the local alluvial and paleosol record suggests a persistence of essentially arid conditions throughout this time span. Despite their obvious ecological significance, the amplitude of the moister intervals should not be overestimated and they generally were brief and, even so, punctuated by recurrent interludes of hyperarid climate.

11.6.2 *The Kurkur oasis*

In the upper reaches of Wadi Kurkur, above and just below the great Libyan limestone cuesta, a sequence of alluvial and spring-fed subaqueous deposits was mapped and studied in detail by Butzer & Hansen (1968: chapter 7). This succession provides a unique record of Pleistocene palaeoclimates at a different scale than the Nile Valley alluvial units. Subsequent to the Pliocene Plateau Tufa, four complexes of clastic and marl-tufa deposits developed within the Oasis valleys and as fans below the escarpment.

The two oldest of these now form inverted topographies, due to erosion of less indurated lateral sediments and accompanying bedrock denudation. In Nubia, indurated wadi deposits that are older than the Wadi Floor Conglomerate frequently show comparable inverted topographies, suggesting that these oldest Kurkur units, Wadi Tufas I and II, are of early to mid-Pleistocene age. Subsequent events can be outlined briefly:

a. Tufa IIIa. 5 m of rounded gravel, sulphide marls and silts with lenticles of plant tufas, stratified, partly current-bedded; freshwater snails (*Melanoides*) common, terrestrial snails (*Zootecus*) rare. The related +6 to 7 m escarpment fan-terrace includes water transported limestone blocks. Radiocarbon age 'greater than 39 900 years'. Rare, presumably reworked Acheulian handaxes.

b. Tufa IIIb. 5 m of tufa-travertines, plant tufas, and calcified montmorillonitic clays; complex, lenticular stratification related to fossil spring vents amid pools and tufa cascades; abundant *Melanoides* and some *Pupoides*, with pockets of plant impressions, including *Ficus*. Followed by 6-10 m of wadi downcutting.

c. Tufa IIIc. 6 m of montmorillonitic marls, in part sulphide rich, in part mottled by limonite; rich in aquatic snails and interbedded with lenticles of organic tufas; grade downstream into calcified alluvium derived from older eolian sands. The marl facies includes two planorbids, *Segmentina, Bulinus* and *Lymnaea*, suggestive of stagnant water and abundant decaying vegetation, as well as a terrestrial snail, *Lamellaxis*. Radiocarbon date 'greater than 39 900 years'. Undiagnostic flakes found within the sandy facies may indicate contemporaneity with the abundant, rich surface sites of the Aterian industry (Barbara Sivertsen, personal communication). Followed by 6-9 m of wadi downcutting.

d. Tufa IV. 3 m of calcreted subangular gravel, sand and marl, in part with sulphides, in part with evaporites; land snails (*Zootecus, Pupoides*) common, but no aquatic genera, suggesting less water than the Tufa III complex; only a minor fan-terrace (+3 m) formed below the escarpment. Radiocarbon date of 31 800 B.P. Occasional unworn artifacts in situ record last episode of major

prehistoric occupation (Aterian) in area. Followed by wadi dissection and one or more episodes of sheetwash, with redistribution of reddish wash derived from now destroyed paleosols.

In terms of general interpretation, Tufa IIIa indicates episodic, torrential stream flow at the height of the rainy season, with subsequent deposition of marls in stagnant valley pools; as this stage advanced, such stream-bed ponding grew more important in the oasis. There was little fluvial activity during the Tufa IIIb stage, when discharge was probably distributed more evenly during the year, fed by waters from 'mound springs' during the dry season and so creating a wide variety of calcareous deposits along the well-vegetated valley floor. Following a drier spell with erosion, Tufa IIIc represents another phase of valley-floor spring ponding, but of more restricted extent. After yet another dry erosional hemicycle, Tufa IV represents a brief return to conditions approximating those responsible for Tufa IIIa, but somewhat less wet.

Tufa IV was contemporary with the upper member of the Korosko Formation in the nearby Nile Valley, and represents a logical geomorphic parallel. Tufa IIIc may record the lower member, Korosko Formation, while Tufa IIIa/b provides a good parallel for the Wadi Floor Conglomerate. The Kurkur sequence consequently demonstrates that the early Upper Pleistocene 'pluvial' intervals of Egypt were considerably more effective and presumably both longer and wetter than those of the terminal Pleistocene and Holocene. A similar pattern emerges in the lower-lying segments of the Libyan Desert, with access to artesian water resources (see Wendorf et al. 1976).

11.6.3 *The Red Sea littoral*

An independent geomorphologic record of late Pleistocene stream activity is provided by the Red Sea littoral, near Mersa Alam. Here dated, tectonically undisturbed, high beaches allow stratigraphic correlation with alluvial deposits or episodes of fill-cutting (Butzer & Hansen 1968: chapter 8). The sequence is:

a. +10 m coral reef (coralline limestone). ? Early Last Interglacial transgression. Minimal wadi activity.

b. +6 m coral reef (calcarenite and coral), with Th^{230}/U^{234} dates of 80 000 B.P. ± 8 000 years (on reef shell) and 110 000 B.P. ± 10 000 years (on shell from older beach gravels back of the reef). Mid-Last Interglacial transgression. Minimal wadi activity.

c. +8.5 m gravel bars and estuarine gravels, indicating accelerated wadi activity.

d. Regressive oscillation.

e. +3.5 m coral reef (calcarenite, some coral). Late Last Interglacial transgression. Minimal wadi activity.

f. Regressive oscillation with wadi dissection.

g. Alluviation of coarse gravels of 'Middle Terrace', indicating 'pluvial' conditions with increased stream competence. Basal beds appear to be contemporary with estuarine conglomerate at modern high-water, while later fluvial sediments extend to below modern sea level. Early Last Glacial regression.

h. Dissection of alluvium and calcification (Paleorthid paleosol).

i. Alluviation of 'Low Terrace', again indicating a 'pluvial' climate. Gravels

indicate an oversteepened gradient at coast, and deposits extend to below modern sea level. Contemporary with early or mid-Last Glacial regression.

j. Long-term dissection of coastal deposits to well below modern sea level during late Last Glacial regression. During Holocene times sea level returned to its present mark, drowning the lowermost wadis, since post-Pleistocene wadi activity has been minimal.

This stratigraphic sequence, although by no means as readily interpreted as that of the Mediterranean Basin (see Butzer 1975b), clearly shows that in south-eastern Egypt the last 'pluvial' episodes of the later Pleistocene are broadly contemporary with the first half of the Last Glacial regression. However, part of the Last Interglacial experienced a climate about as arid as that of today. The Mersa Alam evidence further shows that there was a moister interval during the late, Last Interglacial while the last half of the major glacial-eustatic regression was comparatively dry. This emphasizes that pluvial-glacial or pluvial-interglacial correlations are gross oversimplifications of a rather more complex pattern of events.

Significantly, as at Kurkur, terminal Pleistocene and Holocene moisture fluctuations were not significant enough to leave a geomorphic imprint on the hyperarid Red Sea littoral. Only speculative correlations can be offered with Kom Ombo, Nubia and the Kurkur Oasis. In relative stratigraphic terms and assuming that major geomorphic trends are simultaneous, the 'Low Terrace' may be equivalent to the upper Korosko Formation and Tufa IV, the 'Middle Terrace' to the Wadi Floor Conglomerate and Tufa IIIa/b. If this is indeed so, the entire late Pleistocene sequence of southern Egypt discussed here is younger than 75 000 B.P.

11.6.4 *Late Pleistocene to Holocene overview*

The previous stratigraphic, thematic, and regional information is collated and reviewed in Table 11.2. It provides both a record of palaeoclimatic trends in Egypt, presumably all related to the winter rainfall belt, and a history of the Nile flood regime.

By African standards, the details are remarkably good. Comparison of the Egyptian events with those of higher latitudes are beyond the purpose of this paper, but the data base speaks for itself and provides invaluable information for a proper understanding of the dynamic climatology of the Mediterranean Basin during the late Pleistocene and early Holocene (see also Butzer 1975a, 1975b).

Equally so, the Egyptian nilotic record has major import for an understanding of the subsaharan Nile Basin. It raises more questions than it provides answers, pointing to obvious areas in Ethiopia and the Sudan that require equally searching investigation. Despite several obvious correlations and some superficial resemblances with the subsaharan lake history (see Butzer et al. 1972; Butzer 1976a, 1976b:30ff.), the Nile record would also seem to pose some contradictions. It is essential that interpretations of the East African evidence relevant to the Nile Basin be consonant with the basic Nile flood history documented in Egypt.

11.7 THE HISTORICAL NILE

The saga of the Nile during the course of the Pharaonic era has been recently studied by Butzer (1976b:27ff.), and it would be redundant to review the information here. However, in broad outline (Table 11.2), flood levels declined significantly between 3 000 and 2 800 B.C., representing an overall reduction in volume of 25-30 % (see Bell 1970). Concomitant downcutting appears to have initiated the modern floodplain downstream of Wadi Halfa. A period of catastrophically low floods characterized the interval 2 250-1 950 B.C., with improved floods thereafter. Excessive floods are documented 1 840-1 770 B.C., recurring every two to five years with peak discharge three times that of the ten greatest floods of the 19th century A.D. (see Bell 1975). Average levels remained high thereafter, but declined strongly 1 180-1 130 B.C., and then levelled off until a last interval of generally higher levels about 600-1000 A.D. Broad comparability with hydrographic trends in the subsaharan Nile Basin is evident (Butzer 1976b: Figure 5).

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12

Late Quaternary depositional history of the Blue and White Nile rivers in central Sudan

Histoire des dépôts quaternaires récents du Nil Bleu et du Nil Blanc dans le Soudan central

Les dépôts quaternaires récents du Nil Bleu inférieur comprennent des dépôts de carbonate près de Khartoum datant de 40 000 ans B.P., des dépôts de cendres volcaniques près de Wad Medani datant de 25 000-23 000 B.P., ainsi que des bancs de sables et de graviers à stratification entrecroisée dont l'âge va du Pléistocène le plus récent jusqu'au dessous de la limite de datation par le radiocarbone.

Les dépôts les plus anciens du Quaternaire récent dans la vallée du Nil Blanc inférieur semblent être les calcites et les dolomites microcristallins situés près de Esh Shawal âgés de 40 000-25 000 ans B.P. Sur ces évaporites, se trouvent des bancs de sables et de sables argileux fluviaux, qui sont recouverts par une couche étendue d'argile fluvio-lacustre. Le dépôt final de cette argile a cessé vers 11 000 B.P. et peut avoir commencé après 12 500 B.P., lorsque les lacs Victoria et Albert débordèrent. Des dunes allongées d'orientation nord-sud, se formèrent activement dans la vallée du Nil Blanc inférieur au Pléistocène terminal, immédiatement avant le dépôt de l'argile verte.

Du début au milieu de l'Holocène, une couche étendue d'argile noire fut déposée dans les bassins d'inondation adjacents au Nil Bleu et à ses chenaux secondaires. La majeure partie du dépôt eut lieu entre 12 000 B.P. et approximativement 5 000 B.P., avant que l'enfoncement continu du Nil Bleu décapite les effluents et les prive des eaux d'inondation.

Le dépôt des argiles noires alluviales, le long des rives du Nil Blanc soumises aux inondations saisonnières, se poursuivit de façon intermittente pendant tout l'Holocène avec des transgressions majeures évidentes à 8 400-8 100 B.P., 5 500 B.P., 3 000 B.P., 2 700 B.P. et 2 000-1 500 B.P. Certaines de ces crues du Nil Blanc furent aussi contemporaines des plus hautes eaux de crue du Nil Bleu à 7 500 B.P., 6 900 B.P. et 5 500 B.P., avec de hauts niveaux des lacs en Afrique de l'Est et au Sahara, et des lacs d'eau douce à l'ouest du Nil Blanc vers 8 400-6 800 B.P.

L'alluvionnement du Nil Bleu au Pléistocène récent est en rapport avec la proportion élevée de charge solide à déposer, et avec le creusement holocène, peut être initié par de très fortes crues au début de l'Holocène. Il est associé à un changement de calibre des éléments de la charge solide qui de sables grossiers passent aux limons et aux argiles fins, et à une réduction à long terme du débit après 8 000-7 000 B.P. environ.

Un modèle paléohydrologique des modifications pléistocènes récentes et holocènes de l'écoulement du Nil Bleu et de son régime de transport de charge solide est déduit des changements survenus à la fin du Quaternaire dans l'environnement du bassin d'alimentation en Ethiopie. Il est confirmé par la succession stratigraphique du Soudan central.

* All SUA and I radiocarbon dates quoted are conventional radiocarbon ages corrected for isotopic fractionation, using an assumed group mean value of $\delta\ ^{13}C = -5 \pm 2\%$ for shell and carbonate (Stuiver & Polach 1978). This correction accounts for any difference from values quoted in our previous publications.

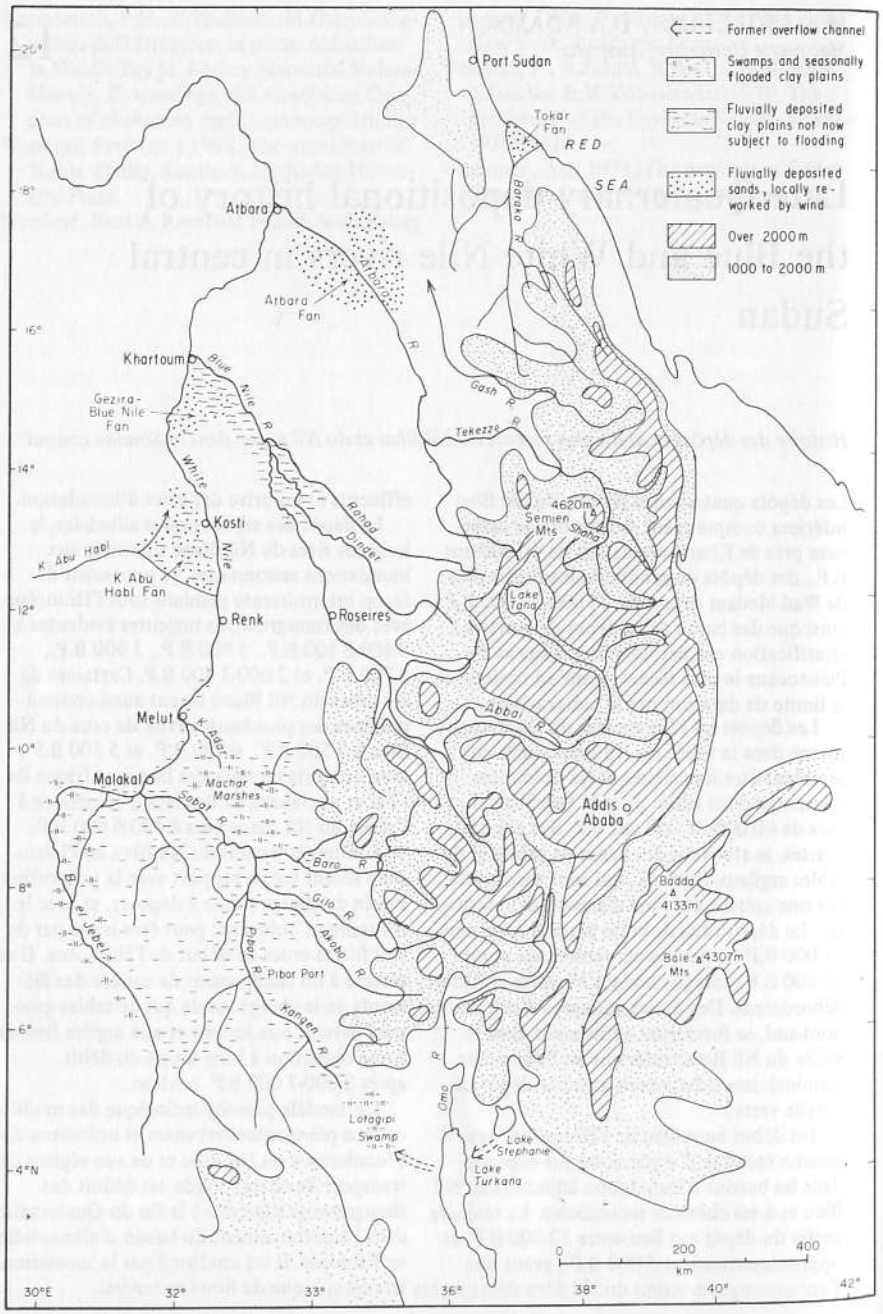


Figure 12.1 Late Quaternary landforms and sediments in eastern and southern Sudan. (Simplified from satellite imagery and from Vail 1974). The boundary of Cenozoic volcanic rocks (a major source of clay-size particles) lies roughly midway between the 1 000 and 2 000 m contours shown here. Below that elevation, sandstones and Basement Complex rocks crop out and supply the rivers with sands and gravels. (See also figure 12.4).

12.1 INTRODUCTION

The contrasting hydrological regimes of the Blue and White Nile rivers are critical to our understanding of the depositional history of much of the south-eastern sector of the Sudan, as well as of the main Nile north of Khartoum (Figure 12.1). Baker's early description of the Blue Nile as a 'mountain stream, rising and falling with great rapidity' (Baker 1866:5-6) and of the White Nile as a river of lake origin, flowing through vast treeless marshes (see Figures 10.1 and 10.2), is as apt today as it was when Herodotus wrote about the Nile, over 2 500 years ago.

In quantitative terms, the Blue Nile, White Nile and Atbara contribute respectively 51 km^3, 27.5 km^3 and 12.5 km^3 of water to the main Nile each year, giving an average annual discharge of 91 km^3 (Hurst and Phillips 1931). The contribution of water and sediment from each of the three tributaries varies according to the season of maximum precipitation in their headwaters. Equatorial Uganda and the mountains of southern Ethiopia, with two rainy seasons and lesser amounts of rain likely throughout the intervening months, provide a more evenly distributed runoff than do the central and northern highlands of Ethiopia, where heavy summer rainfall nourishes the annual floods which have sustained Egyptian agriculture for ten millennia or more. A measure of this seasonality is the ratio of mean monthly peak flow to low flow, which is 40:1 for the Blue Nile, 5:2 for the White Nile and 16:1 for the main Nile (Hurst & Phillips 1931).

Two related factors illustrate the difference between the tributaries of the Nile. Both are of enormous practical importance, and both are highly relevant to our attempts at deciphering the Quaternary stratigraphic record. One is sediment load; the other is seasonality of flow.

Sediment concentration in the White Nile does not vary much downstream from the Sudd. In fact, so efficient are the swamps of the southern Sudan and the lakes of Uganda as filters that only two million tons of sediment reach Khartoum via the White Nile each year, and much of this is brought down from Ethiopia by the Sobat. Sediment yields are extremely high in mountainous catchments with a strongly seasonal rainfall regime (Holeman 1968, Lisitzin 1972). The Atbara and Blue Nile are no exceptions, with the former contributing an average of 14 m.t. and the latter 41 m.t. to the main Nile every year (Hurst & Phillips 1931). Since total suspended load is obtained by summing the partial products of river discharge and suspended sediment concentration, it is instructive to note that sediment concentration in the Blue Nile at Khartoum may range from 100 mg/ℓ in June to 4 000 mg/ℓ in August (Badri 1972). During the summer floods, the concentration of dissolved silica and sulphate also increases significantly, testifying to the seasonal efficacy of both chemical and physical denudation in the Ethiopian headwaters of the Blue Nile.

The time of the year during which peak flow occurs is likewise of fundamental significance (Figure 12.2). During the month of greatest mean flow in the main Nile, the Blue Nile provides 68% of the total discharge, the Atbara 22% and the White Nile a mere 10%. But the White Nile comes to the fore during the time of year when water is most needed, supplying 83% of the low water flow,

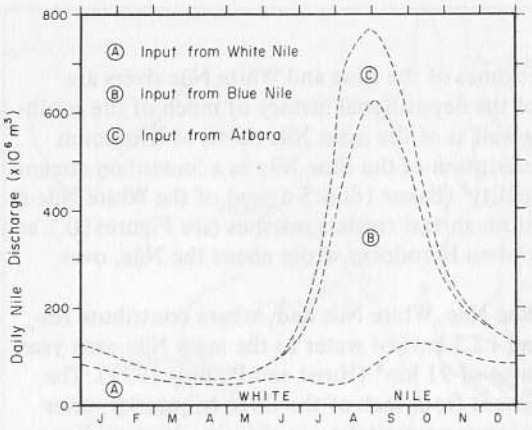


Figure 12.2 Mean daily discharge contributed to the main Nile by the Blue Nile, White Nile and Atbara. (After Hurst 1952)

compared to a modest 17% from the Blue Nile. The Atbara, which dries out in winter, provides nothing.

Two obvious conclusions emerge from these observations. First, the overwhelming bulk of alluvium carried into Egypt, or laid down in the Sudan, is of Ethiopian provenance, and is mostly transported during a few months of the year. Second, it is the White Nile which is largely responsible for sustaining the perennial flow of the main Nile. Were the supply of water from Uganda to be blocked off, as was the case during the terminal Pleistocene (see Chapter 14 and Kendall 1969) the main Nile would become as highly seasonal as the Sobat, Blue Nile, Rahad, Dinder and Atbara rivers that flow down from the mountains of Ethiopia. Were precipitation in upland Ethiopia to diminish also, as it may well have done during late glacial times (see Chapter 5 and 15, and Gasse 1975) then it is highly likely that the main Nile would have ceased to flow during the early half of the year (Williams & Adamson 1974, Adamson, Williams & Gillespie 1979).

The aim of this chapter is to develop and to test the hypothesis encapsulated in the preceding remarks in the light of recently acquired stratigraphic evidence from the Sudan and surrounding areas. In short, environmental changes in the Ugandan and Ethiopian headwaters of the Nile have resulted in the deposition of a distinctive and contrasted suite of late Pleistocene and of Holocene sediments in south-eastern Sudan, with powerful implications for the life-style and economy of the modern and prehistoric inhabitants of this region.

12.2 FACTORS THAT CONTROL SEDIMENT YIELD

The alluvial plains of the central Sudan form a link between the glaciated mountains of East Africa and the desert lowlands of northern Sudan and Egypt. On a scale of 10^6-10^7 years, the erosional history of the uplands and the correlative

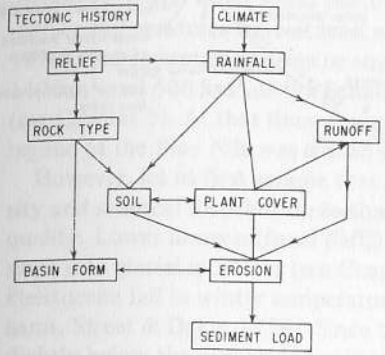


Figure 12.3 Factors that control sediment load (schematic).

depositional history of the lowlands must reflect the interplay of tectonic, volcanic and climatic factors, as outlined in Chapter 9. Major Cenozoic changes in drainage divides related to diversions and river piracy brought about mainly by endogenic processes are illustrated in Chapter 10, and the impact of late Cenozoic baselevel and climatic changes upon sedimentation in the lower Nile is analysed in Chapter 11.

Sediment yield will depend primarily upon such factors as rock-type, available relief, and rainfall amount and seasonality (Figure 12.3) so that in the long run the tempo of volcano-tectonic processes is important. But in the short run, and during the comparatively brief interlude of the past 30 000 years, with which we are concerned here, changes in depositional behaviour over intervals of 10^2-10^3 years are more likely to reflect variations in river load and discharge associated with climatic fluctuations than changes related to oscillations in endogenic activity. Needless to say, catastrophic changes in river load stemming from major volcanic eruptions, or channel diversions resulting from faulting, seismic tremors and related phenomena, such as earthquake-induced landslides, should also be evident in the depositional record, although the after-effects may only have persisted for a few years or tens of years.

The problem of why the Blue and White Nile rivers were sometimes engaged in aggrading their channel-beds and flood-plains and at other times were actively cutting into their alluvial deposits may be expressed in the form of a simple model (Figure 12.4). For clarity, we will consider only the Blue Nile at this stage, and we will apply the model to two discrete intervals: the glacial late Pleistocene, and the postglacial early Holocene. We begin with the glacial model.

12.3 BLUE NILE LATE PLEISTOCENE DEPOSITIONAL MODEL

Major rivers derive the bulk of their sediment load from their mountainous headwaters. For example, roughly 36% of the global annual input of sediment to the oceans is the work of four huge rivers which rise in or near the Himalayas

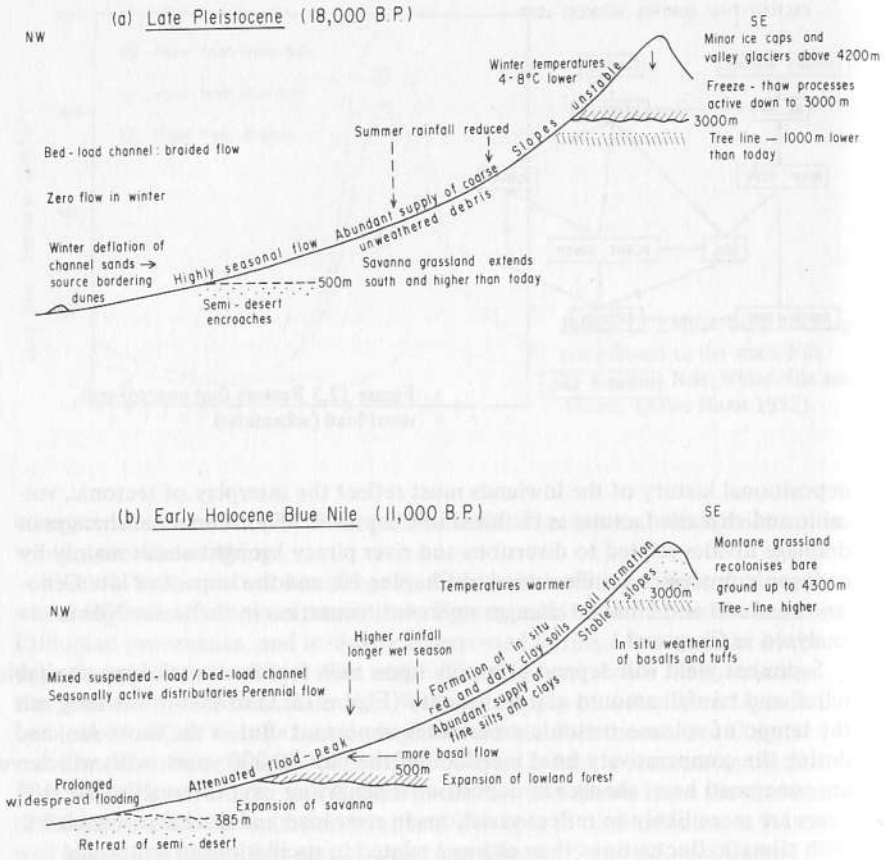


Figure 12.4 Schematic depositional models for the Blue Nile:
a) in the late Pleistocene at 18 000 B.P.;
b) in the early Holocene at 11 000 B.P.

(Holeman 1968, Lisitzin 1972); and on a continental scale, over 80% of the total suspended and the total dissolved load of the Amazon river comes from only 12% of its catchment area, namely, the Andean headwaters (Gibbs 1967). It comes as no surprise, therefore, to note that much of the Blue Nile sediment load comes from a relatively small proportion of its total drainage basin, in the rugged and inaccessible mountains of west-central Ethiopia. Continuous, long-term measurements of river load and discharge are not available for the Abbai-Blue Nile and its upland tributaries. Such data as do exist (Water Resources Department 1961) confirm that the bulk of present-day erosion takes place during July to October, so that maximum sedimentation in the Sudan takes place during the waning stages of the flood (Figure 12.2) in late September and October. At the present time, minimum discharge and load coincide with the dry winter months, January through to April.

During the time of greatest ice volume in the very late Pleistocene, roughly 20 000 years ago when world sea-level was 100-150 m lower, equatorial sea-surface temperatures were at least several degrees centigrade cooler (Climap 1976), and mountain glaciers or small ice-caps occupied respectively 10 km², 140 km² and 600 km² of the Semien, Badda and Bale mountains in Ethiopia (see Chapter 5). At that time, the seasonal precipitation/evaporation/runoff regime of the Blue Nile was almost certainly different from that of today.

However, let us first assume that precipitation was similar in amount, intensity and seasonal distribution to that of today, an assumption we will later qualify. Lower limits of fossil periglacial solifluction mantles which merge upslope into glacial moraines (see Chapter 5, part one) indicate a probable late Pleistocene fall in winter temperatures of 4-8°C in the Semien mountains (Williams, Street & Dakin 1978). Since the upper tree-line generally lies very slightly below the general lower limit of active periglacial solifluction (Galloway 1970 and Chapter 5), which extended down to about 3 000-3 100 m in the Mai Shaha valley of the Semien Highlands (Chapter 5 and Williams et al. 1978), it is reasonable to assume that temperature-controlled vegetation boundaries were probably about 1 000 m lower in this region during the late Pleistocene.

Three predictable consequences of this situation are: a) an increase in sediment yield from the unvegetated slopes prone to intense seasonal freeze-thaw action; b) an increase in runoff from the bare, seasonally frozen slopes; and c) an increase in runoff from the lower slopes as a result of lower rates of evaporation (Figure 12.5). Maximum rates of hillslope erosion and of sediment influx into rivers are likely to have been during the spring thaw and early summer rains, when debris flows and other forms of mass movement were especially active, and when rainsplash and runoff mobilised sediment from the bare, cryoturbated slopes.

We must now amend our initial assumption, for the evidence from a late-glacial pollen spectrum from Mount Badda (Hamilton 1977), together with that of very low lake levels in the Afar and Ethiopian Rifts during the terminal Pleistocene (see Chapter 15 and Gasse 1975: part 2) is incompatible with a summer rainfall approaching that of today. Furthermore, insofar as lower monthly temperatures also imply lower monthly evaporation, the very low lake levels imply that even in spite of a much reduced rate of evaporation, rainfall and runoff from the highlands were unable to sustain perennial lakes at high levels during the interval 18 000 to about 12 000 B.P. A corollary to this is that summer rainfall was much reduced, a conclusion totally in accord with the evidence of accentuated late Pleistocene aridity and reduced summer rains in the Sahel zone of Niger and Chad already discussed in Chapters 3 and 6.

If summer precipitation was less, and winter cold greater, the overall plant cover and protective surface litter in the Blue Nile headwaters must have been less dense. Soil loss per unit momentum of rainfall increases exponentially with the percentage area of bare soil exposed to raindrop impact (Williams 1977). Equally, the highest sediment yields in the world today from more or less undisturbed catchments are from uplands in the seasonally-wet tropics and sparsely-vegetated semi-arid regions (Douglas 1967). The greater vulnerability of the Abbai catchment to hillslope erosion consequent upon reduced plant cover

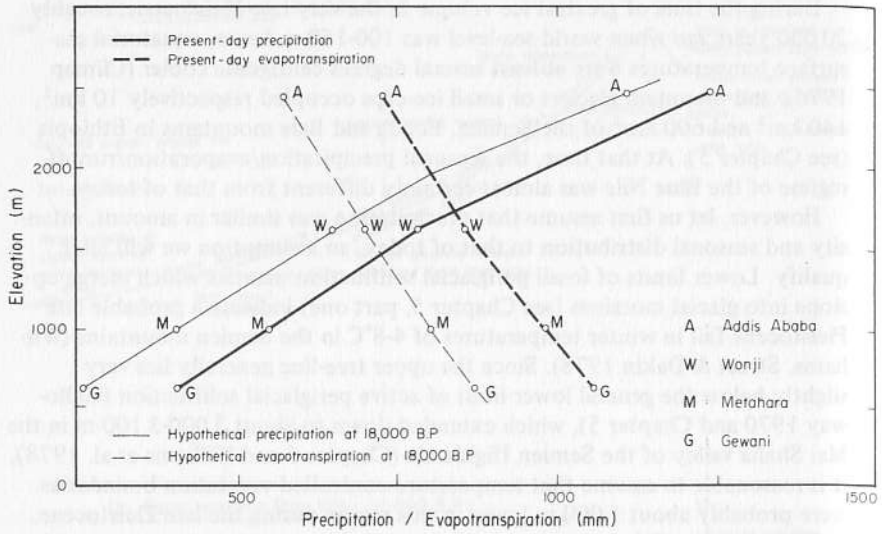


Figure 12.5 Precipitation and evapotranspiration in relation to elevation, east-central Ethiopia:
a) at present (adapted from UN 1971:43);
b) at 18 000 B.P. (hypothetical).

would more than offset the influence of reduced summer precipitation. Furthermore, runoff rates would be far higher from bare, eroded, crusted soil surfaces than from those with a thick organic litter, friable and porous topsoil, and high infiltration capacity. To sum up, sediment yields from the Ethiopian catchment of the Blue Nile and the Tekezze-Atbara system would have been especially high in the highlands (and in the semi-arid lowlands) as a result of depleted plant cover and widespread hillslope instability, related to reduced temperatures and reduced precipitation.

An extension of this argument is that the flood peak would be more accentuated, with lower contributions from basal flow. Likewise, the sediment carried should be coarser, with very little fine material in suspension, since rapid mechanical weathering above tree-line would produce coarse detritus, and rates of slopewash and mass-movement would be too rapid to allow a fine-textured weathering mantle and deep sedentary soils to develop. In short, the late Pleistocene Blue Nile envisaged by this model was a more highly seasonal river than today, with a much coarser, more abundant bed-load and a much reduced suspended load. During the winter months, it may never have reached the main Nile, becoming an unstable bed-load stream which laid down sand-bars in its distal reaches, as flow dwindled and finally ceased. The sandy point-bars and mid-channel bars would have been exposed to deflation from northerly winter winds, leading to the formation of transverse source-bordering dunes along the down-wind channel margins (Williams, Adamson & Abdulla 1979).

In an actualistic discipline like geology it is often instructive to seek present-day analogues to past events or environments. If we note that for a similar

monthly discharge, the sediment load of the Gila river in New Mexico is roughly 100 times greater in August than in November and May (Wilson 1972), the obvious point about the erosive impact of convectional summer downpours upon sparsely vegetated soils is instantly made. Likewise, in the seasonally-wet tropics of northern Australia, a similar rainfall momentum will generate 20 to 40 times more soil detachment at the onset of the wet season, when litter and grass are sparse, than during the height of the wet season (Williams 1969, 1977).

In fact, a more appropriate analogue to the late Pleistocene Blue Nile is the present-day Atbara river, which receives runoff and sediment from the drier northern uplands of Ethiopia as well as from the Semien highlands. With half the annual discharge of the White Nile, the Atbara contributes seven times more sediment to the main Nile in summer, but dries out completely in its arid lower reaches during winter. The Sobat, which originates in the well-watered southern uplands of Ethiopia, and flows down past the swampy Machar Marshes to join the White Nile south of Malakal, is a plausible analogue of the early Holocene Blue Nile, to which we now turn.

12.4 BLUE NILE HOLOCENE DEPOSITIONAL MODEL

The rapid melting of late Pleistocene ice caps and valley glaciers, reflected in the very rapid rate of sea-level rise between c. 18 000 B.P. and 12 000 B.P., becoming progressively slower thereafter, until present sea-level was reached towards 6 000-7 000 B.P., flooded the oceans with a large volume of cold, fresh water. Ocean temperatures did not become discernibly warmer until about 12 000 B.P. (Berger et al. 1977) indicating about a 6 000 year lag between the onset of melting and the warming up of the ocean surface.

In gross terms, high sea surface temperatures and high rates of evaporation over the intertropical oceans, which currently supply about two-thirds of the total world precipitation, are consistent with increased amounts of intertropical rainfall. For example, the incidence of tropical cyclones decreases rapidly once sea surface temperatures fall below 26-27°C (Webster & Streten 1972) as of course does the incidence of heavy cyclonic rain. Again, warm moist air is a great deal less stable than cold moist air, so that abundant rainfall occurs when tropical maritime air masses from the Atlantic and Indian Oceans converge upon the East African uplands during summer.

As post-glacial temperatures rose and the montane forests and meadows, aided by higher summer rainfall, recolonised the former periglacial and glacial domains in the Ethiopian mountains and the former semi-arid lowlands, chemical weathering and soil formation became active once more. Red kaolinite-rich clays and dark cracking montmorillonite-rich clays developed in situ on weathered basalts and tuffs in the Ethiopian uplands, and dark colluvial-alluvial loams buried the former skeletal soils, hillslope debris and solifluction mantles at higher elevations (see Chapter 5).

The Holocene depositional model proposed here for the Blue Nile is that of a seasonal river of high summer discharge carrying a sizeable suspended load of clay and silt together with a still significant bed-load of sand. Seasonal deposi-

tion in the swampy plains of the central Sudan would depend upon the extent and duration of flooding, and upon the trapping action of the vegetation growing along the Blue Nile flood-plain south of Khartoum. We will now confront these two simple models with the stratigraphic evidence from the central Sudan, emphasising the salient features only. A detailed account of the physiography and Quaternary deposits of the central Sudan is presented elsewhere (Chapters 1 to 8 in Clark & Williams 1979).

12.5 LATE QUATERNARY BLUE NILE SEDIMENTS IN THE CENTRAL SUDAN

With few exceptions, the late Pleistocene and Holocene sediments bordering the present Blue Nile between Sennar and Khartoum represent an upward-fining fluviatile sequence. The Holocene alluvium consists of dark, alkaline cracking clays rich in sub-fossil shell fragments; and the late Pleistocene sediments generally comprise current-bedded fine-, medium- and coarse-sands, with extensive outcrops of massive calcium carbonate in bank sections between Hasa Heisa and Khartoum, and more localised patches of water-transported volcanic ash (Figure 12.6).

River-bank sections and deep borehole records from numerous sites throughout the Gezira reveal that much of the Gezira clay is underlain by coarse sands and fine gravels to depths in excess of 180 m (Abdel Salam 1966, Whiteman 1971:123-126, Boushi & Abdel Salam 1979). Abdel Salam (1966) has drawn attention to the linear bodies of gravel at varying depths within the Gezira fan deposits, and lithofacies reconstructions of now buried Blue Nile palaeochannels (Boushi & Abdel Salam 1979) show a radiating distributary pattern similar to that for the now defunct surface palaeochannels of Holocene age. Quartz is the dominant mineral within the sands and gravels, but fragments of basalt, agate, zeolites, feldspar and iron pisolites are not uncommon, indicating a mixed assemblage of sediments derived from Basement Complex rocks, Nubian Sandstone and Cenozoic lavas.

Before turning to the Holocene clays and palaeochannels, we will comment briefly upon the late Pleistocene carbonates and volcanic ash deposits that crop out along the west bank of the Blue Nile between Wad Medani and Khartoum.

12.5.1 *Late Pleistocene carbonates near Khartoum*

North of about El Masid on the Blue Nile there is a marked change in the physical and chemical characteristics of the Gezira soils, reflected in the northern limit of the Gezira irrigation area. Between Khartoum and El Masid the clay sediments are saline, alkaline, calcareous, sandy and massive. Whether they are mainly of Holocene age or older is not yet known, as we have so far failed to find any datable sub-fossil mollusk shells.

It is conceivable that the surface of the Gezira fan is time-transgressive, for thick late Pleistocene carbonate deposits crop out in the west bank of the Blue Nile some 5-8 km upstream of Khartoum. A sample of this massive calcrete

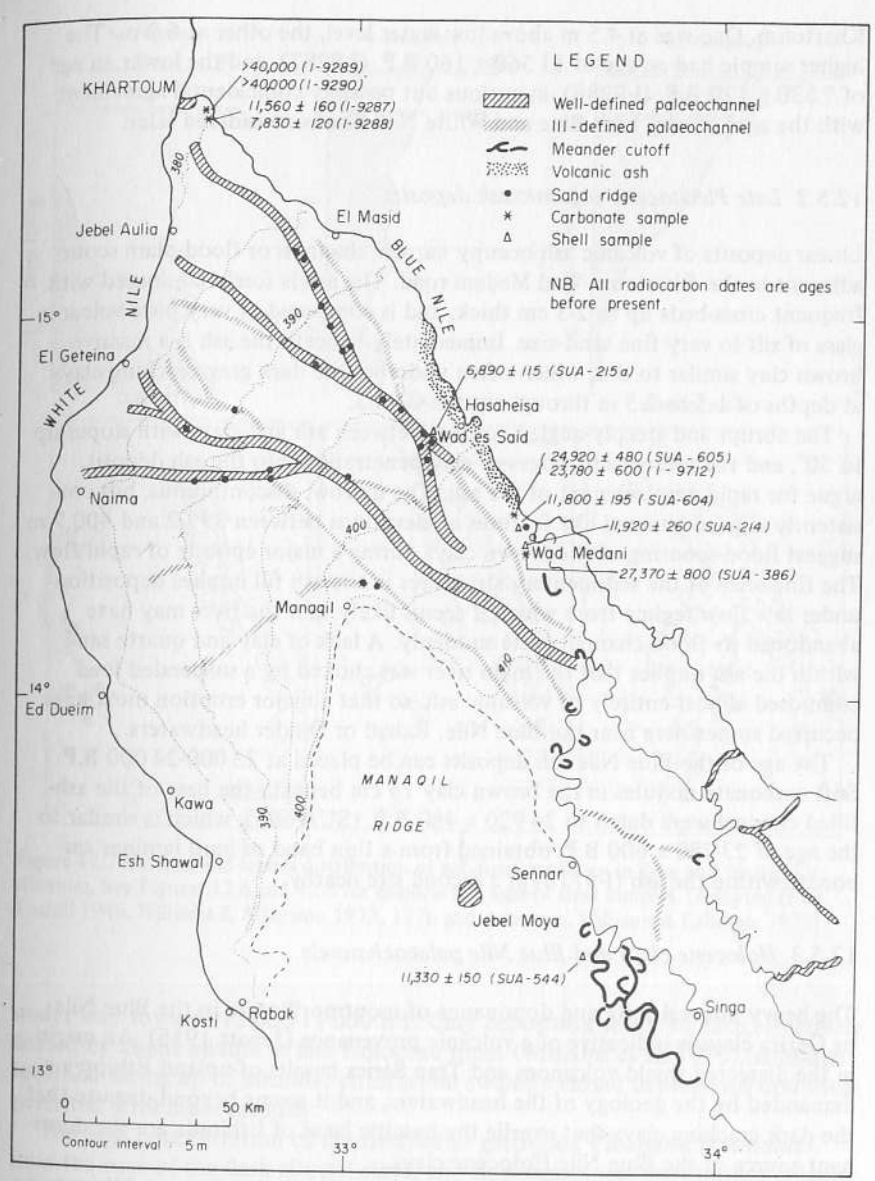


Figure 12.6 Late Quaternary palaeochannels in the Gezira, and radiocarbon sample locations between Sennar and Khartoum, Blue Nile left bank.

(I-9289) was collected 40 m in from the edge of the bank, at a depth of 1 m, and another (I-9290) was taken from 3 m below the top of a bank lapped by the Blue Nile in flood. Both had ages of >40 000 B.P. Two samples of small, porous lumps of carbonate were collected from the Blue Nile bank 8 km above

Khartoum. One was at 4.5 m above low water level, the other at 6.0 m. The higher sample had an age of 11 560 ± 160 B.P. (I-9287), and the lower an age of 7 830 ± 120 B.P. (I-9288), in curious but possibly coincidental agreement with the ages of very high Blue and White Nile floods considered later.

12.5.2 *Late Pleistocene volcanic ash deposits*

Linear deposits of volcanic ash occupy narrow channels or flood-plain scours adjacent to the Khartoum-Wad Medani road. The ash is finely laminated with frequent cross-beds up to 2-3 cm thick, and is composed of very pure volcanic glass of silt to very fine sand-size. Immediately beneath the ash is a massive brown clay similar to that which often underlies the dark grey cracking clays at depths of 1.5 to 2.5 m throughout the Gezira.

The abrupt and steeply-angled contact between ash and clay, with slopes up to 50°, and the presence of ridges of clay penetrating into the ash deposit, argue for rapid emplacement of the ash. The narrow, discontinuous, but consistently aligned channel-like features at elevations between 399.2 and 400.7 m suggest flood-scouring of the brown clays during a major episode of rapid flow. The fine scale of the sedimentary structures in the ash fill implies deposition under low flow regime from which it seems likely that the river may have abandoned its flood channel quite suddenly. A lack of clay and quartz sand within the ash implies that the main river was choked by a suspended load composed almost entirely of volcanic ash, so that a major eruption must have occurred somewhere near the Blue Nile, Rahad or Dinder headwaters.

The age of the Blue Nile ash deposits can be placed at 23 000-24 000 B.P. Soft carbonate nodules in the brown clay 15 cm beneath the base of the ash-filled channel were dated to 24 920 ± 480 B.P. (SUA-605), which is similar to the age of 23 780 ± 600 B.P. obtained from a thin band of hard laminar carbonate within the ash (I-9712) at a second site nearby.

12.5.3 *Holocene clays and Blue Nile palaeochannels*

The heavy mineral suite and dominance of montmorillonite in the Blue Nile or Gezira clays is indicative of a volcanic provenance (Jewitt 1955). An origin in the dissected shield volcanoes and Trap Series basalts of upland Ethiopia is demanded by the geology of the headwaters, and it seems beyond dispute that the dark cracking clays that overlie the basaltic lavas of Ethiopia are the dominant source of the Blue Nile Holocene clays.

Frequency analysis of the relative proportions of freshwater, amphibious, and terrestrial species of mollusca (Figure 12.7) demonstrates that the extent and duration of Blue Nile flooding of the Gezira plain decreased during the course of the Holocene. Tothill's interpretation of the Gezira clays as the flood-plain deposits of the Holocene Blue Nile (Tothill 1946, 1948) has now been amply confirmed (Williams 1966, Williams & Adamson 1973, 1976). A growing body of radiocarbon dates (discussed individually by Adamson, Williams & Gillespie 1979) indicates that widespread Blue Nile flooding was already

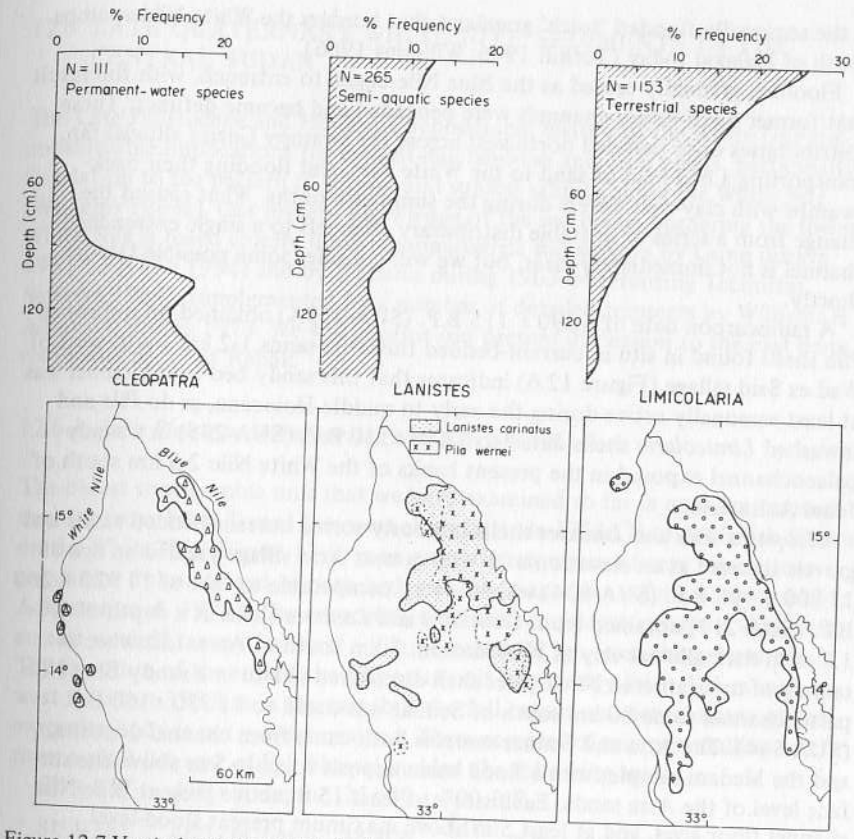


Figure 12.7 Vertical and lateral distribution of sub-fossil mollusca in Blue and White Nile alluvium. See Figures 12.6 and 12.8 for radiocarbon ages of shell samples. (Adapted from Tothill 1946, Williams & Adamson 1973, 1976 and Adamson, Williams & Gillespie 1979)

under way towards 12 000-11 000 B.P. Clay deposition seems to have effectively ceased by about middle to late Holocene times (Williams et al. 1975), although localised silting up of meander cutoffs and swampy closed depressions doubtless persisted until more recently.

The high concentration of the freshwater gastropod *Cleopatra bulimoides* near the base of the dark alluvial clays, and its geographical distribution (Figure 12.7) show quite clearly that during the early Holocene a strip of land up to 60 km wide and at least 180 km long was perennially flooded immediately east of the present Blue Nile channel.

The progressive increase in the abundance of the large amphibious mollusk *Pila wernei* at the expense of the permanent water species, together with the areal extent of *Pila* (Figure 12.7) point to an increase in the extent of seasonal flooding and a decrease in the zone of perennial inundation during the early to middle Holocene. A modern analogue of the Blue Nile flood-plain at this time

is the seasonally flooded 'toich' grassland that borders the White Nile swamps south of Malakal today (Tothill 1946; Williams 1966).

Flooding gradually ceased as the Blue Nile began to entrench, with the result that former distributary channels were beheaded and became defunct. These distributaries once radiated northwest across the swampy Gezira alluvial fan, transporting a bed-load of sand to the White Nile, and flooding their back-swamps with clay-rich waters during the summer months. What caused the change from a series of unstable distributary channels to a single entrenched channel is not immediately clear, but we will consider some possible factors shortly.

A radiocarbon date of 6 890 ± 115 B.P. (SUA-215A) obtained on unbroken *Pila* shells found in situ in current-bedded fluviatile sands 1-2 km south-west of Wad es Said village (Figure 12.6) indicates that this sandy bed-load channel was at least seasonally active during the early to middle Holocene, as do *Pila* and inwashed *Limicolaria* shells dated to 5 480 ±110 B.P. (SUA-295) in a sandy palaeochannel exposed in the present banks of the White Nile 2-3 km south of Jebel Aulia dam.

Cleopatra, Pila and *Lanistes* shells in poorly-sorted current-bedded sands and gravels situated at an elevation of c. 400 m near Atra village yielded an age of 11 800 ± 195 B.P. (SUA-604) which is very comparable to that of 11 920 ± 260 B.P. (SUA-214) obtained from *Cleopatra* and *Lanistes* shells at a depth of 1.6-1.7 m in dark alluvial clay at Wad Medani, 7 km south of Atra. Likewise, a sample of unweathered Nile oyster shell discovered in situ in a sandy Blue Nile palaeochannel some 30 km south of Sennar was dated to 11 330 ±150 B.P. (SUA-544). The Atra and Sennar samples both came from channel deposits, and the Medani sample from a flood basin deposit roughly 5 m above the surface level of the Atra sands. Each site is at least 15 m above present Blue Nile channel floor level, and at least 5 m above maximum present flood-level.

Returning to Figure 12.7, we see that during the terminal stages of deposition of the Blue Nile alluvial clays, *Limicolaria flammata* became very abundant. This terrestrial mollusk is today confined mainly to the Acacia-Tall Grass plains bounded by the 500 mm and 800 mm isohyets. Radiocarbon dates of 7 870 and 6 990 B.P. from the Wad Mansurab sites discussed in section 12.6.5, of 5 480 ± 110 B.P. (SUA-295) from a palaeochannel entering the White Nile near Jebel Aulia, and of 4 500 ± 130 B.P. (SUA-67) from the base of the Jebel Tomat prehistoric site (Williams & Adamson 1973; Clark & Stemler 1976) confirm that *Limicolaria* was widespread in what is now semi-desert scrub between about 8 000 and 4 500 years B.P. Annual rainfall in this area today ranges from less than 200 mm in the north to nearly 400 mm in the south, indicating a southward shift of the isohyets of roughly 200-300 km since that time, and a probable halving of the length of the rainy season.

The depositional history of the Blue Nile in central Sudan is in very good accord with our initial theoretical predictions of probable late Pleistocene and Holocene hydrological changes in the headwaters region of the Blue Nile. As a further test of the palaeohydrological model, we will consider the late Quaternary sedimentary sequence along the lower White Nile.

12.6 LATE QUATERNARY WHITE NILE SEDIMENTS IN THE CENTRAL SUDAN

The Late Pleistocene and Holocene depositional history of the White Nile has considerable implications for present-day land-use and crop yields, particularly in relation to the pattern of topsoil and subsoil salinity along the White Nile (Williams 1968a). Our present knowledge of the sediments bordering the lower White Nile is based chiefly upon reconnaissance soil surveys by Gunn during 1951-53 (Gibb 1954) and by Williams during 1963-64 (Hunting Technical Services 1964), supplemented by a number of detailed transects by Williams & Adamson during 1973. We will confine our present discussion to the east bank sediments north of Rabak.

12.6.1 *Late Pleistocene evaporites near Esh Shawal*

The oldest stratigraphic unit that we have examined so far in an 8 km transect running from Jebel Tomat due west along latitude 13°36'N towards Esh Shawal on the White Nile (Figure 12.8) is an evaporite sequence of very pure microcrystalline dolomite and of both high and low magnesian calcite (Taylor 1974; Adamson et al. 1979). The evaporites are found at a depth of about 4 m, over an east-west distance of at least a kilometre, at 4-5 km from the present river. The elevation of the top of the evaporite unit rises gently from 375 m in the west to about 375.3 m in the east, but the full extent and actual shape of the evaporite body is not yet determined. Three samples of microcrystalline calcite from a pit 3 km east of Esh Shawal yielded the following ages:

SUA-837 410 cm depth : 25 600 ± 700 B.P.

SUA-381 460 cm depth : $36\,800^{+\,3\,100}_{-\,2\,200}$ B.P.

SUA-382 480 cm depth : >40 000 B.P.

The absence of clastic components, the well-ordered crystalline structure and uniform elevation of the evaporites, and their radiocarbon ages all suggest prolonged late Pleistocene evaporation of an extensive body of still, saline water along what is now the White Nile flood-plain. The rough concordance in age between these White Nile evaporites and those that crop out in the Blue Nile south of Khartoum may indicate prolonged aridity and an absence of outflowing drainage in the Gezira at this time.

12.6.2 *Late Pleistocene fluviatile sands*

A minor fluviatile transgression took place before the final phase of evaporite precipitation. This was in turn followed by the deposition of at least a metre of grey, well-sorted medium to fine quartz sands which become more clayey towards the top of the unit. At Tagra (Figure 12.8) a bed of alternating fine clay and sand laminae indicative of seasonal flood-plain deposition grades upwards into finely-laminated silts capped by a thin layer of carbonate nodules of mixed provenance. A hard dolomite nodule at 1.6 m depth within this unit

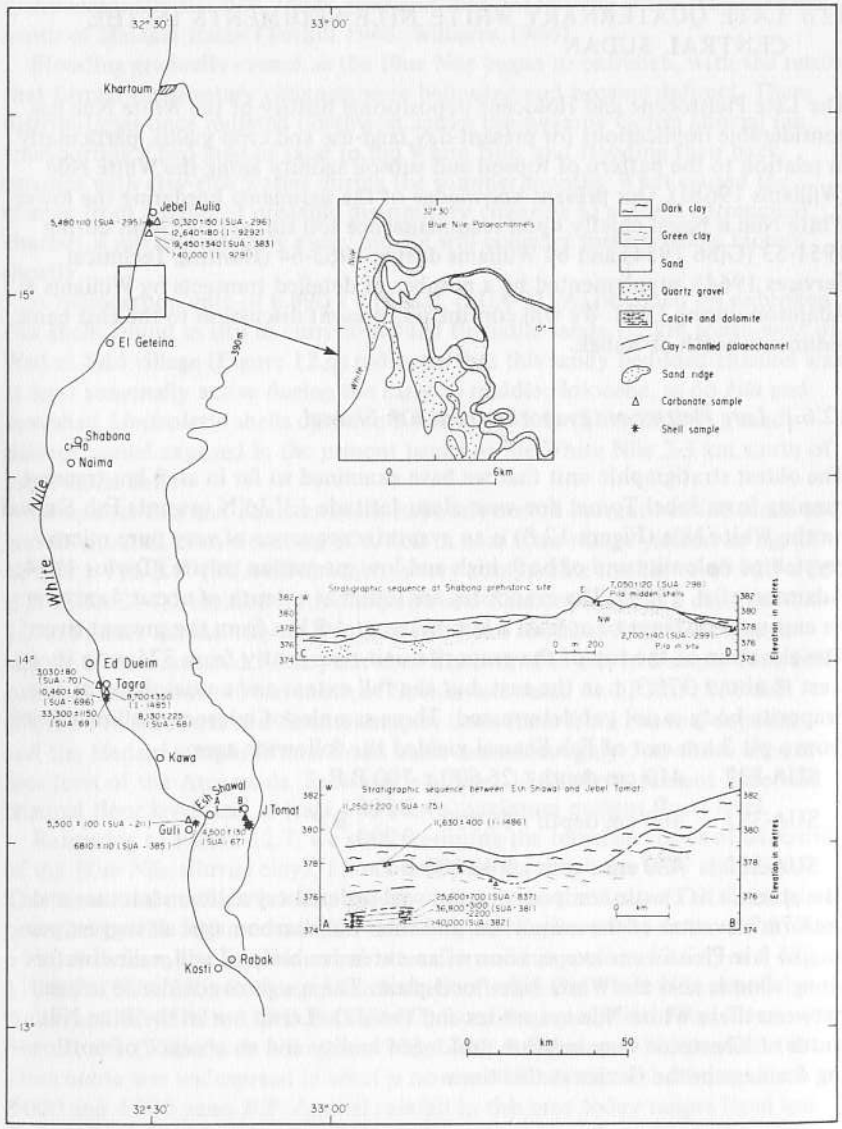


Figure 12.8 Late Quaternary depositional sequence and radiocarbon sample locations between Rabak and Khartoum, White Nile right bank.

proved to have an age of 33 300 ± 1 150 B.P. (SUA-69A), in contrast to a soft calcite concretion from the same level (SUA-69B: 10 460 ± 160 B.P.). No doubt many of the more resistant kankar nodules found within terminal Pleistocene and Holocene deposits in the Gezira emanate originally from the late Pleistocene evaporite unit. For example, hard black nodules collected from the same level

as 12 000 year old shells at Wad Medani were dated to 27 370 ± 800 B.P. (SUA-386). We have already seen that the in situ carbonate nodules within and beneath the reworked volcanic ash deposits north of Wad Medani were dated respectively to 23 450 B.P. and 24 920 B.P., so that an age of 20 000-30 000 for derived nodules in this locality is unsurprising.

12.6.3 *Late Pleistocene aeolian sands*

The close associations between Blue Nile palaeochannels and source-bordering dunes has been described elsewhere (Williams, Adamson & Abdulla 1979). The Blue Nile palaeochannels mostly reach the White Nile north of about 14°30′N, although minor channels were discernible down to 14°N (Figure 12.6), which is also about where the first sand dunes appear on the east bank, at Kawa. North of Kawa dunes become increasingly common, attaining their maximum extent between Naima and El Geteina, near the distal ends of a number of major Blue Nile palaeochannels (Williams 1968b, and Figures 12.6 and 12.8).

Prehistoric sites on the summits of many sand-ridges near the White Nile allow us to specify minimum ages for the dunes. The earliest assemblages of stone and bone implements so far discovered on the dunes belong to the Early Khartoum tradition, so that the dunes must have been in existence by at least 7 000-8 000 B.P. (Adamson et al. 1974). Many of the dunes display evidence of scalloping and marginal trimming by both White and Blue Nile palaeochannels and they are almost invariably flanked by stratigraphically younger alluvial clays (Figure 12.8). This partial submergence of irregular parabolic and meridionally-aligned linear dunes beneath a mantle of alluvium is especially evident on the west bank of the White Nile north of Ed Dueim, and is a direct legacy of the early Holocene transgressions of the White Nile (Adamson, Williams & Gillespie 1979).

12.6.4 *Early Holocene White Nile alluvial clays*

A transect running west of the 7 000 year old Shabona prehistoric site located some 25 km southwest of El Geteina shows that the Holocene White Nile attained a level of at least 379 m at latitude 14°40′N, which is 3 m above the uncontrolled flood level in this locality. Further south, at Tagra (13°56′N), 8 000 year old alluvial clays at 378.5 m are some 2.5 m above the gauged flood level at Ed Dueim. At Esh Shawal (13°35′N), dark alluvial clays with basal ages of 11 000-11 500 B.P. extend inland to 380 m, which is over 4 m above the mean flood level reached by the White Nile before construction of the Jebel Aulia dam created a reservoir up to 377.8 m above mean sea-level at Alexandria. The influence of the dam extends 500 km upstream to above Renk. There can be little doubt that the area flooded by the early Holocene White Nile was more extensive still; with inundation of all land up to at least 380 m in elevation.

The Esh Shawal-Jebel Tomat transect depicted in Figure 12.8 indicates that several metres of green clay and silt accumulated under permanently reducing conditions during the terminal Pleistocene. Low water level at this time cannot have been lower than 380 m, and during flood, the river must have lapped the base of the twin peaks of Jebel Tomat.

Widespread accumulations of freshwater mollusk shells dated to 11 630 ± 400 B.P. (I-1486) and 11 250 ± 220 B.P. (SUA-75) near the top of the green clay unit give a terminal age for this very important transgression. Thereafter, dark clays generally devoid of shells, or else containing occasional amphibious and terrestrial species, accumulated in seasonal swamps as the White Nile began to cut down into its former alluvium.

The ultimate impact of the White Nile transgression which ended towards 11 250-11 300 B.P. was felt well beyond the local confines of central Sudan, and was of course triggered off by events far upstream.

There is striking evidence of very high flood levels in southern Egypt at this time (Chapter 11, and Butzer & Hansen 1968:328). Dark sapropelitic layers in eastern Mediterranean deep-sea cores (Herman 1972) testify to a dramatic change in water stratification towards 12 000 B.P., presumably related in part at least to a sudden influx of organically-rich Nile water.

Kendall's (1969) geochemical and pollen studies demonstrate that Lake Victoria was a closed basin from at least 14 500 B.P. until roughly 12 500 B.P., and Lake Albert had a similar history (see Chapter 14). The time at which overflow from Lakes Victoria and Albert initiated the 12 500-11 500 B.P. transgression of the White Nile was also a time of high lake levels throughout Kenya and Ethiopia (see Chapters 14 and 15) with overflow of Lake Turkana into the White Nile via the Lotagipi Swamp and the Kangen, Pibor, and Sobat rivers (Figure 12.1).

We can obtain some idea of the volume of the expanded White Nile by assuming a flood level gradient of 1 cm/km (similar to that on Jebel Aulia reservoir), a minimum flood level of 380 m at 13°30′N, and a flooded channel extending from Malakal to Khartoum. A minimum value of 20 km^3 of water must be added to the 3.2 km^3 now stored in the Jebel Aulia reservoir, giving a low water volume of about 23 km^3. A gross estimate of the static flood volume would be about 75 km^3 of water. Since flood velocities would normally be somewhat higher than those during low water, the ratio of peak to low flow would have been greater than 7:2, and probably in the order of 5:1, possibly indicating a somewhat greater seasonality of flow than is the case today.

Before turning to the last 5 000 years of White Nile history, we need to consider what was taking place towards 7 000-8 000 years ago, when high White Nile flood levels are once more in evidence.

Seasonal communities of fishermen gathered on top of sand-ridges overlooking the White Nile swamps to hunt hippo and fish for Nile perch using spears and/or harpoons fitted with barbed-bone points. The age of the 'aqualithic' or 'Early Khartoum' (see also Sutton 1977 and Chapters 3, 18 and 22) is slightly more than 8 000 B.P. at Tagra and 7 050 ± 120 B.P. (SUA-298) at Shabona prehistoric site south of Khartoum (Adamson et al. 1974).

Prehistoric flood levels at the Early Khartoum site excavated by Arkell were at least 4 m higher than present-day flood levels (Arkell 1949:12), and a Blue Nile palaeochannel was active near Wad es Said several metres above present flood level towards 7 000 years ago. Also instructive is the evidence for wetter conditions west of the White Nile at about this time.

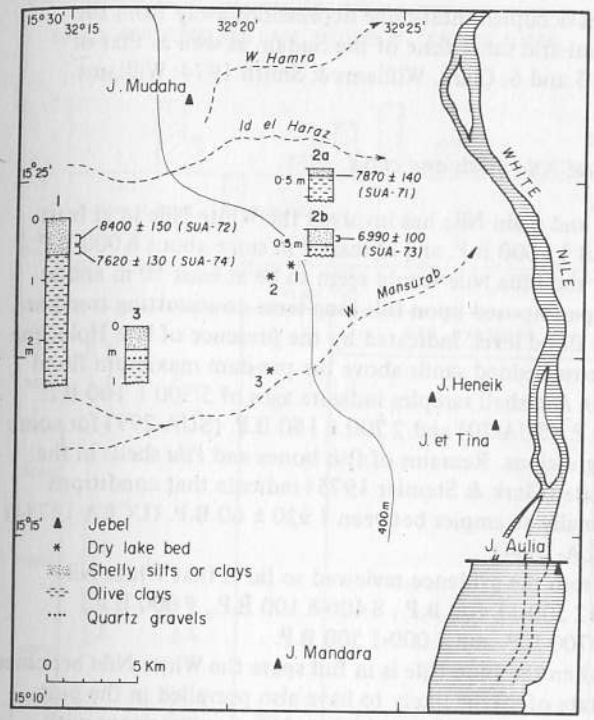


Figure 12.9 Holocene lake deposits and radiocarbon ages of sub-fossil freshwater mollusca in Wad Mansurab basin, west of the White Nile. (Adapted from Williams, Medani, Talent & Mawson 1974)

12.6.5 *Holocene lakes west of the White Nile*

A series of small lake basins situated in Wad Mansurab basin 13 km west of the White Nile and 20 km north-west of Jebel Aulia dam (Figure 12.9) supported an abundant freshwater mollusk fauna at about the same time that the Wad es Said palaeochannel was active, and flood levels were high on the White Nile. Four dates from three of the Wad Mansurab lake basins indicate that lakes were full between 8 400 ± 160 B.P. (SUA-72) and 6 990 ± 100 B.P. (SUA-73) (Williams et al. 1974). The significance of these sites lies in their elevation 20-40 m above the highest Holocene flood level of the White Nile, and in the presence of occasional terrestrial species (*Limicolaria, Zootecus*) amidst the otherwise dominantly freshwater mollusk assemblage. Two further points deserve mention.

A sample of *Bulinus, Biomphalaria* and *Pila* shells from a calcareous silt sandwiched between fluviatile sands in En Nahud in Kordofan collected by the late Dr W.H.Morton in 1976 was dated at 6 800 ± 110 B.P. (SUA-606). More extensive collections of sub-fossil freshwater mollusks from elsewhere in Kordofan (Huckriede & Venzlaff 1962) confirm that there were numerous shallow lakes in hollows between dunes during the early-middle Holocene in west-central Sudan.

The implications of the archaeological, stratigraphic and fossil evidence summarised above seem clear. Flood levels of both the Blue and the White Nile were very high towards 12 000-11 000 B.P. and again towards 8 400-6 800 B.P.,

when numerous small lakes occupied inter-dune depressions away from the Nile in what is now the semi-arid sahel zone of the Sudan, as well as that of Niger and Chad (Chapters 3 and 6, Clark, Williams & Smith 1974; Williams 1976).

12.6.6 *Late Holocene White Nile sands and clays*

Downcutting by the Blue and main Nile has involved the White Nile in at least 4 m of incision since about 11 000 B.P. and at least 2 m since about 8 000 B.P. Corresponding figures for the Blue Nile would seem to be at least 10 m and at least 4 m respectively. Superimposed upon this long-term downcutting trend are episodes of above average flood level, indicated by the presence of late Holocene dark clays and fluvially cross-bedded sands above the pre-dam maximum flood level. Dates obtained upon *Pila* shell samples indicate ages of 5 500 ± 100 B.P. (SUA-211), 3 030 ± 80 B.P. (SUA-70) and 2 700 ± 140 B.P. (SUA-299) for some of these White Nile transgressions. Remains of fish bones and *Pila* shells in the Jebel Tomat prehistoric site (Clark & Stemler 1975) indicate that conditions here were probably seasonally swampier between 1 930 ± 60 B.P. (UCLA-1874I) and 1 600 ± 80 B.P. (UCLA-1864).

An initial conclusion from the evidence reviewed so far is that White Nile levels were high around 12 500-11 400 B.P., 8 400-8 100 B.P., 7 000 B.P., 5 500 B.P., 3 000 B.P., 2 700 B.P. and 2 000-1 500 B.P.

At the present time, when the Blue Nile is in full spate the White Nile becomes a ponded backwater, a state of affairs likely to have also prevailed in the past. Accordingly, it is useful to compare the dated White Nile transgressions with dated Blue Nile floods, and especially with independent evidence for increased river flow and higher lake levels beyond the immediate confines of the Nile valley in central Sudan.

High Blue Nile flood level at 12 000-11 000 B.P. (11 920; 11 800; 11 330; 11 230 B.P.), 7 500 B.P., 6 900 B.P. and 5 500 B.P. (Figure 12.10) tally in detail with those recorded for the White Nile.

Permanent freshwater lakes in now dry hollows between dunes indicate greater runoff and/or higher water-tables in west-central Sudan towards 8 400-6 800 B.P., coinciding with the second major White Nile transgression, with high Blue Nile floods, and with palaeochannel activity in the Gezira. A comparison with published lake level curves for the Sahara and East Africa (Figure 12.10; see also Chapters 3, 6 and 15; Butzer 1976: Figure 5; Rognon & Williams 1977) strongly confirms that the late Quaternary environmental changes that took place in central Sudan were a response to long-term climatic changes that affected the whole of North Africa during that time.

12.7 CONCLUSION

Earlier in this chapter we asked why the late Quaternary Nile was sometimes aggrading and sometimes cutting into its flood-plain. We also noted a change in Blue Nile channel pattern from comparatively straight sandy distributary chan-

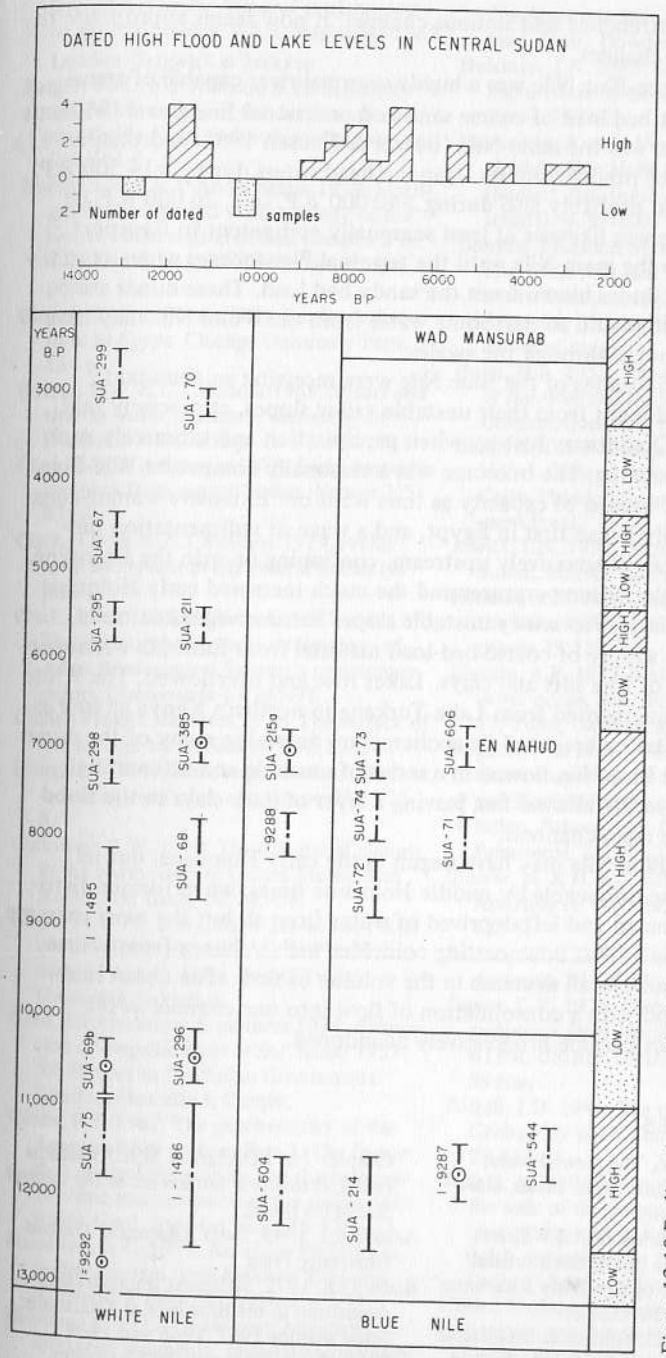


Figure 12.10 Radiocarbon ages of high Blue and White Nile flood levels and of high lake levels in central Sudan west of the White Nile, 13 000 B.P. to 2 000 B.P. Note that ages shown here, unlike those in Butzer 1976:31, are not converted into calendar years.

nels to its present entrenched and sinuous channel. It now seems appropriate to try to explain these changes.

The late Pleistocene Blue Nile was a highly seasonal river capable of transporting an abundant bed-load of coarse sand and occasional fine gravel (Williams et al. 1975). So, too, was the main Nile (Butzer & Hansen 1968, and Chapter 11). Although deprived of runoff from its Ugandan headwaters during ⩾14 500 B.P. to c. 12 500 B.P. and probably also during >40 000 B.P. to c. 26 000 B.P. or later, the White Nile was likewise at least seasonally competent to transport gravels and sands to the main Nile until the terminal Pleistocene, when its valley became blocked by dunes blown from the sandy bed load. These dunes are usually aligned north-south, so that some water from the White Nile may have continued to flow north through the swales.

The Ethiopian tributaries of the Blue Nile were receiving an abundant supply of coarse sediment from their unstable valley slopes, at precisely that stage in Ethiopian Quaternary history when precipitation and ultimately runoff were rapidly declining. The outcome was a seasonally competent Nile-Blue Nile, which became loaded to capacity as time went on. Extensive waning-stage aggradation probably began first in Egypt, and a wave of sedimentation probably worked its way progressively upstream, continuing on into the Holocene.

The higher postglacial temperatures and the much increased early Holocene rainfall had two effects. Previously unstable slopes became vegetated, soils developed, and the supply of coarse bed-load material from Ethiopia was superseded by an influx of fine silts and clays. Lakes rose and overflowed. The White Nile, its flow now augmented from Lake Turkana in northern Kenya as well as from the Ugandan lakes, breached its aeolian dam, drowning many of the dunes in the process. The Blue Nile flowed in a series of unstable and bifurcating channels across its sandy alluvial fan, leaving a layer of dark clays in the flood basins between the main channels.

Incision by the Blue Nile may have begun in the early Holocene, but its effects only became noticeable by middle Holocene times, when former distributaries were beheaded and left deprived of water from all but the most extreme floods. It seems, then, that downcutting coincides with a change from coarse to fine load, with an overall decrease in the volume of flow after about mid-Holocene times, and with a consolidation of flow into one channel as the Gezira distributaries became progressively abandoned.

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13

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Jebel Marra volcano: a link between the Nile Valley, the Sahara and Central Africa

Jebel Marra Volcano: un lien entre la Vallée du Nil, le Sahara et l'Afrique centrale

Le Jebel Marra est un massif volcanique de la fin du Cénozoïque situé dans le Darfur, Province du Soudan Occidental semi-aride, presque à mi-chemin entre la Vallée du Nil et le Bassin du Tchad. C'est ainsi une région critique pour toute tentative de corrélation entre les climats passés des régions ouest et est du Sahara méridional. Ce chapitre présente les résultats initiaux d'une tournée de reconnaissance entreprise pour rechercher les preuves de changements plus anciens de l'environnement dans la région du massif Jebel Marra, ainsi que dans d'autres localités choisies au sud du Darfur.

Des feuilles fossiles de palmier à huile se rencontrent dans une mince couche de cendres à l'intérieur des tuffs et des graviers de piémont de la formation Umm Mari au sud du Jebel Marra. Des industries bien conservées d'aspect oldowaien et acheuléen indiquent un âge pléistocène inférieur à moyen pour cette formation qui s'est en partie déposée sous des conditions tropicales humides.

A l'ouest du Jebel Marra près de Kebkabiya des diatomites de lac finement laminées et relativement pures sont recouvertes par des fins gravillons qui contiennent des outils acheuléens suggérant à nouveau une période humide juste avant le début du Pléistocène moyen.

Les sols polygéniques qui s'étendent sur les plaines vallonnées au sud-ouest du Jebel Marra révèlent une histoire complexe et pas encore complètement élucidée de soulèvement, de volcanisme et de fluctuations climatiques. Des terres noires alluviales plus récentes dans une terrasse fluviale inférieure située au sud du massif, suggèrent un intervalle au début de l'Holocène moyen de précipitations bien réparties et de cours d'eau permanent.

Il est probable que les investigations les plus fructueuses soient celles obtenus à l'intérieur de la caldera Deriba du Jebel Marra, où deux lacs de cratère apportent la preuve évidente de fluctuations des lignes de rivage. Des calcaires algaires et des pellicules calcaires sur des galets de plage ont permis des datations préliminaires au radiocarbone de ces fluctuations, bien que la nature des échantillons loin d'être parfaite invite à la prudence.

Le plus grand des deux lacs a des lignes de rivage à environ 25 m, 5-10 m, 2.5 m et 1.5-1 m au dessus du niveau actuel du lac. Le niveau le plus élevé et le plus ancien fut érodé à une époque située avant 19 000 B.P. A la fin du Pléistocène terminal (19 000 à 14 000 B.P.) le lac a atteint les niveaux +5 m à +10 m, et pendant l'Holocène les deux lignes de plage les plus basses ont été emportées par l'érosion dans les dépôts littoraux plus anciens.

Le lac de cratère plus petit est contenu dans un cratère d'explosion subsidiaire, qui peut être aussi jeune que 3 250 ans B.P.; des rapports et documents ainsi que des arbres noyés indiquent que le niveau de ce lac au cours du siècle actuel, a connu des fluctuations s'élevant jusqu'à 7-10 m, probablement dues à des variations dans les précipitations.

Les sols polygéniques des champs de dunes du Qoz Dango, à quelque 250 km au sud du Jebel Marra, indiquent plusieurs phases alternatives de construction de dunes et d'érosion

de rivières à la fin du Quaternaire. Les levées situées sur les berges de bras de rivières fossiles (regebas) à l'est du Qoz Dango contiennent des tessons de poterie néolithiques et plus jeunes, suggérant une activité au moins saisonnière des chenaux au début de l'Holocène moyen. Des matériaux de provenance volcanique dans les dépôts d'origine fluviale du Qoz Dango, et de très hauts niveaux riches en phosphore dans certains sols alluviaux en relation avec le système regeba, suggèrent une connection fluviale plus ancienne avec le Jebel Marra à travers des plaines sableuses éoliennes maintenant asséchées.

A plusieurs reprises au cours du Quaternaire, la limite extérieure du désert s'est étendue bien au sud du Jebel Marra, de la même manière qu'à d'autres époques la savane est parvenue bien au nord du massif.

En attendant que soient établies des datations absolues plus étroitement contrôlées du cadre stratigraphique, seules des conclusions et des corrélations provisoires peuvent être effectuées à partir des faits présents. Les palmiers à huile fossiles et les diatomites de lacs suggèrent que le Soudan occidental a connu un, ou plusieurs, intervalle humide au début du Pléistocène, probablement en relation avec les conditions plus humides indiquées par les hauts niveaux des lacs dans le Hoggar, le Tibesti, le Tchad et l'Afar.

Les positions élevées des lacs Deriba indiquent des phases humides à 19 000-16 000 B.P. et 14 000 B.P., qui peuvent être mises en corrélation avec une époque où il existait un lien fluvial entre le Jebel Marra et les régions du sud actuellement sèches, et peut être avec l'activité fluviale du Pléistocène terminal dans la région de Gezira dans le Soudan oriental. Le Pléistocène récent et l'Holocène ont vu plusieurs phases de construction des dunes, d'érosion et d'alluvionnement des rivières, de fluctuations des précipitations et de l'évaporation qui ont culminé à l'Holocène récent avec l'assèchement et la disparition accélérée de la végétation en raison de l'élevage, du défrichage et du brûlage.

13.1 INTRODUCTION

A key issue in African Quaternary research is the degree to which major regional climatic changes were contemporaneous in the arid zones and their Sahelian fringes (Rognon & Williams 1977). Detailed investigations of lake sediments and diatomites in the Chad basin (Servant 1973) and in the lakes of the Afar Rift (Gasse 1975) have revealed a high degree of synchroneity between lake-regressive and lake-transgressive phases in both regions during the past 40 000 radiocarbon years, as well as a number of intriguing differences. The 1968-1973 Sahelian drought affected the entire southern margin of the Sahara as well as the Afar desert – a zone 4 500 km long between the Atlantic and the Red Sea. The same seems true of the late Pleistocene intertropical arid phase, dated at roughly 20 000-12 000 years B.P., when live dunes were active down to latitude 10° N, a shift of 500-800 km south of their present limits (Williams 1975). During the early Holocene, however, cool, wet conditions are indicated by diatoms in Mauritania and Lake Chad, in notable contrast to the Kenya-Ethiopia Rift and Afar, where lake flora indicate hot, wet conditions at that time (see Chapters 6 and 15).

Any attempt to seek mechanisms capable of explaining the pattern of late Quaternary climatic changes in Saharan Africa is immediately impeded by our almost total ignorance of what was happening between Lake Chad and the Nile nearly 2 000 km to the east. Jebel Marra, a mountainous volcanic complex located in this critical region, almost midway between the Nile valley and the Chad basin, is thus of major interest (Figure 13.1). Situated too in the climatically transitional Sahelian zone between the arid Sahara desert to the north and the

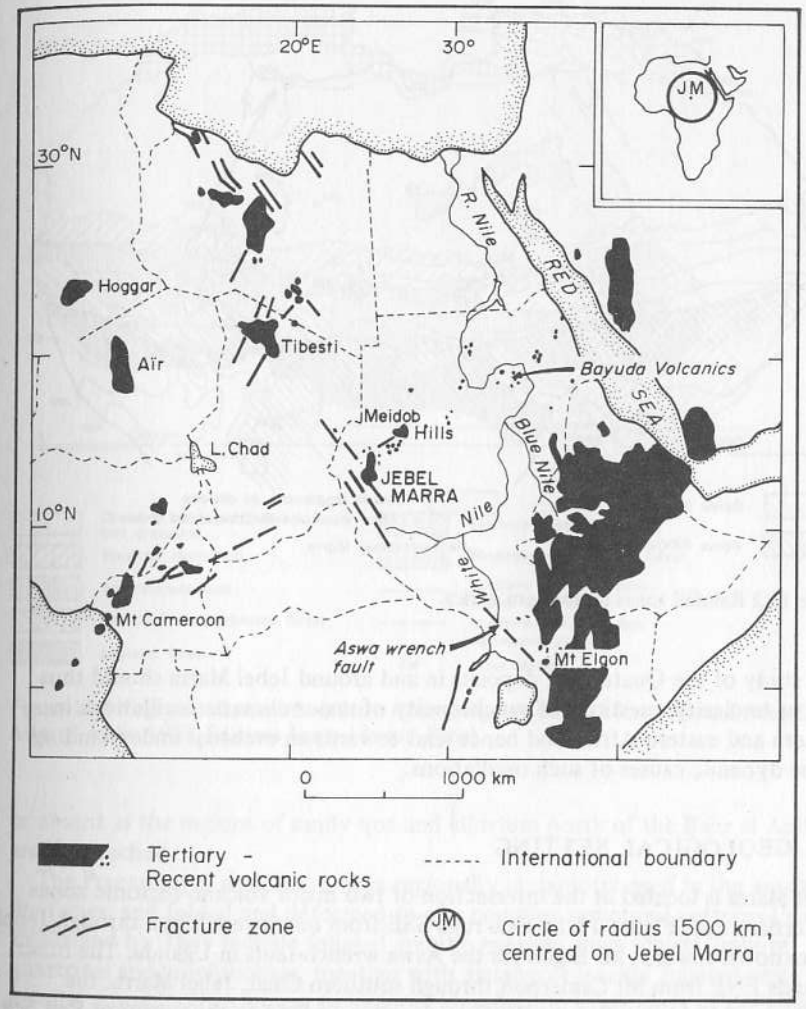


Figure 13.1 Volcano-tectonic setting of Jebel Marra (after Vail 1972a).

seasonally-wet tropical savanna to the south, Jebel Marra is in a region sensitive to both short- and long-term shifts in the latitudinal climatic and related vegetation zones (Figures 13.2 and 13.3). Being high (3 042 m above sea level), with two significant crater lakes and well served by perennial rivers and springs, the mountain has long been a refuge for plants, animals and men during the drier climatic phases of the Quaternary, as well as a staging-point along east-west and north-south migration routes during the wetter periods. The past and present flora is richer and more varied than that of the surrounding desert, containing both Mediterranean and tropical elements (Wickens 1976a and b), and the area has high potential for the preservation of Quaternary plant and animal remains, as well as possible prehistoric sites.

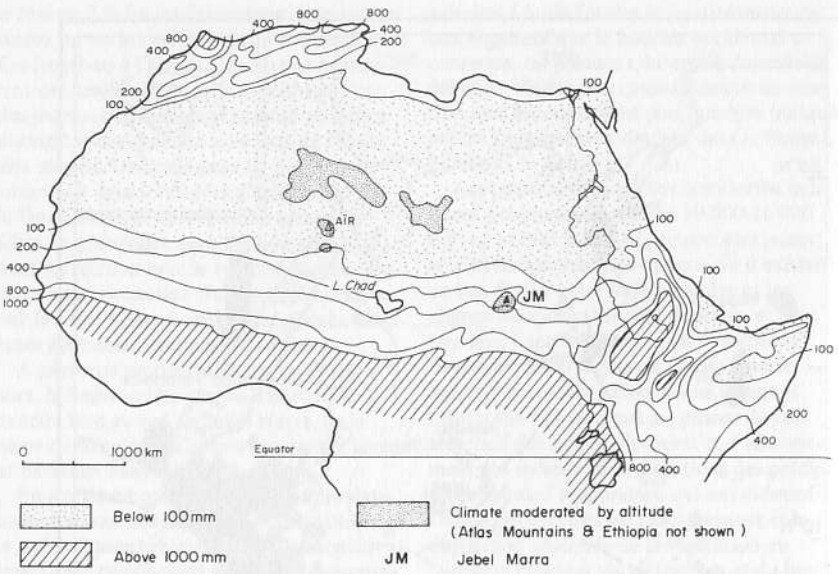


Figure 13.2 Rainfall zones of northern Africa.

A study of the Quaternary deposits in and around Jebel Marra should thus help us to clarify questions of synchroneity of major climatic oscillations in western and eastern Africa and hence lead towards an eventual understanding of the dynamic causes of such oscillations.

13.2 GEOLOGICAL SETTING

Jebel Marra is located at the intersection of two major volcano-tectonic zones of Tertiary age (Figure 13.1). One runs SSE from northwest Libya through Jebel Marra down towards Mt Elgon via the Aswa wrench-fault in Uganda. The other extends ENE from Mt Cameroon through southern Chad, Jebel Marra, the Tagabo and Meidob hills, and the Bayuda volcanic field to the northern Red Sea Hills (Vail 1972a). Situated as it is on an updomed platform of Basement Complex rocks, Jebel Marra lies astride the watershed between the Chad and Nile drainage basins, at roughly equal distances from the Atlantic, the Mediterranean, the Red Sea and the Indian Ocean (Figure 13.1 inset).

13.2.1 *Pre-volcanic formations*

The solid geological formations in the Jebel Marra region consist of three distinct groups: Precambrian basement rocks, pre-Tertiary sedimentary rocks, and late Tertiary and younger volcanic rocks which comprise Jebel Marra, the Meidob Hills and a multitude of scattered plugs and flows (Figure 13.4). Exposure of bedrock is generally good in the northern and central parts of the area, north of the latitude of Nyala; but to the south exposure becomes poor

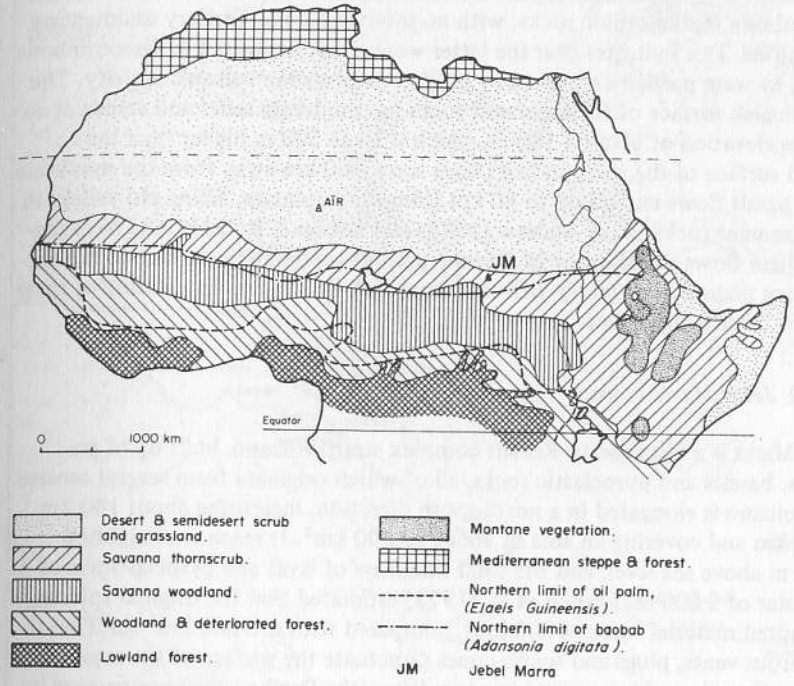


Figure 13.3 Vegetation zones of northern Africa (Figures 13.2, 13.3 are abapted from The Atlas of Africa 1973, Editions Jeune Afrique, Paris).

or absent as the regions of sandy qoz and alluvium north of the Bahr el Arab are approached.

The Precambrian rocks have been regionally metamorphosed in the amphibolite facies, and folded and deformed to give complex structural patterns (Vail 1972a and b). They include foliated granitic gneisses, mica schists, impure quartzites and amphibolites, together with massive or weakly foliated areas of granite. Amphibolites appear to be more abundant in some parts of the area (for instance, east of Zalingei on the Nyertete road, and south of Kebkabiya on the Zalingei road) than previous reports suggest. Minor amounts of tremolite-chlorite schist occur associated with amphibolites south of Kebkabiya.

Unmetamorphosed pre-Tertiary sedimentary rocks locally overlie the Precambrian basement. The main area of outcrop in Darfur is to the northeast of Jebel Marra, but sporadic exposures occur in the qoz- and alluvium-covered parts of southern Darfur. They comprise grits, sandstones, siltstones and shales, the arenaceous rocks often showing fluviatile cross-bedding. These rocks are generally ascribed to the Nubian Sandstone Formation of Cretaceous age but may also include both younger and older formations, and Vail (1972a) has pointed out that similar sediments in eastern Chad have been mapped as Ordovician and Devonian in age.

In most places the volcanics of the Jebel Marra massif directly overlie the

Precambrian metamorphic rocks, with no intervening pre-Tertiary sedimentary formations. This indicates that the latter were either deposited in discontinuous basins, or were partially removed by erosion prior to the volcanic activity. The sub-volcanic surface of the basement rocks has moderate relief and stands at an average elevation of about 1 100 m, which is some 500 m higher than the eroded surface of the surrounding plains some 100 km away from the mountain. Some basalt flows extend up to 80 km from the mountain, filling old valleys in the basement rocks. If, as Andrew (1948) and Lebon & Robertson (1961) suggest, these flows are Miocene in age, the present topographic surface of the surrounding plain is not greatly different from that of 15 m.y. ago. Dating of these flows is clearly important.

13.2.2 *Jebel Marra volcano*

Jebel Marra is a Miocene to Recent complex strato-volcano, built up of trachytes, basalts and pyroclastic rocks, all of which originate from several centres. The volcano is elongated in a north-south direction, measuring about 140 km by 50 km and covering an area of about 13 000 km^2. It reaches a height of 3 042 m above sea level, and the total thickness of lavas and pyroclastics is of the order of 2 000 m. Francis et al. (1973) estimated that the original volume of erupted material was c. 8 000 km^3, compared with c. 3 000 km^3 for Tibesti. Numerous vents, plugs and scoria cones punctuate the surface of the massif and a 5 km diameter caldera containing two lakes (the Deriba lakes) occurs near its southern end. Pyroclastic deposits associated with the collapse of the caldera and subsequent explosive activity within it cover large areas of the southern part of the mountain and interdigitate with Quaternary sedimentary deposits on its lower flanks and on the surrounding plains. Prior to erosion, the ash blanket must have been very extensive. Pockets of wind-borne ash occur beyond Zalingei, 100 km away from the volcano (FAO 1969).

Volcanic activity occurred in two main phases of mixed lava and ash eruption. These phases were separated by a period of erosion, and followed by the main explosive phase which accompanied and followed caldera collapse (Lebon & Robertson 1961; FAO 1968). Intrusion of plugs and dikes seems to have occurred throughout the history of the volcano. Pyroclastic volcanism from several different sources has continued until very recent times as indicated by the presence of carbonised wood dated at 3 250 years B.P. in a pumice deposit (Francis et al. 1973). At present the volcano is in a dormant (fumarolic) state.

13.2.3 *Superficial deposits*

During the period of erosion which separated the two earlier eruptive phases of Jebel Marra as outlined above, large quantities of lava and ash were washed from the slopes of the volcano and deposited on the surrounding plain. These piedmont alluvial deposits form a gently sloping apron around the mountain and are now dissected by rivers and partially covered by material from later eruptions. They are particularly well developed to the west and south of the

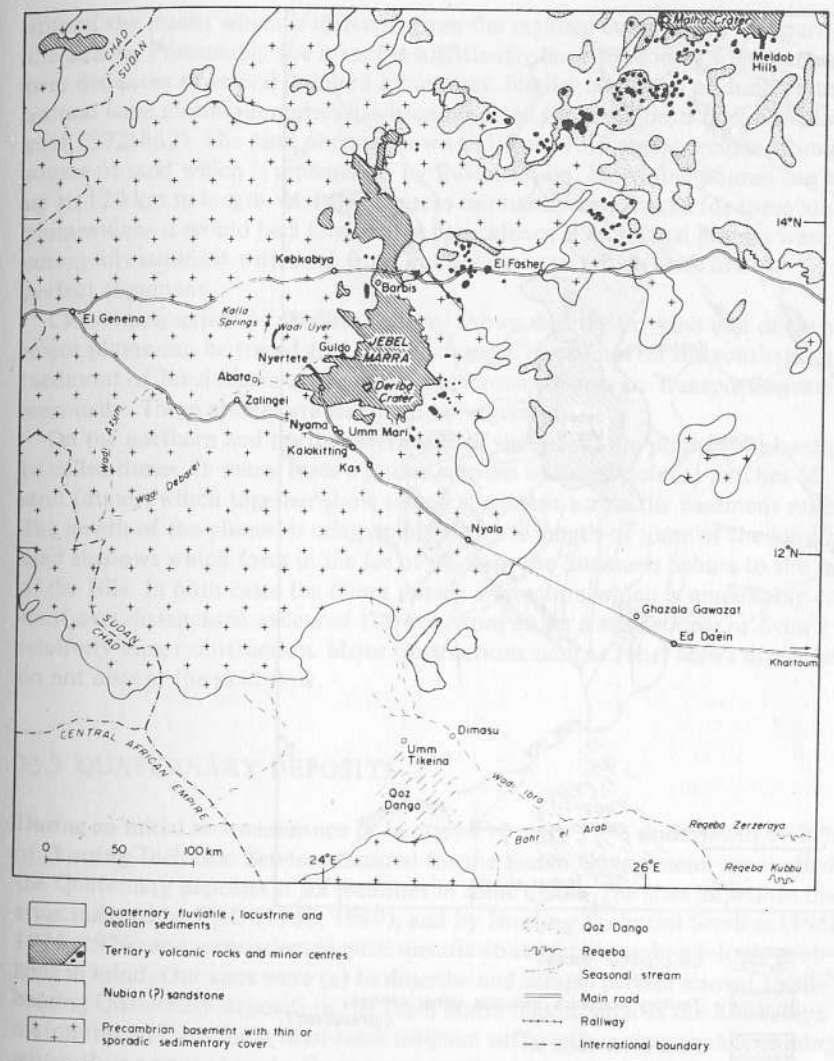


Figure 13.4 Geology of Jebel Marra region, showing localities mentioned in text (geology after Vail 1974).

massif, in the regions of Guldo, Nyertete, Kalokitting and Kas (FAO 1969).

Superficial deposits of fluviatile, lacustrine and aeolian origin form a sporadic cover over the Precambrian basement in the northern part of the region, and a continuous cover in the south. Alluvial deposits are mostly associated with the Wadi Azum, the Bahr el Arab and their tributaries. Lacustrine deposits, which include clays, diatomites and reworked volcanic ash, occur in scattered basins (for example, 30 km southeast of Kebkabiya). Aeolian deposits are widespread, the most striking type being 'qoz': an ancient fixed sand sea (Figure 13.4). Qoz

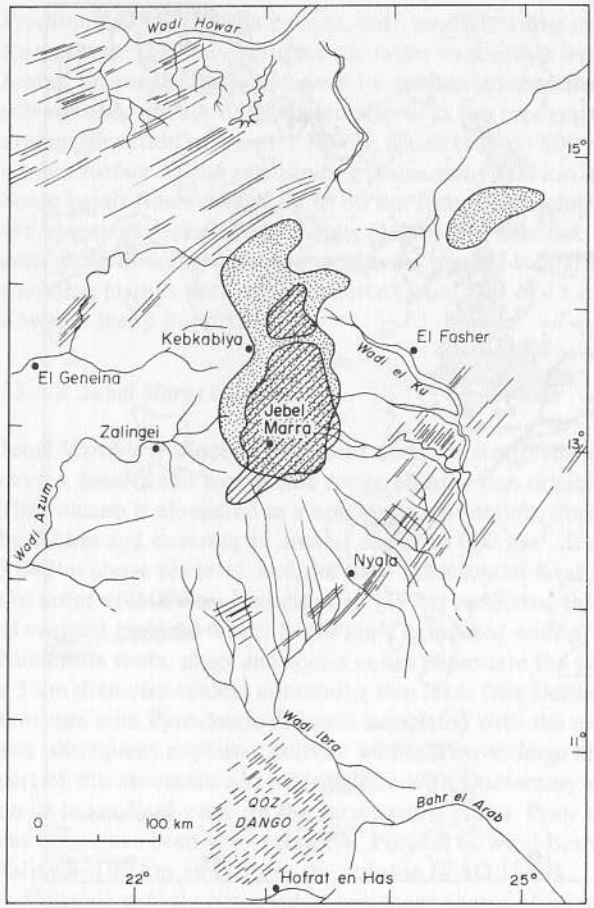


Figure 13.5 Late Quaternary sand dunes around Jebel Marra (based upon ERTS imagery).

is most extensively developed to the east and south of Jebel Marra and is typified by gently undulating dunes, now fixed by savanna vegetation, and clay-filled swales. In contrast, many of the linear dunes north of about El Fasher are unvegetated and active and follow a deflected path around the massif (Figure 13.5).

Separate from the large areas of fixed qoz are linear orientations of wind-blown sand of remarkable length (Figure 13.5). They occur to the north, northwest and southeast of the volcanic massif and show a definite curvature

around the massif which is different from the regional curvature in this part of the Sahara. Presumably the massif is sufficiently large to modify wind patterns over distances of several hundred kilometres. Similar curvature of dune patterns around large mountain masses has been reported for the Tibesti region (Mainguet 1972:462). The sand plumes shown in Figure 13.5 each originate from a source of sand which is replenished by fluvial action. Individual plumes can be up to 120 km in length. Multiple sources can hardly be invoked for these long plumes since it would be a remarkable coincidence if individual plumes were commonly supplied with sand from multiple sources which were in near-perfect alignment.

Close examination of satellite imagery shows that the up-wind end of each major plume can be traced to a fluvial source. The plumes on the southeastern piedmont of Jebel Marra occur where numerous streams are transporting sand seasonally. These plumes are stabilised by vegetation.

On the northern and northwestern side of the massif the plumes can hardly be called dunes. In many cases a plume consists of many isolated patches of sand (dunes) which together show strong alignment across the basement surface. The length of the plumes is comparable with the length of some of the longer sand shadows which form in the lee of jebels in the Sudanese Sahara to the west of the Nile. In both cases the dunes pursue a direction which is remarkably constant over distances in excess of 100 km, from either a sand source or from a relatively minor obstruction. Major obstructions such as Jebel Marra divert but do not disrupt the sand flow.

13.3 QUATERNARY DEPOSITS

During an initial reconnaissance in January-February 1976 undertaken on behalf of Hunting Technical Services Limited for the Sudan Government, we studied the Quaternary deposits at six localities in some detail. The sites lie within the areas mapped by FAO (1968, 1969), and by Hunting Technical Services (1958, 1974, 1976) and were selected with specific stratigraphic and pedologic problems in mind. Our aims were (a) to describe and sample certain known fossil-bearing Quaternary deposits in the Jebel Marra region, such as the Kebkabiya diatomites and the Umm Mari fossil oil-palm tuffs, with a view to determining where they occurred in the Quaternary stratigraphic column; (b) to test the potential of Deriba caldera as a Saharan palaeo-rain-gauge (to use Professor D.A. Livingstone's vivid expression); and (c) to clarify certain questions of soil genesis with major implications for soil fertility in this region. The six localities studied comprised a wide variety of depositional milieus and of sediments spanning much of the time-range of the Quaternary, and were as follows:

1. The volcanic ash piedmont deposits between Kas and Nyertete.
2. The complex of 'Drift' soils between Nyertete and Zalingei, comprising both Basement Complex and derived soils.
3. The polygenic soils between Zalingei and Kebkabiya, and the diatomite deposit near Kebkabiya.
4. The dissected ash deposits in and around the Deriba caldera, Jebel Marra.

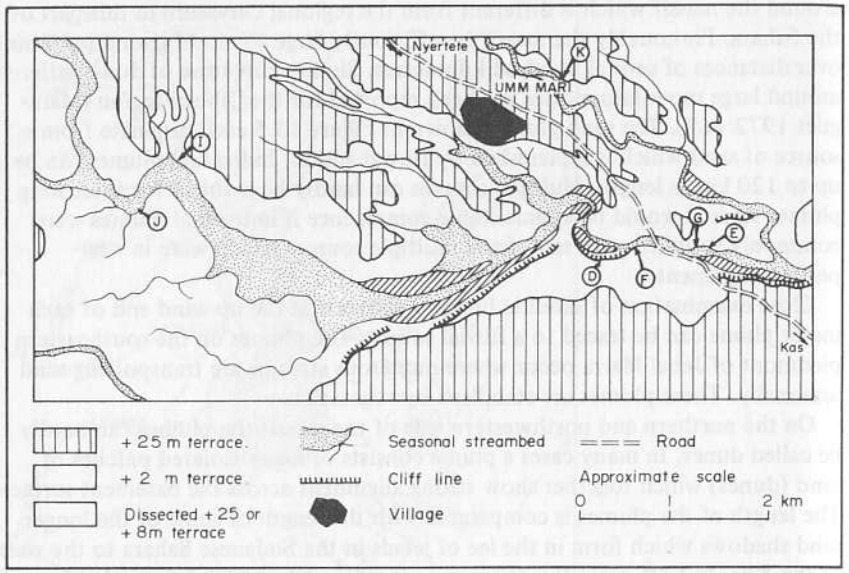


Figure 13.6 Location of Umm Mari sections.

5. The red sands and peripheral dark loams of the Qoz Dango region in Southern Darfur.
6. The dark fluviatile Regeba clays and associated soils between Ed Da'ein and the Bahr el Arab in Southern Darfur.

13.3.1 *The volcanic ash piedmont between Kas and Nyertete*

The locality investigated is situated near Umm Mari village on the Kas-Nyertete road, some 20 km west of Kalokitting and 10 km south of Nyama village (Figures 13.4 and 13.6). In this locality a thick sequence of alluvial deposits overlies granitic gneiss and weakly foliated granite of the Precambrian Basement Complex. The basement rocks crop out in wadi beds, and also form several steep-sided jebels which rise some 30-50 m above the alluvial plain. About 3 km southeast of Umm Mari village, a wadi is floored by aphanitic basalt at an elevation at least 50 m below the tops of the jebels; this basalt thus appears to fill an old valley in the basement rocks.

Our reconstruction of the stratigraphic and geomorphic history of this locality is based upon the detailed study of eleven sections within a 4 km radius of Umm Mari village, the more important of which are given in Figure 13.7, supplemented by two rapid vehicle traverses through the area. The sequence of events inferred from the stratigraphy is enumerated below:

1. Weathering of the Basement Complex and formation of sedentary soil on granitic gneiss.
2. Extrusion of basalt and flow down piedmont valleys.

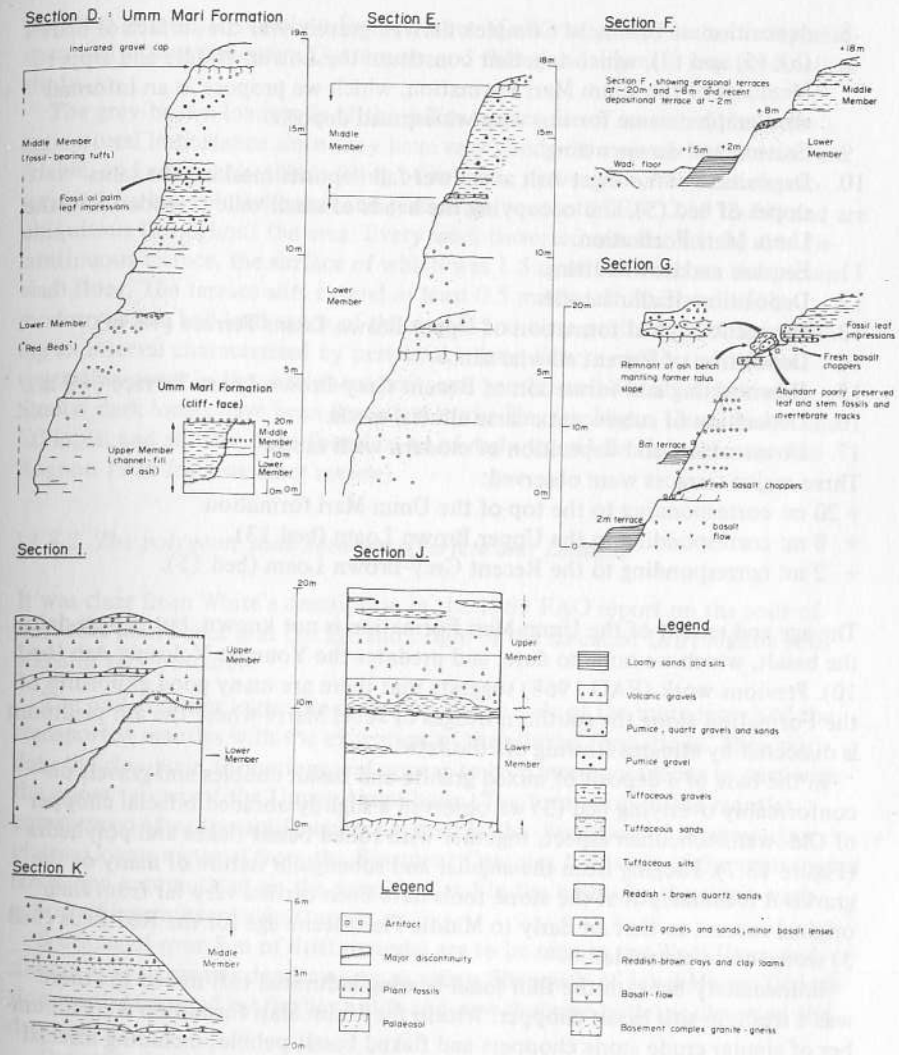


Figure 13.7 Stratigraphic sections, Umm Mari.

3. Deposition of Red Beds: Basement Complex derived gravelly sands and sandy gravels, with minor lenses of fine basalt gravel, but no pumice.
4. Erosion and downcutting.
5. Deposition of pumiceous sands and fine gravels, and of the tuffs containing the fossil oil-palm leaf and stem impressions described in detail by Wickens (1975a).
6. Erosion and channelling of beds (3) and (5).
7. Deposition of volcanic ash as channel-fill sediments within beds (3) and (5).

8. deposition of Basement Complex derived gravels over the surface of beds (3), (5) and (7), which together constitute the Lower, Middle and Upper Members of the Umm Mari Formation, which we propose as an informal stratigraphic name for this very widespread deposit.
9. Erosion and downcutting.
10. Deposition of Younger Ash as shower-fall deposits masking the talus slopes of bed (5), and occupying the heads of small valleys eroded into the Umm Mari Formation.
11. Erosion and downcutting.
12. Deposition of alluvial silts.
13. Downcutting and formation of Upper Brown Loam Terrace (+8 m).
14. Deposition of Recent alluvial silts.
15. Downcutting and formation of Recent Grey-Brown Loam Terrace (+2 m).
16. Deposition of sub-recent coarse alluvial sands.
17. Downcutting and deposition of modern wadi sands.

Three major terraces were observed:
+20 m: corresponding to the top of the Umm Mari formation.
+ 8 m: corresponding to the Upper Brown Loam (bed 13).
+ 2 m: corresponding to the Recent Grey-Brown Loam (bed 15).

The age and extent of the Umm Mari Formation is not known, but it post-dates the basalt, which we hope to date, and predates the Younger Volcanic Ash (bed 10). Previous work (FAO 1968) suggests that there are many good exposures of the Formation along the southern fringes of Jebel Marra where the ash piedmont is dissected by streams flowing off the Jebel.

In the base of a deposit of mixed granite and basalt cobbles and gravels unconformably overlying bed (3) we observed a slightly abraded bifacial chopper of Oldowan/Acheulian aspect, together with rolled basalt flakes and polyhedra (Figure 13.7). Judging from the angular and subangular nature of many of the gravels it is unlikely that the stone tools have been carried very far from their original source, so that an Early to Middle Pleistocene age for the Red Beds (bed 3) seems quite plausible.

Immediately beneath the thin fossil-bearing indurated tuff in bed (5) there was a fresh, in situ basalt chopper. Within the Umm Mari formation were a number of similar crude stone choppers and flaked basalt pebbles including bifacial and unifacial choppers, pushplanes, discoids, hammerstones, and flake scrapers of developed Oldowan or Early Acheulian aspect. Dates obtained for similar assemblages in East Africa suggest a maximum time range from c. 1.5 m.y. B.P. to 0.2 m.y. B.P. and a more probable range from 1.5 m.y. B.P. to 0.8 m.y. B.P. (Dr John Gowlett 1976, personal communication) for the Umm Mari Formation, including the fossil oil-palm leaves in bed (5).

Our investigations indicate that previous interpretations (Wickens 1975a and b) of the palaeoclimatic history of the area now need to be revised; and in particular that the fossil oil-palm and *Combretum* leaf impressions do not date from an early Holocene wet phase but are a great deal older. The essential point to retain is not so much that the oil-palm fossils may be up to a million or more years old, as the important fact that at Umm Mari there is a well exposed, complex and potentially highly informative set of alluvial and pyroclastic deposits spanning almost the entire Quaternary and that these urgently require detailed study.

The grey-brown loam soils of the +2 m terrace are of considerable local agricultural importance since they have very good soil moisture properties, are friable, and are readily tilled. Being of volcanic provenance, they are characterised by a high phosphorous and potassium content (TESCO 1973-74) and are ubiquitous throughout the area. Every wadi traversed was flanked by this discontinuous terrace, the surface of which was 1.5 m to 2.0 m above the present wadi floor. The terrace silts extend at least 0.5 m beneath the level of the modern coarse bed-load sands of the wadis, and were probably laid down during an interval characterised by perennial stream flow, a moderately dense vegetation cover in the catchment area, and gentle, well-distributed rainfall. Similar dark loams have been described in the Hoggar, Niger, Chad, Nubia and Ethiopia, and all have been found to be of early to middle Holocene age (see Rognon 1976 for a succinct review).

13.3.2 *The polygenic soils between Nyertete and Zalingei*

It was clear from White's description in the 1969 FAO report on the soils of the Jebel Marra area that the age and origin of the so-called Drift Mantle soils was still very obscure:

> The unit is rather imprecise including all the soils of the more recent of the transported mantles with the exception of the alluvial formations. They post-date the clay-plain formations and appear to be contemporaneous in part with the upper terrace of the Upper Azum basin. The formation of the mantles commenced after the uplift which resulted in the dissection of the grey clay plains. Coarse material from the Basement Complex hill-lands of the rejuvenated landscape accumulated on the peneplain and in the basins by the slope-wash action of intermittent rain storms.
>
> Sections of over 5 m of drift material are to be seen in the Wadi Uyer, and similar or even greater depths occur as valley fills south of Jebel Marra. Deposition was interrupted by further uplift and new drainage patterns dissected the deposits.
>
> The unit as mapped consists of low, smooth-lying interfluves, separated by gully zones along the insequent, dendritic drainage lines. Towards the watersheds the gully zones coalesce, creating large areas of truncation.
>
> (Ibid., p. 44)

The so-called 'Drift' soils between Nyertete and Zalingei include stony lithosols developed over granite-gneiss, minor areas of deep red sandy clay loams, and isolated small patches of dark grey-brown sandy clay. The clay has a very patchy distribution, sharp contacts with the red loam, and occurs in a variety of topographic situations, including the level interfluves. In every instance investigated by us, the dark clay was underlain by amphibolite bedrock of hornblende-plagioclase-garnet mineralogy. At one site we found a duplex soil

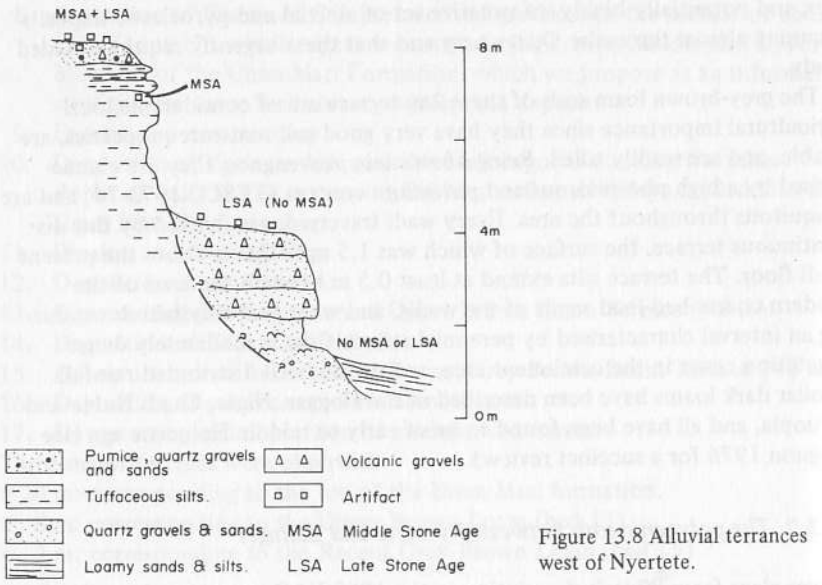


Figure 13.8 Alluvial terrances west of Nyertete.

in which transported gneiss-derived soil material overlay a sedentary dark clay developed on amphibolite. Compared to the other rock types present, the amphibolites are notably richer in Ca, Mg, Fe and other base metals, and poorer in K, Si and to some extent in Na.

Seasonal watercourses in this area are flanked by a low terrace up to 1.5 m above the modern sandy wadi floor, on which are fields of *durra* and *shatta*. The terrace consists of a dark brown loam, and is similar to that already described in the Umm Mari area. Above this alluvial terrace there were three older river terraces at relative elevations of 3, 4 and 8 m above the channel floor (Figure 13.8).

Eroding out from near the surface of the 8 m terrace in one locality there was a large worked flake of Middle Stone Age aspect, and on the surface of this terrace was a mixed concentration of both Middle and Late Stone Age quartz flakes (Figure 13.8). The terrace itself comprised three stratigraphic units: a basal tuffaceous loam some 3 m thick, a series of several indurated ash bands, and a caprock of iron-cemented coarse pumice and feldspar sand. Inset into and abutting unconformably against the 8 m terrace was a 4 m terrace consisting of an upper unit of fluvially bedded volcanic gravels and a lower unit of red-brown loam developed from Basement Complex granite-gneiss. Late Stone Age quartz flakes were strewn across the surface of the 4 m terrace, but were not seen on or within either the 3 m red-brown loam terrace or the 1.5 m dark brown loam terrace. The agricultural value of the two lower terraces far exceeds that of the two upper terraces in this area.

To sum up, the 'Drift' soils complex east of Zalingei includes at least five distinct types of alluvial soil material and at least three distinct types of sedentary soil material, as well as a number of truncated palaeosol remnants left isolated by later dissection:

Alluvial

1. Indurated ash and volcanic gravels capping the 8 m terrace.
2. Volcanic gravels of the 4 m terrace.
3. Red-brown granite-derived sandy clay loam of the 3 m terrace.
4. Dark brown loam of the 1.5 m terrace.
5. Modern wadi sands.

Sedentary

6. Skeletal lithosols over granite gneiss.
7. Deep red-brown sandy clay loams over granite gneiss.
8. Dark grey clays over amphibolite.

From an agricultural point of view the most useful soil materials would seem to be 4, 8, 3 and 7, in that order.

The probable time-range for the 8 m terrace is 100 000-15 000 years B.P., for the 4 m terrace is 15 000-5 000 B.P. and for the 1.5 m terrace is 3 000 ± 2 000 B.P. These estimates are only intended to indicate the likely order of magnitude, and assume that ages obtained on stone tool assemblages in East Africa may be extrapolated to this region.

13.3.3 *The polygenic soils between Zalingei and Kebkabiya, and the diatomite deposit near Kebkabiya*

In the valley floors many of the soils are polygenic, and buried soils are common. For example, 16 km north of Abata at a site mapped by White as a 'Drift soil' in the Wadi Uyer basin (FAO 1969) we found 2 m of brown pedal clay capped unconformably by 1.1 m of red-brown gravelly sand consisting of crudely stratified lenses of quartz and igneous gravels in an indurated matrix of iron-stained sand. Deposition of the clay implies prolonged sedimentation in a low-energy swamp or flood-plain environment, in contrast to the high-energy intermittent deposition of the younger gravels.

About 10 km further north, dark calcareous clays with calcium carbonate concretions were developed in situ over high-grade metamorphic rocks, including granite-gneisses, impure quartzites, mica schists and, less commonly, amphibolites. There is an absence of marbles or calc-silicate rocks which could provide a source of carbonate for concretion formation, but there is a possibility of accessory carbonate minerals occurring in the rock types present, particularly in the amphibolite.

An 11.5 m section exposed in the wadi east of the in situ clay revealed five main alluvial units in which overbank deposits of sandy loams alternated with channel deposits of gravel and sand. Deep fluviatile deposits are common in this region of low relief, extensively mantling former valley floors and lower valley sides. These alluvial deposits are presently being eroded to reveal the former land surfaces.

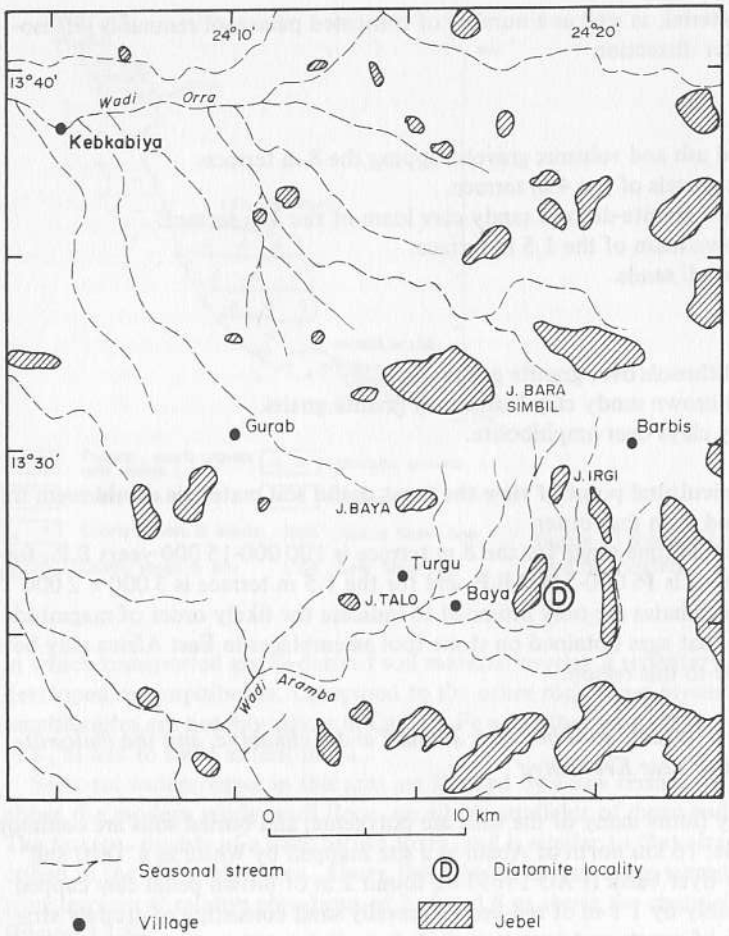


Figure 13.9 Location of diatomite deposit near Kebkabiya (topography after 1:250 000 sheet 54-1).

The 'Drift soils' in this area thus include four genetically distinct categories of soil material:

1. Deep alluvial clays formed under conditions wetter than present.
2. Shallow colluvial-alluvial Basement Complex derived gravels and sands.
3. Deep alluvial sands and gravels characterised by a coarse bedload facies and a fine overbank facies.
4. Dark calcareous sedentary clays associated with localised outcrops of amphibolite and schist.

Tectonic changes on the western side of Jebel Marra associated with uplift and volcanic activity may account for the deep accumulations of unconsolidated

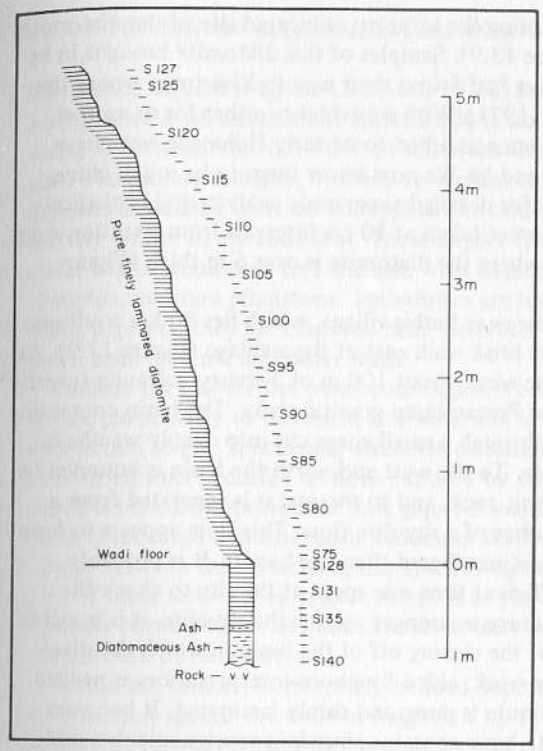


Figure 13.10 Barbis diatomite section.

sediment overlying the Precambrian basement. The mantles of 'drift' in the catchment area of the Wadi Azum described by L.P.White (FAO 1969) and further examined on our reconnaissance may have formed as a result of the development of the Jebel Marra volcanic field. Chapter 10 proposes that the extrusion of the volcanic mass and the probable associated updoming of the basement caused a reversal of drainage, so that streams which originally flowed eastwards from near the position of the Sudan/Chad border were diverted to the west into the Lake Chad basin. Incompetence of the streams during this process of reversal could account for the deposition of a thick mantle of poorly sorted sediments. The westward flowing streams of the Wadi Azum system are presently eroding these accumulated sediments.

That there have been hydrological changes in this area during the Quaternary is well demonstrated at the alkaline springs south of Kalla (Figure 13.4). Here a bench of silicified limestone containing sub-fossil shells of *Bulinus* and *Biomphalaria* (both freshwater mollusca and vectors of Bilharzia) occurs up to 10 m above the modern wadi floor. A fossil tortoise shell was also found in this deposit, which, with the mollusca, suggests permanent water and vegetation in the area. The base of the limestone bench consists of a carbonate-cemented conglomerate of quartz, Basement Complex gravels, and reworked secondary calcrete.

The very long record of climatic change in this region was apparent when we

succeeded in locating and sampling the hitherto unlocated site of the diatomites southeast of Kebkabiya (Figure 13.9). Samples of this diatomite brought in by donkey and camel to Kebkabiya had found their way to Khartoum where they had been described by Prasad (1971). With no evidence either for or against, the diatomites had previously been ascribed to an early Holocene wet phase (Prasad 1971; Wickens 1975a and b). We now know them to be much older, and have collected 66 samples for detailed taxonomic analysis and ecological interpretation. These samples were taken at 10 cm intervals from a section near the centre of the former lake where the diatomite is over 6 m thick (Figure 13.10).

The diatomite deposits occur near Barbis village, which lies 30 km southeast of Kebkabiya and is two hours brisk walk east of Baya village (Figure 13.9). As the site is approached from the west, about 100 m of Tertiary volcanics (mostly basalts) are observed to overlie Precambrian granitic rocks. The basin containing the diatomite is now drained through a small gorge cut into deeply weathered basalts on its southwestern side. To the west and north the basin is bounded by high and broad ridges of volcanic rock, and to the east it is separated from a deep SSE trending valley by lobes of a rhyolite flow. This flow appears to have come from the north, and is less weathered than the basalts. It is probably younger than them, but insufficient time was spent at the site to check the relationships of the two. Assuming a younger age for the rhyolite, it is possible that this flow was the cause of the closing off of the basin in which the diatomites were deposited. Further work, aided by photo-interpretation, is needed.

The upper part of the diatomite is pure, and thinly laminated. It becomes clayey and tuffaceous near the base, contains abundant sponge spicules, and seems to directly overlie bedrock (Figure 13.10). Above the diatomite is a veneer of sand, alluvium and scattered fragments of slightly abraded, very fine-grained aphyric basalt, pink trachyte and possibly welded tuff. Among these gravels there were occasional large trimmed flakes, flake scrapers, bifacially worked choppers and scrapers, and the broken butt of a hand-axe. Typologically this material is similar to that in Acheulian industries at Olorgesailie and Olduvai Bed IV which straddle the Brunhes-Matuyama palaeomagnetic boundary (Dr John Gowlett 1976, personal communication). A minimum age of 1.0 m.y.-0.5 m.y. is therefore quite likely for the diatomites near Barbis. If the rate at which the diatomite accumulated amounted to 0.1 mm per year, which is in keeping with diatomite sedimentation rates measured in East Africa (Washbourn-Kamau 1971), then the Barbis lake may have existed for some 50 000-100 000 years. The Umm Mari oil palms may also relate to this late Lower-early Middle Pleistocene humid interval.

The probable geomorphic sequence near Barbis may be summarised as follows:

1. Valley erosion.
2. Valley dammed by rhyolite flow.
3. Deposition of volcanic ash in lava-dammed lake.
4. Deposition of diatomites within the lake.
5. Breaching of lava dam and drying out of lake.
6. Acheulian occupation of the general area during (4) and (5).
7. Clay deposition and soil formation above the diatomite.

13.3.4 *The dissected ash deposits in and around the Deriba caldera, Jebel Marra*

The Deriba caldera (Figures 13.11 and 13.12) has a diameter of about 5 km and its floor lies at an elevation of about 2 000 m above sea level. Its rim is uneven, rising to between 300 and 1 000 m above the floor, with a gap on the eastern side. The caldera is walled by steep to vertical cliffs of trachyte. Pyroclastic deposits associated with the collapse of the caldera and subsequent explosive activity within it, are abundant. These largely take the form of air-fall and water-borne pumiceous tuff and ash, with fragments of trachyte, Basement Complex, and rare pitchstone. Ignimbrites are less conspicuous than the pumiceous deposits; they are observed near the crater rim and appear to have flowed down both its inner and outer walls.

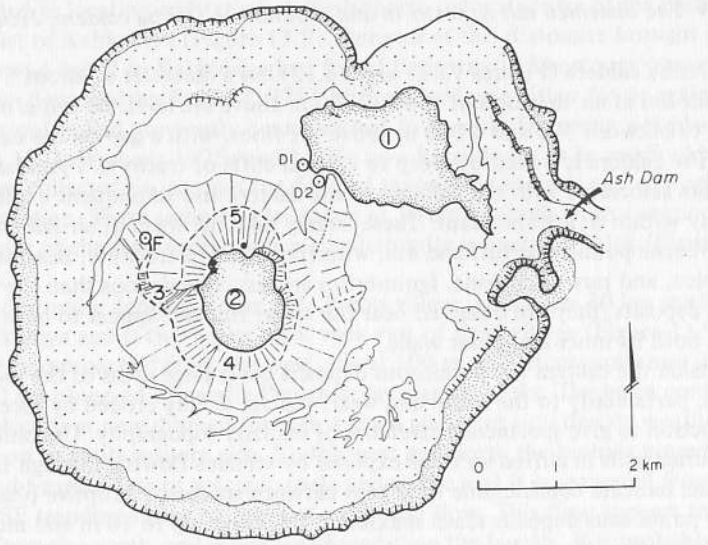
Outside the caldera the pumiceous deposits cover large areas of the mountain slopes, particularly to the south and west, and are deeply eroded by recent river action to give spectacular stretches of badland topography. Unconformities and buried soils in cliffed sections exposed by streams flowing through these deposits indicate considerable time gaps between successive eruptive phases. These pumiceous deposits reach maximum thickness, up to 10 m and more, in valleys between the underlying trachyte flows, but thin out on the flanks and tops of these flows. Their lateral extent is as yet undetermined. A thick sequence of water-borne pumice and ash extends at least as far as Umm Mari some 50 km to the south of the caldera.

Within the caldera, horizontally bedded deposits of pumiceous ash and tuff are plastered against the walls to heights of up to 250 m. These deposits also are eroded to give badland formations, and they form a 100 m high barrier across the eastern gap in the caldera wall (Figures 13.12 and 13.13).

The caldera contains two lakes. One, about 2.5 km long, is shallow (maximum depth 11.6 m) and highly saline and alkaline; the other, about 1 km in diameter, is deep (maximum depth 108.8 m) and moderately saline, and occupies an explosion crater within the main caldera (Hammerton 1968). Apart from the lakes, the caldera floor is covered by late Pleistocene to Recent lacustrine and alluvial deposits.

The explosion crater in which lies the deeper lake is a complex structure consisting of at least five nested cones, representing successive phases of explosive activity (Figure 13.11). The central part of this structure has collapsed to give a deep crater. The highest point of the crater rim lies well over 200 m above the surface of the crater lake which, to the accuracy of our aneroid measurements (c. 2 150 ± 20 m), lies at approximately the same level as the surrounding caldera floor. The rim deposits consist of layers (a few millimetres to several centimetres thick) of pumiceous tuff and ash, with fragments of trachyte up to 0.5 m diameter, minor pitchstone and only very rare Basement Complex material. Bomb sags beneath many of the blocks indicate that the explosion debris was moist at the time of deposition. The beds of the latest explosion deposits dip gently outwards from the crater and are sharply truncated by the crater collapse.

The only present indication of the age of the explosive activity is the date of 3 250 B.P. obtained by Francis et al. (1973) on a piece of carbonised wood from



Trachyte (forming caldera walls).

Pumiceous ash (not including recent explosion crater products). Fine ash and tuff with fragments of trachyte and basement material in places overlying trachyte.

Explosion crater products: mostly tuff with fragments of trachyte and very rare basement material.

Quaternary - Recent alluvial and lacustrine deposits of low angle of slope.

Lakes ① Shallow saline lake
② Deep lake

Steep cliffs (former caldera rim)

Explosion crater rim summit

Ridges

Outer rim of explosion crater

Inner rims of explosion craters numbered in probable order of formation.

Hot springs } After Hammerton
Fumarole } (1968)

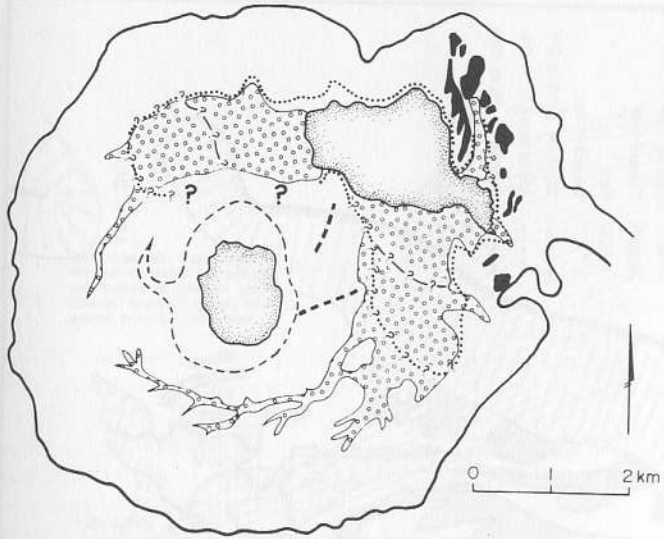
Borehole

(Map not corrected for air photo distortion)

Figure 13.11 Jebel Marra caldera: geology.

a pumice deposit of unspecified location outside the caldera. Although the full significance of this date cannot be determined until further information on the nature and location of the sample has been obtained, it is possible (Kevin Smith 1976, personal communication) that it could represent the age of the final phases of explosive activity within the caldera.

The volcano is at present in a dormant (fumarolic) state. Hammerton (1966, 1968) described fumaroles in a deep valley in the northwestern part of the inner explosion crater rim, and hotsprings along the northwestern shore of the crater lake (Figure 13.11). Hammerton (1968) also suggests that hot saline springs are intermittently active at the bottom of this lake, as evidenced by the intermittent presence of a saline layer at the base of the lake.



Summit of caldera rim

Residuals of former higher caldera floor.

Explosion crater - rim summit

Ridges

Present lakes

Active and incised fans.

Former Lake (+5 to +8m)

Shoreline

Shoreline indefinite:

--?...?... Highest estimate

—?—?— Lowest estimate

Figure 13.12 Jebel Marra caldera: geomorphology and extent of former lake.

The geomorphic map of Deriba caldera shown in Figure 13.12 was prepared using 1:40 000 (approximate) scale air photos supplemented by prior foot traverses around the shallow saline lake and around the northern and eastern margins of the younger crater with its deep fresh lake. Auger holes near the southwest margin of the shallow lake, gully sections around the lake, and sampling of the algal limestones discovered initially on boulders resting on the +2.5 m lake terrace, and then in association with each of the four high shorelines (c. +1 m, +2.5 m, +5 m to +8 m, +25 m) (Figures 13.12, 13.13 and 13.14) of the shallow lake, enabled us to reconstruct in very broad outline the geomorphic history of the caldera:

1. Formation of the main caldera.
2. Accumulation of pyroclastics as high-level talus deposits.
3. Erosion and reworking of talus to form high level caldera floor and probable deep lake. Overflow through high-level (c. +40 m gap) in southwest wall of caldera. Gap later blocked by ash dam.
4. Deposition of tuffaceous laminites within a caldera lake at least 25 m deep, probably at some stage before 19 000 B.P.
5. Formation of algal limestone up to 25 m above caldera floor level.



Figure 13.13 Jebel Marra caldera: former lake shorelines.

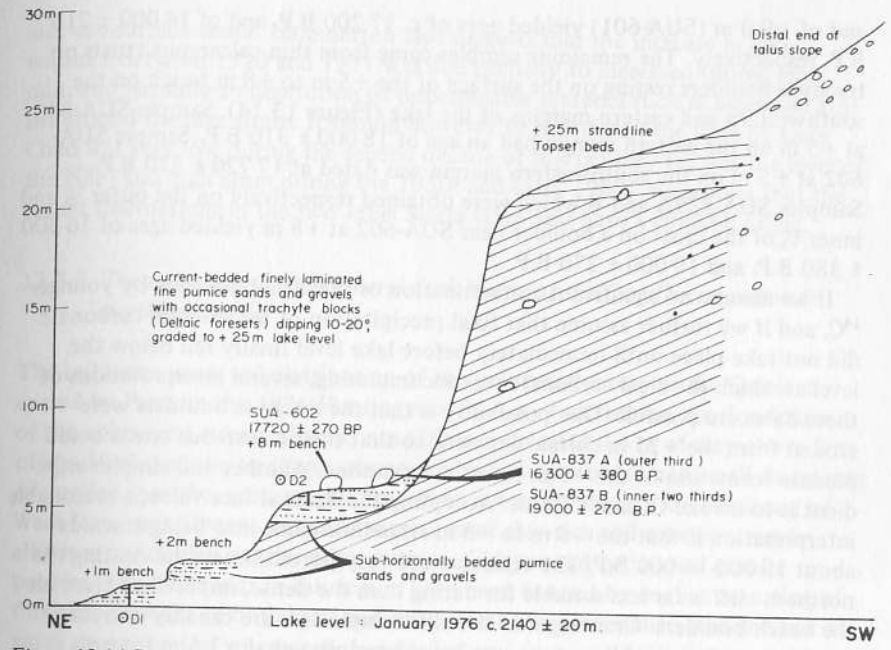


Figure 13.14 Section at southwest edge of shallow Deriba lake, Jebel Marra caldera, showing former lake shorelines.

6. Fall in lake level.
7. Lake stable at +5 m to +8 m from c. 19 000 B.P. to c. 16 000 B.P.
8. Fall in lake level, followed by possible rise to +9 m towards 14 000 B.P.
9. Formation of inner crater in five or more stages, the last of which was younger than 4 and 5, and possibly 7. Formation of present deep crater lake, probably towards 3 000 B.P.
10. Lake stable at +2.5 m in main caldera.
11. Fall in lake level.
12. Lake stable at +1 m.
13. Fall in lake level to −2 m.
14. Modern level, with minor fluctuations of ±1 m during past 70 years. Level lower in 1918, high in 1960s and probably lower again in early 1970s.

The possible extent of the former +5 m lake is shown in Figure 13.12, and the high shorelines (omitting +1 m) of the shallow saline lake in Figure 13.13.

Six radiocarbon dates have been obtained to date on algal limestone associated with higher shorelines around the shallow lake. On the northern side of the lake the vertical trachyte cliffs are coated with a crust of algal limestone up to 30 cm thick which vanished abruptly above about +25 m. On the southern and eastern margins of the lake there is clear stratigraphic evidence that the +25 m deltaic deposits are older than the +5 m to +8 m beach which is in turn older than the two lower strandlines (Figure 13.14). Two samples collected from the continuous crust coating the northern cliff at elevations of +1.5 m (SUA-600)

and of +9.0 m (SUA-601) yielded ages of c. 17 200 B.P. and of 14 000 ± 210 B.P. respectively. The remaining samples came from thin calcareous crusts on trachyte boulders resting on the surface of the +5 m to +8 m beach on the southwestern and eastern margins of the lake (Figure 13.14). Sample SUA-840 at +5 m on the eastern margin had an age of 18 000 ± 310 B.P. Sample SUA-602 at +5 m on the southwestern margin was dated at 17 720 ± 270 B.P. Samples SUA-837A and B which were obtained respectively on the outer ⅓ and inner ⅔ of the crust on a boulder near SUA-602 at +8 m yielded ages of 16 300 ± 380 B.P. and 19 000 ± 270 B.P.

If we assume no significant contamination of the algal limestone by younger ^{14}C, and if we further assume that final precipitation of the calcium carbonate did not take place until immediately before lake level finally fell below the level at which the algal carbonate was accumulating, several interpretations of these dates are possible. One possibility is that the trachyte boulders were eroded from the +25 m deltaic deposits, so that their calcareous crusts could predate formation of the +5 m to +8 m strandline. Another and simpler expedient is to invoke Occam's Razor. Accepting the dates at face value, a reasonable interpretation is that the +5 m to +8 m strandline came into being towards about 19 000-16 000 B.P. The vesicular and very porous limestone coating the northern cliff is far less suitable for dating than the dense, impervious crust on the beach boulders. Granting that the cliff sample ages are broadly correct, it would seem that algal limestone was being precipitated at +1.5 m towards 17 000 B.P. and at +9.0 m towards 14 000 B.P., suggesting a fall in level after formation of the +5 m to +8 m beach, followed by a renewed transgression during the terminal Pleistocene.

Given the far from ideal nature of the samples dated, these estimates must be viewed with caution, but they are at least consistent with the more solidly-established lake chronologies of Chad (Servant 1973) and Afar (Gasse 1975).

Any discussion of past lake-level variations will be greatly enhanced by knowledge of recent and current lake behaviour. An excellent summary of this is given by Hammerton (1968). He found evidence of two former beach levels at depths of 3 and 5-7 m in the deeper, smaller lake, indicated by drowned tree and other plant remains. This suggests that the water level has risen abruptly on at least two occasions in relatively recent times. Hammerton suggests that these rises may result from landslips of rim material into the lake. However, both he and we also found evidence for a recent rise in level of the larger lake: a number of dead trees standing in 2-3 m of water. This does not seem to have been caused by landslips and we prefer to conclude that increased rainfall was responsible for the rise in levels of both lakes.

Hammerton also notes that in 1966 the large lake was almost twice the length reported by Hobbs and Gillan in 1918 (Hobbs 1918; Gillan 1918) and that a marked decrease in salinity had occurred since the measurements of Lynes in 1920 (Lynes 1921). In addition, the present seasonal variation in level of both lakes is remarkably small (less than 0.5 m) for a region of highly variable precipitation. It appears that excess water following the rains must drain away through permeable layers a little above normal lake level while losses in dry weather due to evaporation must be nearly balanced by inflow from springs

and sub-surface water. Hammerton also suggests that the increase in lake volumes between 1920 and 1957 was due partially to increased inflow from rain, and partially to deposition of impermeable material such as algae and fine silt around the lake shore. It should however be noted that the level of Lake Chad was very low during the second decade of this century (as was the level of the Nile) and high again during the 1950s and early 1960s, suggesting that the recent fluctuations in the two Jebel Marra lakes also have a climatic origin.

13.3.5 *The red sands and peripheral dark loams of the Qoz Dango region in southern Darfur*

The influence upon soil distribution of the polygenic nature of the Qoz is discussed by Parry in the 1976 Hunting report. A well section on the floodplain of the ephemeral stream channel near Dimasu revealed 0.6 m of clay above 2 m of stratified medium to coarse quartz sand which also contained small fragments of pumice. Another section, this time from a 4 m borehole 1 km northeast of Wadi Ibra, near Dimasu, revealed some 2 m of clay-rich soil overlying sandy alluvium containing quartz, mica, pumice, feldspar and occasional granite pebbles. The Qoz sands in this region have been formed by aeolian resorting of fluviatile deposits of both local and more northerly provenance, and contain a small proportion of volcanic material.

Inspection of a number of auger hole and channel-bank sections in and near Qoz Dango (Figures 13.15 and 13.16), revealed the following depositional sequence:

1. Widespread deposition of fluviatile sands.
2. Dune development by aeolian reworking of existing alluvial sands, and formation of older qoz.
3. Older qoz vegetated. Soil development.
4. Aeolian reworking of sand from blowouts in older qoz, and formation of younger qoz.
5. Surface reddening and weak soil development on younger qoz.
6. Deposition of coarse fluviatile sands.
7. Deposition of fine fluviatile sands.
8. Deposition of late Holocene dark Nagaa clays (SUA-603: 3 825 ± 105 B.P.)
9. River downcutting.
10. Aeolian deposition and development of recent qoz.
11. Deposition of recent alluvial silts.
12. River downcutting.
13. Deposition of modern wadi sands.

13.3.6 *The dark fluviatile Regeba clays and associated soils between Ed Da'ein and the Bahr el Arab*

During the course of our reconnaissance survey of the landforms and late Cainozoic deposits on and around Jebel Marra, it became increasingly clear to us that the present-day distribution and physico-chemical properties of soil materials

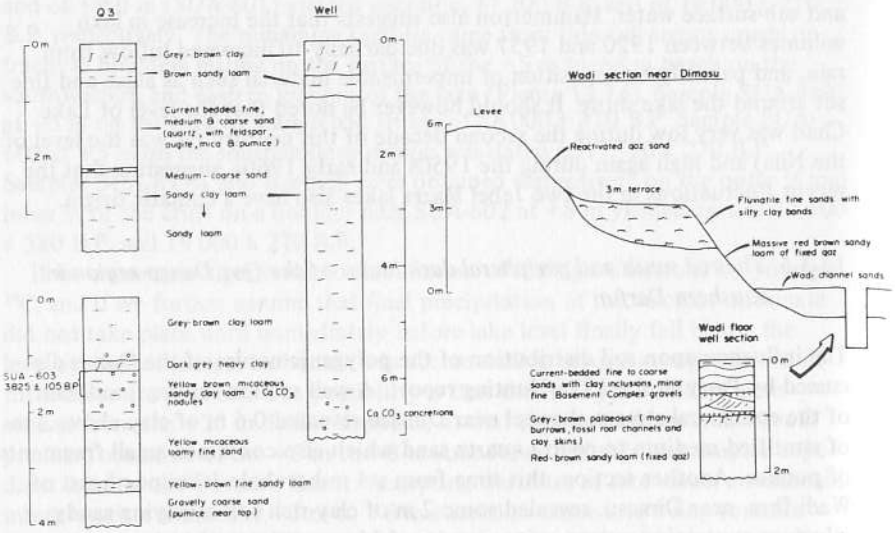


Figure 13.15 Stratigraphic sections near Dimasu.

reflected past fluctuations in the erosion and deposition of pyroclastic, fluviatile and wind-blown materials well beyond the immediate range of the massif itself. Anomalously high available phosphorus levels in certain of the alluvial soils belonging to the Baggara and Regeba land systems (Hunting Technical Services 1976) suggested that long-distance transport from a volcanic source to the north was a distinct possibility, to be tested by mineralogical analysis of the relevant soils. It thus seemed logical to seek evidence for a former fluviatile connection between the Baggara and Regeba sediments and the Jebel Marra volcanic complex (Figure 13.4).

Both the Baggara and Regeba systems consist of discontinuous and interconnected fossil river channels. These palaeochannels are wide, sinuous and in process of silting up. The false-colour satellite imagery indicates that the Qoz is breached by two major drainage systems which flowed from the north towards the Bahr el Arab (Hunting Technical Services 1976). At each of the pits and boreholes sampled by us in the Baggara-Regeba country between the Bahr el Arab and Ed Da'ein we found a surface mantle of clay up to 2 m thick overlying micaceous fine and medium alluvial sands (Figure 13.17). Prehistoric sites with scattered Neolithic or younger sherds occur on former levees flanking certain of the palaeochannels and meander cutoffs of the Regeba Zerzeraya and suggest that the former channels were probably seasonally active during the early to middle Holocene, and possibly more recently.

Our present understanding of the sequence of events which gave rise to the Baggara and Regeba land systems agrees with that of Parry (Hunting Technical Services 1976) and is essentially as follows:

1. Deposition of widespread sandy alluvium by rivers flowing south from the Jebel Marra piedmont across the Basement Complex plains and by rivers flowing west across sandstone terrain.

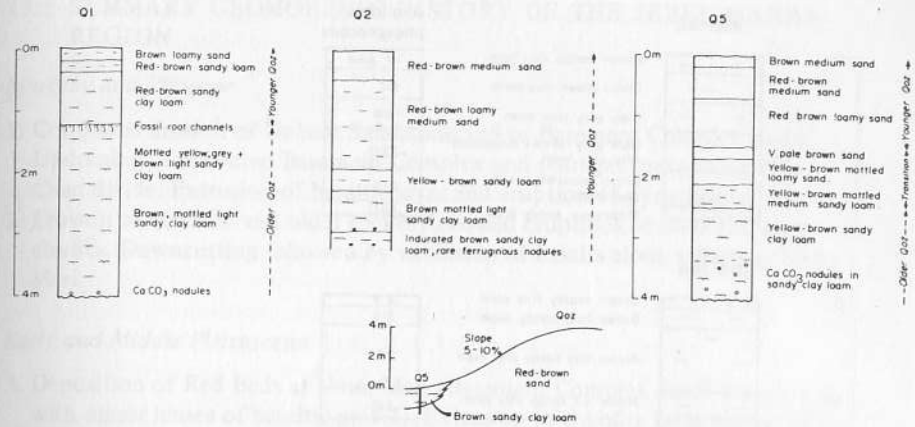


Figure 13.16 Stratigraphic sections, Qoz Dango (Q1 and Q2 are 1 km SW of Umm Tikeina, and Q5 is near Ligediba).

2. Climatic desiccation and aeolian reworking of the alluvial sands to form the older qoz.
3. Weathering, leaching and new mineral formation under more humid conditions leading to soil formation on the now fixed and vegetated older qoz. Fluviatile breaching of older qoz.
4. Desiccation and reactivation of formerly fixed dunes and reworking of sandy bedloads of ephemeral streams to form the well-defined dunes of the younger qoz.
5. Increasing stream competence as rainfall increased culminating in renewed breaching and erosion of the dunes by rivers from the southern piedmont of Jebel Marra flowing south into a region of higher rainfall. Erosion and redeposition of the qoz sands together with sandy alluvium, mainly of Basement Complex provenance, but with a minor volcanic component. Formation of an extensive alluvial sand-plain north of the Bahr el Arab, probably as a low-angle alluvial fan complex.
6. Decreasing stream competence and change from dominantly bed-load transport to suspended load transport, together with change from braiding to meandering. Deposition of widespread surface clays over sandy alluvium. River discharge (both annual and bankfull) greater than that of today. Numerous prehistoric sites on levee banks.
7. Reduction in discharge following reduction in annual rainfall. Abandonment, segmentation and silting-up of former channels.

Although no absolute ages are so far available to date any of the above events, it is tempting to relate phase 5 with the terminal Pleistocene phase of widespread deposition of fine fluviatile sands near Dimasu and throughout the Gezira clay (Williams & Adamson 1976). The discharge of the White Nile was also significantly greater at this time as, most probably, was that of its major tributaries, including the Bahr el Arab drainage system. Deposition of the Nagaa and Buta clays probably also took place towards this time.

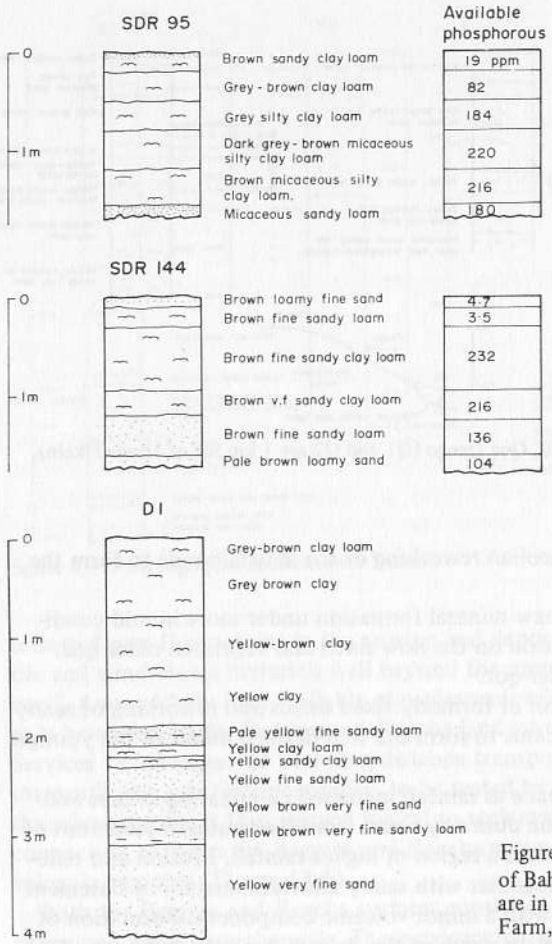


Figure 13.17 Regeba sections north of Bahr el Arab (SDR 95 and 144 are in Ghazal Gawazat Research Farm, and D1 is near Zerzeriya).

13.4 DISCUSSION

A very provisional summary of the late Cenozoic geomorphic history of the Jebel Marra region is offered here. While the relative sequence of events in any one locality is probably reasonably correct, correlation between localities is more problematic, and the suggested ages are of course very poorly established indeed. Despite these misgivings, and in view of the almost complete absence of any stratigraphic framework within which to evaluate earlier attempts at palaeoenvironmental reconstruction of this region, we feel that the conclusions embodied here may well constitute a useful starting point for later researchers in this area. Our suggested correlations can be no more than working hypotheses to be refuted or improved in the light of later work.

13.5 SUMMARY GEOMORPHIC HISTORY OF THE JEBEL MARRA REGION

Miocene and Pliocene

1. Continued erosion of Nubian Sandstone and of Basement Complex rocks. Updoming of dissected Basement Complex and younger rocks along Nile-Chad divide. Extrusion of basaltic lavas and eruption of pyroclastics.
2. Erosion of volcanic and older rocks. Renewed eruptions of lavas and pyroclastics. Downcutting followed by extrusion of basalts along valleys at Umm Mari.

Early and Middle Pleistocene

3. Deposition of Red Beds at Umm Mari (Basement Complex sands and gravels with minor lenses of basaltic gravel). Extrusion of rhyolite lavas blocks valley and creates large lake near Barbis. Explosive volcanic activity and caldera formation and widespread deposition of water-lain tuffs along piedmont, including deposition of tuffs containing fossil oil-palm leaves at Umm Mari. Evolved Oldowan/Early Acheulian artifacts in situ above and below oil-palm tuffs. Breaching of lava dam and draining of Barbis lake. Upper Acheulian on surface of dried lake bed.
4. Deposition of tuffaceous Upper Member of Umm Mari Formation above earlier oil-palm tuffs (Middle Member) and Red Beds (Lower Member). Dissection of Umm Mari Formation and related piedmont deposits to form 20 m terrace. Deposition of fluviatile sands in southern Darfur (mainly Basement Complex derived, with minor volcanics). Aeolian reworking of sandy alluvium to form Older Qoz of southern Darfur.

Late Pleistocene

5. Soil development on eroded and stabilised Older Qoz. Fluviatile breaching of Older Qoz. Erosion of +40 m caldera floor. Deltaic sedimentation in 25 m lake at Deriba caldera. Fluviatile deposition of tuffaceous silts at Umm Mari and in Zalingei-Nyertete area. MSA in situ in alluvial silts near Nyertete.
6. Downcutting and formation of 8 m terrace at Umm Mari and at Zalingei-Nyertete (mixed MSA/LSA on surface near Nyertete). Aeolian reworking of Older Qoz sands and younger alluvium to form Younger Qoz of southern Darfur. Fall in Deriba lake level.

Holocene

7. Fluviatile breaching of Younger Qoz by rivers flowing south from Jebel Marra piedmont, and widespread deposition of a fining-upwards sequence of coarse and fine sands in southern Darfur. Deposition of and incision into alluvial silts near Nyertete to form 4 m terrace (LSA on surface). Erosion of deltaic deposits and of prior caldera floor, and formation of 5-8 m wave-cut bench inside Deriba caldera.
8. Continued explosive volcanism and successive stages in formation of younger

crater within Deriba caldera. Alternating silt aggradation and river downcutting leading to formation of 3 and 1.5 m terrace near Nyertete and of 2 m terrace at Umm Mari. Deposition of dark Nagaa clays in southern Darfur, followed by downcutting and later aeolian sand and fluviatile silt deposition. Progressive infilling and abandonment of Regeba channels north of the Bahr el Arab, and development of modern underfit channels.

9. Incision below modern channel floor in southern Darfur and between Zalingei and Umm Mari, followed by present-day aggradation of channels with coarse bedload sands.

The presence of oil-palm fossils at Umm Mari and the existence of a large permanent lake at Barbis for perhaps tens of thousands of years during the earlier part of the Pleistocene indicates that what is now an arid to semi-arid area was once significantly wetter. Deep freshwater lakes of late Pliocene to early or middle Pleistocene age are also known from the Hoggar, Tibesti, Chad, Ethiopia, and Afar (see for example Chapters 5, 6 and 15), but precise correlation with the Barbis lake north of Jebel Marra must await the outcome of diatom analyses and K-Ar dating.

The question of the time relationships and cultural affinities between the Evolved Oldowan/Acheulian artifacts at Umm Mari and the dated assemblages from Olduvai, East Rudolf and Gadeb in south central Ethiopia highlights the need for systematic archaeological excavation of the Jebel Marra sites and cannot be resolved until such work is undertaken.

Warren's (1970) subdivision of the Kordofan Qoz into two major stratigraphic units is vindicated by our preliminary survey of the Qoz of southern Darfur, but we cannot yet correlate the several phases of dune building and erosion with the various phases of late Quaternary piedmont alluviation and downcutting south and west of Jebel Marra, or with the four phases of late Quaternary higher lake levels within Deriba caldera except in a very general sense.

Suggestive analogies between the depositional behaviour of the Bahr el Arab tributaries and that of the Blue and White Nile rivers, although pointing to plausible time correlations, may in fact be mere wishful thinking. Clearly, the alluvial stratigraphy of southern Darfur would repay detailed study. Given all these caveats, what may we safely conclude?

13.6 CONCLUSION

13.6.1 *Jebel Marra: A link or a barrier?*

At the outset of this chapter, we noted the strategic location of Jebel Marra between the Chad basin to the west and the Nile basin to the east as well as between the Sahara desert to the north and the savannas and forests of tropical Africa to the south. What has been the impact of such a location upon the history of Jebel Marra?

Several generations of now fixed dunes in southern Darfur show that on occasion the effective southern margin of the Sahara desert has advanced over 500 km, to well south of Jebel Marra. At such times, plants, animals and

men would have sought refuge in the cooler, less arid uplands of the volcanic massif, where perennial thermal springs would be unlikely to succumb to climatic desiccation. Equally, the Barbis diatomite and Umm Mari oil-palm fossils strongly suggest that the northern limits of the savanna once lay well to the north of the massif, even if rain-forest only encroached along restricted gallery-forests.

The field evidence suggests that these shifts occurred at intervals throughout the Quaternary. Wickens (1976b) has given a detailed and authoritative review of the likely provenance of the present flora of Jebel Marra, three major sources being from the Mediterranean littoral, from the uplands of Ethiopia, and from the savanna lowlands. Curiously enough, there is a significant floristic difference between the savanna of West Africa and that of the Sudan, and Wickens (1976b:63) suggests that a much enlarged Lake Chad would have provided an effective barrier for the free east-west migration of savanna plants between West Africa and the Sudan. There is no floristic evidence to suggest that Jebel Marra itself was ever a barrier to the free movement of plants and animals. In fact, the rich and heterogeneous flora of the massif so well described by Wickens suggest that the contrary was more likely, with the Jebel acting as a refuge for isolated relict communities.

Sporadic occurrences of artifacts ranging in age from Oldowan through to Late Stone Age within virtually every major section inspected by us also suggest that the Jebel Marra piedmont has a history of prehistoric settlement far longer and more significant than intimated by earlier visitors to the mountain, who may have been misled by the paucity of surface finds – a not unexpected situation on piedmont slopes periodically blanketed in volcanic ash.

13.6.2 *Summary and conclusions*

Six major traverses to the northwest, west, south and southeast of Jebel Marra as well as one within the caldera itself have yielded new information on the possible age and origin of Quaternary sediments and soil materials in this part of south-central Darfur. In particular, the palaeoclimatic significance of Jebel Marra volcano as a Saharan palaeo-rain-gauge is now evident from a preliminary geomorphic study of the caldera and its enclosed lakes, as is the antiquity of the depositional record around the massif. Deposition of some of the materials hitherto regarded as Holocene (Prasad 1971; Wickens 1975a and b) probably goes back to early or middle Pleistocene time, some 0.5 m.y. to 1 m.y. ago. The distribution of dark calcareous clays within the so-called Drift complex (FAO 1969) is lithologically controlled, being related to the weathering in situ of amphibolites and other basic metamorphic rocks. Models of the geomorphic history of the Ash Piedmont, Qoz and Regeba-Baggara regions account in a rational way for the present pattern of soil material within these areas. The high phosphorus levels in certain soils north of the Bahr el Arab may well reflect a former fluviatile link with the volcanic uplands to the north. The upward-fining of the Baggara and Regeba soils is likewise probably inherited from late Quaternary fluctuations in river regime related to regional variations in climate. A

detailed long-term study of the prehistory, palaeobotany and Quaternary geology is now needed to clarify the precise age and origin of soil materials in this area.

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14

Environmental changes in the Nile headwaters

Changements du milieu dans les cours majeurs du Nil

Les glaciers du Haut-Nil ont connu une grande extension au moins trois fois pendant le Pléistocène. Cela prouve que le climat a été beaucoup plus froid qu'il n'est actuellement.

Depuis la dernière glaciation, il y a eu quelques petites avancées glaciaires qui sont encore mal datées. La phase terminale de la dernière glaciation se situe vers 14 500 ans B.P.

Une comparaison entre l'érosion postglaciaire, la taille des moraines anciennes, et la décomposition des roches qui les constituent, montre que les glaciations antérieures sont beaucoup plus anciennes . . . d'au moins 100 000 ans.

La cartographie détaillée et l'analyse statistique des moraines, dans diverses montagnes, suggèrent que les glaciers sont descendus de 880 à 640 m. Si l'on admet qu'il n'y a pas eu de changements de la pluviosité, il serait nécessaire d'admettre une diminution de la température de 5°,8C à 4°,2C pendant la dernière glaciation. Grâce aux études palynologiques et paléobathymétriques, nous savons qu'il y a eu une diminution de la pluviosité. Si l'on admet une diminution de 25% (grâce aux données paléohydrologiques) l'abaissement de la température serait de 8°,3C à 6°,7C.

Il existe des plages fossiles au bord du Lac Victoria et du Lac Rudolf (Turkana). Celles du Lac Victoria sont en relation avec des mouvements tectoniques et des phénomènes d'érosion au débouché du Nil, et on ne peut pas les utiliser comme indicateurs paléoclimatiques. Par contre, celles du Lac Rudolf montrent des variations complexes du plan d'eau. Ce lac se situait dans un bassin fermé très sensible aux variations climatiques.

De manière générale, l'Holocène inférieur a été l'époque la plus humide de la fin du Quaternaire. Au maximum de cette époque, le lac se déversait dans le Nil. Bien que l'Holocène supérieur n'ait pas été aussi humide que l'Holocène inférieur, on a mis en évidence une série de transgressions significatives qui se sont poursuivies jusqu'à l'époque historique.

Des études effectuées sur des carottes prélevées dans les lacs Victoria et Mobutu Sese Seko (Albert) montrent que ces lacs n'étaient pas en relation avec le Nil juste avant 12 500 ans B.P.

La plus longue histoire connue est celle du Lac Mobutu Sese Seko. On sait que ce lac s'est déversé dans le Nil entre 28 000 et 25 000 ans B.P., puis entre 18 000 et 14 000 ans B.P., et depuis 12 500 ans B.P. Pendant les périodes sèches, le niveau du plan d'eau s'est abaissé d'au moins 56,6 m et la profondeur du lac était inférieure ou égale à 23 m. Cependant en l'absence de sondages dans le fond du bassin, il n'est pas possible de savoir si le lac s'est, ou non, complètement asséché.

Les premiers renseignements concernant le Lac Victoria se situent vers 14 500 ans B.P. Ce lac était fermé au moins à partir de 14 500 ans B.P. jusqu'à 12 500 ans B.P. et probablement de manière brève vers 10 000 ans B.P. A 14 500 ans B.P., les eaux étaient riches en carbonates dissous, ce qui plaide en faveur de son caractère endoréïque. Pendant ces périodes plus sèches, le niveau du lac s'est

abaissé d'au moins 75 m, la profondeur était alors de 26 m au maximum.

De manière générale, les associations polliniques d'âge pléistocène sont dominées par les Graminées dans tous les sites étudiés. Dans la baie de Pilkington (Lac Victoria), les pollens d'arbres de forêt ont remplacé les Graminées à 12 500 ans B.P. Mais dans certains endroits situés à des altitudes plus élevées, des pollens de petits arbres et d'arbustes dominent les associations avant l'apparition massive des pollens d'arbres de forêt. Pendant les tout derniers millénaires, l'importance relative des pollens forestiers décline partout.

L'interprétation de ces modifications et surtout des changements particuliers à chaque région, même au point de vue de la végétation, n'est pas facile. La flore du Haut-Nil est très riche, ce qui augmente les difficultés de détermination précise. D'autre part, on manque de données sur les relations qui existent actuellement entre la pluviosité et la répartition des pollens, on manque également de prélèvements actuels en basse altitude et en forêt.

Pour presque toutes les études publiées, les datations au ^{14}C sont insuffisantes pour permettre de faire des calculs précis de la vitesse de sédimentation des pollens. Pour ces diverses raisons, on rencontre de nombreuses difficultés pour interpréter les variations paléoécologiques et paléoclimatiques.

Il est cependant possible de proposer l'interprétation suivante: il y a eu suppression totale de la forêt au Pléistocène, non seulement des pollens forestiers mais des arbres eux-mêmes. Cette disparition pourrait être due à une diminution de la pluviosité dans toutes les régions étudiées et à une diminution de la température en haute altitude.

Le début du réchauffement et l'augmentation de la pluviosité n'ont pas pu être datés avec précision. La plupart des données suggèrent que la pluviosité a du s'accroître vers 12 500 ans B.P., mais d'autres données indiqueraient qu'il y a eu également des changements climatiques à partir de 14 500 ans B.P. jusqu'à 10 000 ans B.P. Pendant les derniers millénaires, la diminution des pollens forestiers pourrait être due essentiellement à des actions anthropiques.

En ce qui concerne les nombreux problèmes d'interprétations, qu'ils soient palynologiques, ou paléohydrologiques, il serait nécessaire d'obtenir des renseignements sur les paléotempératures qui ne soient pas influencés par la pluviosité, mais aussi des renseignements sur la pluviosité qui ne soient pas influencés par les températures. Il serait peut-être possible d'utiliser les isotopes qui ne sont pas sensibles aux variations hydrologiques ou la racemization des acides aminés des sédiments lacustres; on peut espérer également qu'un nouveau paléothermomètre pourra être fourni par l'étude des cuticules fossiles de Graminées selon leur voie photosynthétique.

On pense que la similitude des faunes de poissons du Nil avec celles du Tchad, du Niger et du Sénégal a une cause climatique. Elle serait due à l'extinction d'une grande partie de la faune nilotique pré-pléistocène quand le Nil Blanc ne coulait pas et à son remplacement par des poissons ayant émigré de l'Afrique de l'Ouest pendant la période humide de l'Holocène ancien.

14.1 INTRODUCTION

The modern relation between the Nile and the Sahara is straightforward and spectacular. The Nile is a ribbon of life through the desert, tying the Mediterranean zone to humid tropical Africa. It also gives the tropical curse of schistosomiasis access to the temperate lands of the Delta. With metronomic regularity it brings the seasonal floods whose fertile silts nourish Egypt. For people, for other animals, for plants, it is an easy and reliable highway through a hostile arid land.

Dry desert wadis, thick valley silts, and even the details of present biogeography show that this relation has not always been so simple. In modern times there is a great similarity in the fish faunas of all the waters adjacent to the

southern part of the desert (Roberts 1975). Of 115 species of Nilotic fishes, 74 occur in the River Niger (Greenwood 1976). By contrast, only 22 Nilotic species are to be found in the Zaire, which interdigitates so intimately with the headwaters of the Nile over an enormous distance. The present regime of the Nile and the Sahara provides no explanation for this curious ichthyogeographical anomaly. For that we shall have to examine the evidence for environmental change in the headwaters of the river.

The Nile is peculiarly dependent on conditions at its headwaters, and highly sensitive to changes in them. It gains no nourishment às it flows through the desert, and little from much of the area of even the equatorial parts of its catchment, which are relatively dry for their latitude. Nile water comes overwhelmingly from orographic rain in the highland areas of its southern catchment. The Ethiopian Highland provides most of the annual discharge via the Blue Nile and the Sobat; the White Nile, smaller but less seasonal, draws on Mt Elgon, Ruwenzori and other moist East African uplands to sustain the river during the season of low flow (Rzóska 1976; Hurst 1952). Changes in the total amount and seasonality of water from either source could have a profound effect on the length, discharge, catchment area or reliability of the river.

Much of the land in and around the Nile catchment is arid or semiarid, and relatively small changes in runoff can produce great changes in the area drained by the river. There is good reason to believe that Lake Rudolf (Turkana) drained into the Nile via the Pibor and the Sobat (Figure 14.1) during relatively recent time (Butzer 1971). In geological perspective, Lake Rudolf is as much a part of the Nile as Lakes Victoria, Mobutu Sese Seko (Albert) or Idi Amin Dada (Edward). In considering the past environment of the headwaters it will be necessary to include areas that are not part of the Nile catchment today. With so little evidence about past climate and vegetation in the Nile basin itself, we must occasionally consider better-studied lakes in neighbouring Kenya and Tanzania that are not known to have been part of the Nile at any time.

14.2 GEOMORPHOLOGY

Environmental changes are likely to have geomorphic expression, and sometimes these geomorphic consequences can be assigned a reliable age. Stabilized dunes in the Zaire cuvette, for example, indicate a past time when the climate of western Africa was much dryer than it is today (Livingstone 1975; Cooke 1958, 1964). Dating of such dunes depends on the rare accident of discovery of some carbon-datable material within or beneath them, or on the discovery of artifacts or fossils that will permit correlation with dated sites. Although there must certainly be stabilized dune fields somewhere between the currently-active barchans near Olduvai Gorge in northern Tanzania and the vast areas of active sand in the Sahara, there seems to have been no systematic investigation of the inactive dunes of the Nile headwater area, with dating and climatic interpretation of the periods of activity.

Much geomorphic investigation in the area has been devoted to peneplanes (Doornkamp 1968), but these are difficult to date and very difficult to inter-

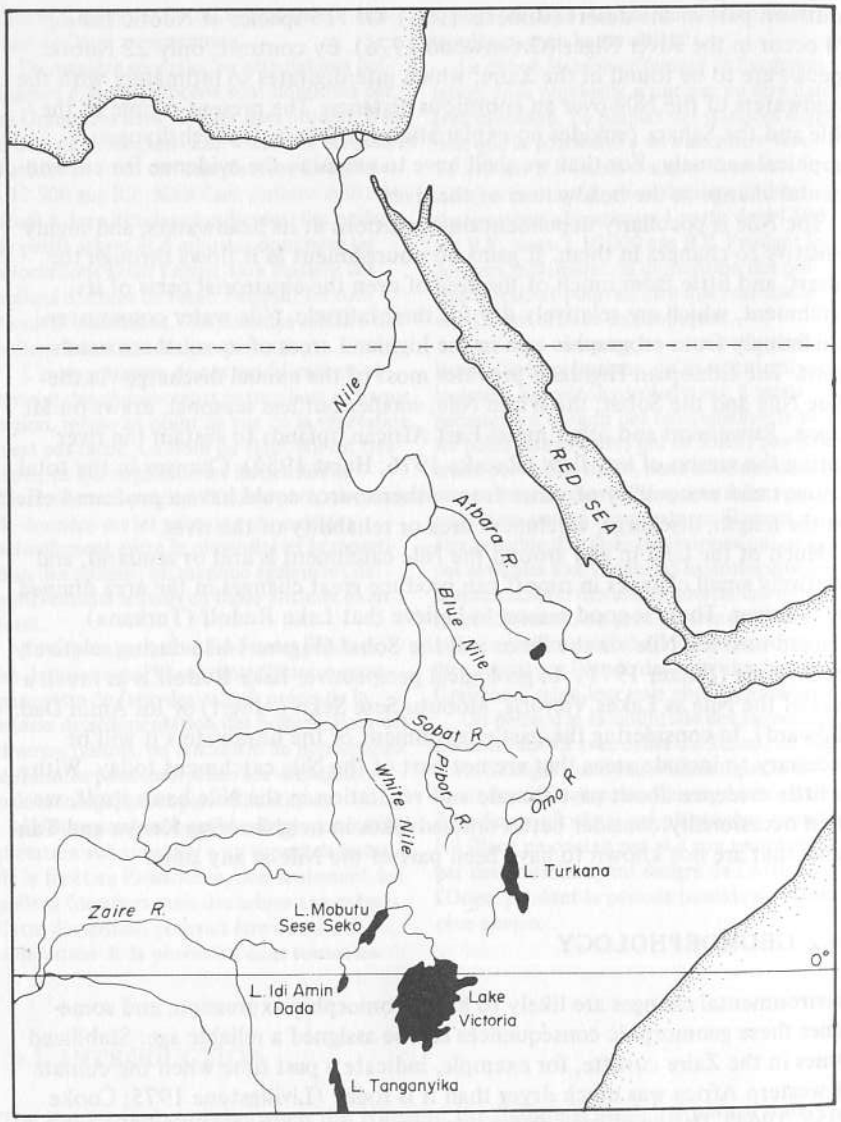


Figure 14.1 The Nile and its neighbours.

pret in climatic terms. They are mostly too old to have a great pertinence to the Quaternary.

River terraces have been studied in the lower Nile Valley (Butzer in this volume; Fairbridge 1962, 1963, 1964; Wendorf 1968; Williams & Adamson 1973, 1974), but not in its headwaters, where the preservation of terraces is not good enough to tempt investigators into the difficult climatic interpretation of past changes in stream regimen.

Geomorphic results of montane glaciation in the Nile-headwater area have been used successfully to reconstruct environmental change. Nilsson (1929, 1931, 1935, 1940, 1953) provided the classical inventory of this evidence. Among later workers, Osmaston (1965) has been outstanding for his detailed presentation of the glacial geology of Ruwenzori (Figure 14.2) and for his thoughtful, critical and ingenious interpretation of the evidence in terms of climatically-controlled changes in firnline.

Ruwenzori is critically situated on the equator at the headwaters of the White Nile, and consists of a dissected upthrust block of Precambrian rocks, which supports over 40 glaciers today and many others in the past. After careful mapping of the separate glaciated areas Osmaston was able to estimate the regional firnline's altitude by an iterative statistical procedure. This procedure he applied to Mahoma Lake Glaciation, the last of the main Ruwenzori glaciations, to a series of later retreat stages of lesser significance, and to the preceding Rwimi Basin Glaciation, which affected the same valleys to a somewhat lower altitude. A pre-Rwimi episode, the Katabarua Glaciation, is represented by very old till remnants on interfluves between the valleys scoured by Rwimi Basin and Mahoma Lake ice, and these remnants cannot be used to estimate firnline changes in the same way. No doubt these glaciations were contemporary with three of the four ice advances that have occurred on Kilimanjaro during the past half-million years (Downie & Wilkinson 1972).

The Mahoma Lake Glaciation ended about 15 000 radiocarbon years ago (Livingstone 1962), but the older Ruwenzori glaciations are uncontrolled by radiometric dates. Ingenious comparisons of weathering, erosion, and relative sizes of moraines and screes enabled Osmaston to show that they are very much older than the Mahoma Lake Glaciation. Even the Rwimi Basin Glaciation seems to be of the order of 100 000 years in age, and the Katabarua Glaciation must be much older than that. Osmaston's summary of firnline changes is shown in Table 14.1.

The standard lapse rate in East Africa is two degrees C per 300 m (1 000 ft). On the assumption that the firnline lowering was due only to a decrease in temperature, Osmaston suggested that the Mahoma Lake Glaciation involved a temperature lowering of about 4.2°C on Ruwenzori, 5.0°C on Mt Kenya and 5.8°C on Kilimanjaro. Lake level changes suggest that the last glaciation was actually rather dry, at least during its closing phase, and pollen evidence from Ruwenzori suggests dry conditions around Mahoma Lake shortly after deglaciation. Palaeohydrologic considerations have led to two estimates of the late-glacial drought in this area, 29% rainfall reduction (Harvey 1976) and $\geqslant 10\%$ reduction in precipitation:evaporation ratio (Kendall 1969). Harvey's estimate

Table 14.1 Firnline lowering from apparent modern level, in m

Glaciation	Ruwenzori	Kilimanjaro	Mt Kenya
Lake Mahoma	640	884	762
Rwimi Basin	731	914	
Katabarua	640		1 067

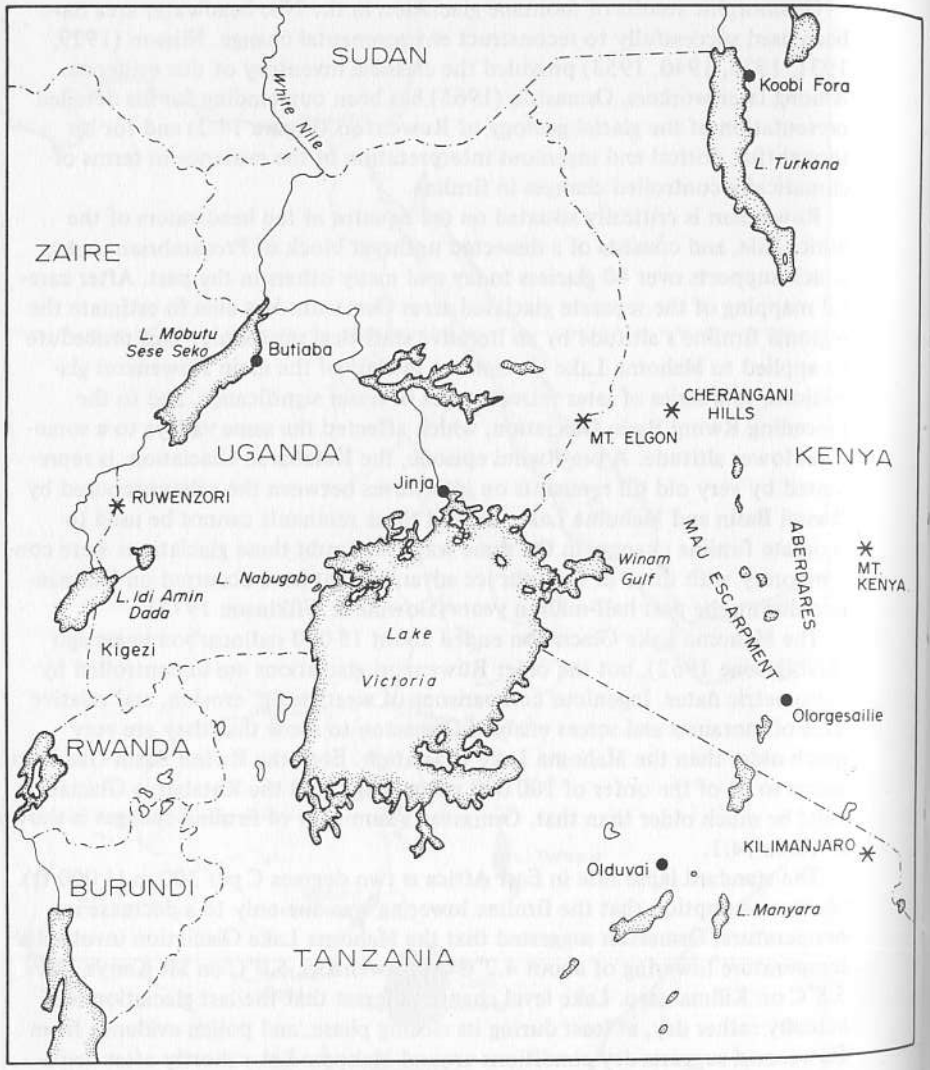


Figure 14.2 Headwaters of the White Nile.

takes into account Pleistocene temperature lowering of 5°C and can be used to adjust Osmaston's temperature estimates for rainfall decrease by about 25%.

The modern firnline and the Mahoma Lake firnline both tilt down toward the east because most rain comes from that direction. Weather records are sparse, but Osmaston (1965:141) suggests that the tilt is due to a 50% difference in precipitation on the two sides of the mountain. The Mahoma Lake firnlines differed in altitude by 760 m because of this precipitation difference. Presumably a 25% decrease in precipitation would raise firnlines some 380 m,

Table 14.2 Temperature lowering during glaciations in °C

Glaciation	Ruwenzori	Kilimanjaro	Mt Kenya
Lake Mahoma	6.7	8.3	7.5
Rwimi Basin	7.3	8.5	
Katabarua	6.7		9.5

and be roughly equivalent to a 2.5°C difference in temperature. If we add 2.5°C to Osmaston's estimated temperature lowering, we get the result shown in Table 14.2.

These estimates are probably the best we can make of ice-age cooling on the mountains. The Ruwenzori estimates, being based on the largest body of data, are the most likely to be correct. Differences between the three mountains are more likely to spring from differing altitudinal distribution of precipitation than they are to genuine differences in amount of cooling.

14.3 PLANT MACROFOSSILS

Ash-falls around the Nile headwater volcanoes have preserved fossils of vascular plants of ages back to the Miocene (Chaney 1933; Chesters 1957; Osmaston 1965: chapter 4), but many of the fossils are only leaf impressions. Holocene leaf impressions identified by a forester thoroughly conversant with the modern forest flora (Osmaston 1965: chapter 4) may be accepted with assurance, but identifications of Miocene leaves by an overseas investigator lacking a good reference collection can be used in only the tentative way in which they were proposed (Chaney 1933).The macro-fossils suggest that many of the modern genera and at least some species not markedly different from modern ones were already growing in our area during the Miocene, which is accordant with what is known of the much better-studied Neogene deposits of West Africa (Germeraad, Hopping & Muller 1968). There are also indications of the coexistence of forest and more open vegetation, not only in modern times, but as far back as the Miocene. This indication receives strong support from fossil mammals, some of which were adopted to forest life, others to grassland or savanna (Leakey, cited in Andrews & Van Couvering 1975).

14.4 LAKES AND LAKE SEDIMENTS

Lake Rudolf (Turkana), without an outlet to govern its level, is presently very sensitive to climatic change (Butzer 1971, 1973; Butzer et al. 1972). The modern level of Rudolf is about 80 m below that at which overflow to the Nile would occur, and both the exposed shore of the basin and the sediments of the Omo River flowing into the north end of the lake provide evidence of many times when the water level was much higher than it is today (Butzer 1971; Butzer et al. 1972).

The lake was low for a long time after 35 000 B.P., but by 9 500 B.P. it had

risen to +80 m. For about 2 000 years it fluctuated between +80 and +60, and then fell to the modern level until some time before 6 600 B.P., when it started to rise, reaching +65 m 6 200 years ago. The water stayed at this level until after 4 400 B.P., when it fell sharply, rising again to +70 m about 3 000 B.P. The lake has been relatively low ever since, and has varied from +15 m to −5 m since 1897.

Cerling (1977) showed from the fossils, mineralogy and base exchange status of exposed sediments around Lake Rudolf that it was consistently fresh during Pliocene and early Pleistocene time, but intermittently saline since then. While it was fresh many endemic species of molluscs evolved in the lake. Under modern conditions endemic animals are few – the fishes are a subset of Nilotic ones, presumably gained during periods of overflow via the Lotigipi depression to the Nile.

Of the major lakes that currently discharge into the Nile, only Victoria possesses an interesting array of raised strand lines; these seem to be the result of tectonic warping of the basin and incision of the outlet at Jinja, and so are devoid of palaeoclimatic significance (Temple 1964, 1966, 1967; Kendall 1969).

Kendall (1969), working on Lake Victoria, and Harvey (1976), working on Lake Mobuto Sese Seko (Albert) found mineralogical and micropalaeontological evidence that these sources of the Upper Nile contributed no water to it during part of late Pleistocene time. Discharge from these lakes maintains the modern lower Nile during the season of minimum flow in the Ethiopian tributaries, and lack of this discharge must have made the late Pleistocene Nile a very different river.

The sedimentary record from Pilkington Bay of Lake Victoria showed that Victoria was without an outlet for at least 2 000 years prior to 12 500 B.P. Kendall demonstrated that the water fell at least 26 m below its modern level. Later coring by Livingstone (1976) demonstrated a fall of at least 75 m, at which stage the lake can have been no more than 26 m deep. Closed lakes are unstable and the lake may have dried up completely, but complete drying seems incompatible with the present rich fauna of endemic cichlid fishes (Greenwood 1976). It is known that five endemic species of *Haplochromis* have developed in Lake Nabugabo, a beach-pond of Victoria, in less than 3 720 years (Stuiver, Deevey & Gralensky 1960; Greenwood 1965). This cichlid stock is capable of rapid speciation, but probably not of producing the widely divergent food-specialized endemic Victoria sub-genera of *Haplochromis* in 12 500 years. If the lake did dry up so recently, the fishes must have resorted to an effective refugium, perhaps billabongs of rivers draining well-watered Mt Elgon, the Rwanda-Burundi highlands and the Mau escarpment.

Harvey (1976) used diatom analysis of a 10.6 m core taken in 46 m of water off Butiaba in Lake Mobutu Sese Seko (Albert) to show that it, too, was without an outlet prior to 12 500 B.P. The period of closure appears to have been short-lived, for a bed rich in freshwater diatom frustules has an interpolated radiocarbon age that extends from about 18 000 to about 14 000 B.P. Between 18 000 and 25 000 B.P. the lake seems to have lacked an outlet, but it evidently was open from 28 000 B.P., the beginning of the period represented by the core, until 25 000 B.P.

Seven radiocarbon dates spread over 28 000 years reveal drastic changes in sedimentation in Mobutu Sese Seko. Some of the complexities of the section may be due to reworking of older sediments by the waves of a rising or falling lake, but Harvey's conclusion that the Pleistocene was not uniformly dry, and was punctuated by at least one moist episode around 17 000 years ago, is supported by Holdship's (1976) investigation of Lake Manyara in northern Tanzania. There are also suggestions of a late-Pleistocene moist episode between 14 050 and 33 350 B.P. at Sacred Lake on Mt Kenya (Coetzee 1967).

The important climatic change recorded by all this evidence is an increase in humidity 12 500 B.P. The earlier dry time was punctuated by brief humid episodes of some localities. The recent wet time has been less markedly wet during the last 5 000 years.

14.5 POLLEN ANALYSIS

Pollen analysis has long provided impressive insights into the vegetational and climatic history of the temperate zone. In recent decades the pollen-analytical technique has been extended to the tropics, including the headwaters of the Nile. Geologists, palaeoclimatologists and archaeologists have frequent occasion to use the new palynological information, so this review will attempt to provide some basis for a realistic appraisal of the current state of upper Nilotic palynology.

Temperate palynology depends on certain aspects of temperate natural and economic geography. First, the temperate flora, and especially that of temperate Europe, is very small. This permits a confident familiarity with the pollen morphology of the entire flora, and fossil grains in most families are identifiable to genus. The ecological requirements of the separate species in a genus is commonly different. It is, accordingly, very useful to have a small flora in which the number of monotypic genera is large.

A typical advantage of a small flora may be illustrated by the grasses, a family in which the genera are not, in general, distinguishable by their pollen grains. In the small European flora, pollen grains larger than 44 microns in diameter come only from *Elymus*, a genus restricted to coastal localities, and cultivated cereals (Faegri & Iversen 1964). Away from the coast cultivated cereals can be separated from wild grasses on the basis of size alone, and this fact has been used skillfully by European investigators to trace the history of human agriculture. In tropical Africa the size of wild grass pollen grains covers a wider range than that of pre-Columbian cultivated cereals, so such an approach is not possible (Hamilton 1972:141).

The advantage of a small flora has been assiduously exploited by several generations of skillful microscopists so that most European laboratories, and some in America, maintain a standard of pollen identification close to the maximum permitted by the structure of pollen grains and the limitations of light microscopy.

The flora of tropical Africa is very large. Although most African palynologists have pollen reference collections several times as large as those common in

the temperate zone, the collections should be several tens of times as large to provide comparable coverage of the enormous African flora. We are still far from approaching the limit of what can be done with light microscopy to distinguish the pollen grains of the tropical African flora.

There are many cases in which the standard of identification that we have attained is simply not good enough. For example, in most of the published diagrams (Bonnefille 1971a and b being the exception) from the Nilotic region the families Combretaceae and Melastomataceae, very different in their vegetational significance and their climatic requirements, are lumped in a single category. It frequently occurs that a pollen type can be identified to genus, for example, *Myrica, Anthospermum,* or *Euphorbia,* but that the genus includes several species of very different ecological significance.

Many temperate species, including most of those important in forest vegetation, are wind-pollinated or, if insect-pollinated, produce sufficient pollen to register clearly in the fossil record. In tropical Africa animal pollination is much commoner, especially among trees. Whole families such as the Caesalpinaceae and Meliaceae produce so little pollen that they are represented in pollen asemblages by inconsequential traces, even in localities where they dominate the vegetation. In the temperate zone we are reconciled to having only a hazy idea of the past abundance of *Populus.* In the tropics we must be reconciled to having only a hazy idea of the past abundance of a large part of the forest flora.

The main pollen producers in a wide array of African vegetation are grasses, and the pollen grains of African grass genera cannot be distinguished from each other. Much effort has been devoted to the problem of grass identification, which is critical to the interpretation of farmland, grassland, woodland and savanna vegetation, and not trivial with respect to the interpretation of forest and montane vegetation. Most of this work has been disappointing and it seems unlikely that any combination of ordinary light microscopy, phase contrast microscopy, interference microscopy and scanning electron microscopy will yield useful identifications of tropical African grass pollen even to tribe. Size statistics is almost as hopeless, because such common and widespread lowland genera as *Themeda* and *Eragrostis* cover between them almost the entire range of known grass sizes (Hamilton 1972:140ff.).

Hundreds of radiocarbon-dated cores from Europe and America provide the redundancy that is always needed to convey information along a noisy channel. The stratigraphy of temperate microfossil assemblage zones is well established, and their ages and areal extents are known well enough to permit the computation of former vegetational clines, of migration routes and migration speeds, in a way that will not be possible in Africa for many years. In the Nile headwater area our pollen diagrams are still very scarce. We do not yet have a good idea of the extent to which their differences are consequences of idiosyncracies of site or investigator, or the extent to which each diagram reflects general trends in the region from which it comes.

In the temperate zone, and especially in America, there is much information about the relation between modern pollen rain and vegetation. This is used in the intuitive interpretation of pollen diagrams, and it also permits more objective statistical methods of interpretation. In the Nilotic area, by contrast, we

have one published investigation of the relation between pollen and vegetation (Hamilton 1972), an investigation limited to the highland parts of Uganda, and seriously constrained by the scarcity of suitable sampling sites in the important montane forest belt.

Temperate palynologists are many and have been working for a long time. They check each other's interpretations, and occasionally re-examine the entire body of data. Now climate, now soils, now human land use and now biogeographic adjustment are used to interpret microfossil stratigraphy. The interpretive papers of Morrison (1961, 1966, 1968) and Coetzee (1967), or of Livingstone (1967, 1975) and van Zinderen Bakker (1962, 1964; van Zinderen Bakker & Coetzee 1972) show that tropical African palynologists have not all been the disciplined devotees of any single interpretive method, but limited man-power has gone into this most difficult part of the palynological enterprise. Future workers, even without new field data, will put different interpretations on some of our published diagrams.

African palynologists have one major advantage over most of their temperate colleagues: the sedimentary record available for analysis is a hundred times as long.

14.6 THE PALYNOLOGICAL EVIDENCE

Published pollen diagrams covering the Holocene and part of the Upper Pleistocene come from the Ruwenzori Mountains in Uganda (Hedberg 1954; Osmaston 1958; Livingstone 1967), the Cherangani Hills in Kenya (van Zinderen Bakker 1962, 1964; Coetzee 1967), the Kigezi Highlands of western Uganda (Morrison 1961, 1968; Morrison & Hamilton 1974) and Pilkington Bay of northern Lake Victoria in Uganda (Kendall 1969). An important body of surface spectra has been provided for highland Uganda by Hamilton (1972), used by him to reinterpret the highland Uganda diagrams, and used by van Zinderen Bakker & Coetzee (1972) to reinterpret other East African diagrams.

Of these workers only Kendall (1969) provided accurate pollen deposition rates. Osmaston & Hedberg's pioneering investigations produced short cores without absolute dates, and the other investigations have depended on a very limited number of dates, sufficient to provide an indication of the age of at least the upper part of each section, and to permit some correlation of pollen zone boundaries by interpolation between dates. Dates based on organic lake mud are reliable, but the shallow slow-growing peat of Cherangani seems to have been infiltrated to a varying degree by modern roots.

In broadest terms, all of these diagrams suggest the same vegetational history. Below a level that is nowhere more than 12 500 years old, all long sections contain a microfossil assemblage much richer in grass grains than the more modern ones. Above the grass-dominated zone there are assemblages in which shrubs or small trees are relatively important, especially in the highland sites. Above the shrub pollen zone the grains of forest tree genera rise, to a different extent at different sites, and maintain their importance for some considerable part of the Holocene. At all sites there is some tendency for the relative abundance of many forest taxa to decline during the past few thousand years; the taxa that

rise in abundance at the expense of forest trees vary from site to site.

Modern vegetation of the Nile's headwaters is a complex mosaic, and it is a pleasant surprise that so much order is actually discernible in the fossil record. Some of this order may come from the selection of sampling sites: all but one are in highland areas, even, for the most part, in the montane forest belt of highland areas. The remaining pollen record comes from a forested environment along the well-watered north shore of Lake Victoria that shares many important forest genera with the lower montane forest belt. When sites are investigated in the woodland, savanna, grassland, semi-desert and desert parts of the Nile headwaters we may not find such a simple four-fold division of the late Pleistocene and Holocene vegetational history.

There does seem to be considerable parallelism in the history of vegetation types in which forest trees are important. Possibly atmospheric mixing of pollen may occur on a sufficient scale to disseminate the strong forest signal over a wide area, far from the actual area of forest. Hamilton (1972) provided very useful insights into the extent of wind transport of forest pollen to the higher parts of mountains, but only a minimum estimate for the distance of effective pollen transport, because each high mountain is closely ringed by a belt of forest vegetation.

In the details of vegetational interpretation there are divergent opinions among African palynologists. Van Zinderen Bakker (1964) and Coetzee (1967), for example, believe that most grass pollen at all levels in the highland diagrams comes from temperate grasses of the alpine moorlands. Livingstone (1967), Morrison (1966) and Hamilton (1972) are at least skeptical of this belief. They note the occurrence of modern vegetation in which grasses are important at all altitudes in East Africa, the impossibility of identifying grass pollen even to tribe and the lack of any empirical association between high grass pollen percentages in the modern pollen rain and alpine grassland.

Most pollen analysis in this area has been concentrated in the highland areas. The flora is small above 2 500 m, and it includes many genera that are already familiar to pollen analysts from their experience elsewhere. The vegetation can be described in terms of three broad belts recognizable on all East African mountains (Hedberg 1951). From 1 700-2 300 m to 3 000-3 300 m there is a montane forest belt, from 2 600-3 400 m to 3 550-4 100 m an ericaceous belt, and above 3 550-4 100 m an afroalpine belt extending to snowline or to the top of each mountain. The limits of each belt vary from mountain to mountain or even on different sides of the same one, but some correlate of increasing altitude, usually assumed to be low temperature, is the main control of this vegetational zonation. Departures from regularity are usually understandable in terms of human land-use, humidity, or cloud cover.

Interpreting pollen diagrams from this seemingly simple environment has turned out to be surprisingly difficult. As Morrison (1966) pointed out, the general altitude-dependence of the vegetation belts is not sufficiently precise for close estimates of palaeotemperature. Further, the vegetational zones, up to three in number, of which each belt is composed, do not seem to be under the control of any simple factor associated with altitude, and still elude ecological understanding.

If all vegetation belts retain their integrity through time, and if all were equally productive of identifiable pollen, vegetational reconstruction would be simple. Constituent species of the belts, however, behave at least to some extent individualistically. An impression of the past vegetation must be built up taxon by taxon. In addition, the pollen assemblage in a particular basin of sedimentation comes not only from the vegetation belt around the basin, but also from other belts above and below it. If one of these other belts is a stronger pollen disseminator than the local one, long-distance transport becomes very serious.

Hamilton's (1972) investigation of modern pollen rain in highland Uganda goes a long way toward making these problems explicit, and suggests a procedure for coping with them. By discovering pollen grains that occur in the pollen rain of places far from the nearest station for the parent plants he identified taxa that are transported far. By discovering taxa that are not represented in the pollen rain even of stations in vegetation that include the parent plants he identified poorly disseminated taxa. In this way, he built up a body of information about the pollen dissemination of a usefully large part of the highland flora. Then, by computing past pollen percentages based on a sum that included only plants that disseminate their pollen locally, he traced the history of at least some part of each vegetation belt.

In principle, this method is capable of resolving many of the interpretive problems involved in reconstructing the mountain vegetation. In practice, it has several serious limitations. Grasses are to be found in the vegetation and the pollen rain at all altitudes on the mountains, so Hamilton's method cannot be used to determine their effectiveness of dissemination. This is a very serious limitation, because grass pollen is an important constituent of pollen assemblages of all ages, and the spectacular decrease in grass pollen abundance near the end of the Pleistocene is one of the strongest signals of changing vegetation in all our published diagrams.

A second limitation comes from the shortage of suitable sites for sampling the modern pollen rain. Above 4 000 m on Ruwenzori, for example, there is an abundance of glacial lakes, and the glacier ice provides another useful source of more or less modern pollen. Between 3 000 and 4 000 m there are, for the most part, only bogs, which are much less suitable because of the strong local overrepresentation of plants such as *Alchemilla,* Cyperaceae, woody *Senecio* and giant *Lobelia* growing on the bog surface. Below 3 000 m even bogs are scarce, and one is reduced to working with moss polsters, leaf litter and forest soil, which are so influenced by the plants growing over and around them that they give a very unsatisfactory impression of the regional pollen rain. This means that the montane forest belt, the most species-rich, the most extensive areally, and probably the most profligate in pollen dissemination of all the vegetation belts of highland areas, is known only from a small number of satisfactory surface samples.

A third problem is the labour of counting the very large number of pollen grains needed to establish the modern pollen rain. We have had one major investigation of the pollen rain and five of pollen stratigraphy. An optimal mix for purposes of understanding past vegetation would probably be closer to equal parts of modern and stratigraphic work. In trying to cover an enormous need

Hamilton reduced his counting totals to 150 grains per sample. Occasionally, some important element in the long-distance component of the pollen such as *Olea* (his p. 85) seemed not to be transported even locally because of the statistical error associated with small counts.

Until more surface spectra are available it is impossible to use multiple correlation techniques and go directly from pollen assemblages to meteorological parameters (Webb 1973, 1974; Webb & Bryson 1972). We have a useful number of surface samples only from localities in the mountains where there is not a useful number of weather stations.

All investigators agree that the main factors controlling the changing vegetation of East Africa are human land-use, temperature and humidity. In the highland areas from which most of our stratigraphic information comes, an increase in temperature, an increase in moisture, and a decrease in human interference would all tend to enhance forest at the expense of shrubby and grassy vegetations. The late-Pleistocene grass-dominated pollen assemblage zone cannot be due to a human impact more intense than that of modern times. The regression of the past few millennia might be due to the beginning of the Iron Age but we can seldom rule out some measure of climatic change as well. Indeed, what is known elsewhere about Holocene climatic change suggests that climate may have contributed to the pollen changes of the Christian era. Most palynologists believe that they have evidence for both climatic change and human deforestation; evidence for anthropogenic effects is strongest where the altitude is lowest, in Kigezi and around Lake Victoria.

It is difficult to distinguish effects of drought and low temperature in the late-Pleistocene grass pollen assemblage zone. No doubt both are involved: we know from lake levels that the Pleistocene climate was dry on the East African plateau, and Kendall's basal grass zone from Lake Victoria must be due very largely to dryness. On the other hand, Osmaston's glacial geology shows that there was a substantial reduction in mountain temperature during the late-Pleistocene. No doubt the basal grass pollen zone of Mt Kenya, Cherangani and Ruwenzori is due partly to low temperature. All available evidence suggests that the late-Pleistocene was both cooler and dryer at all altitudes, and the interpretive problem is not one of making a choice, but the more subtle one of estimating the extent of each influence.

No pollen diagram has been published from the area of the Nile headwaters that embraces more than the 35 000 years of Coetzee's splendid profile from Sacred Lake on Mt Kenya, but there is every reason to expect a very much longer pollen record from the area. Lake Mobutu Sese Seko (Albert) occupies a graben first down-thrust during the early Miocene (Cahen 1954; Bishop 1967). Although it has not held water continuously since that time, it is likely to provide a very long record of Neogene vegetation. Long cores that have been taken from the basin (Harris, Pallister & Brown 1956) penetrated the coarser marginal facies, the most promising for petroleum but the least for pollen, and most of them were discarded without palynological study. I have scanned a few samples from Kibuku borehole No. 4, and at least some of the upper part of the core is polliniferous. The middle part contains only fern spores, presumably a lag concentrate of a more complete microfossil assemblage, and the lower part of the

core did not yield microfossils.

Long records are likely to be obtainable from Winam (Kavirondo) Gulf of Lake Victoria, which also formed in the Miocene, and from Lake Rudolf which is known to have a history going back to the Pliocene.

Bonnefille (1968, 1969b, 1970, 1971, 1972a, b, 1976a, b) has circumvented the problems of drilling in large old lakes by sampling exposures of ages back to Upper Pliocene.

Most of the sediments exposed are not polliniferous, and those with pollen have such low concentrations that kilogram lots must be processed to obtain a few hundred grains. Lake and bog sediments, by contrast, commonly yield a few hundred million grains per kilogram of sediment. Material of such age imposes additional burdens of pollen identification. Extinction, evolution and serious biogeographic change become likely, and the simplifying assumption that all fossil grains come from species still living in the area is less likely to be valid than it is for Holocene or Upper Pleistocene materials.

Interpreting the microfossils from such exposures once they have been identified is also difficult. The low pollen concentrations, for example, might be due to a low rate of pollen deposition or a rapid rate of deposition of the matrix, or they could be due to post-depositional destruction of most of the assemblage. If the fossil assemblages were only one part in 10^6 of what was originally present, differential destruction would destroy the vegetational significance of the microfossil assemblage. Bonnefille's spectra, however, contain a wide array of pollen types, and the assemblages are internally consistent ones, with a balance of genera such as one would expect from a modern vegetation; they do not look like the lag concentrates of fern spores or *Podocarpus* and grasses I have found in samples from Lake Mobutu Sese Seko, Olorgesaillie and Olduvai.

Bonnefille (1969a) matched her fossil work with studies of the modern pollen assemblages of her field areas, and concluded that the vegetation sometimes resembled that of today, sometimes required more moisture, and sometimes required less, over a time-span of 2 or 3 million years. This conclusion is consistent with our expectations, but one must not lose sight of the basically unsatisfactory nature of the material with which Bonnefille has been obliged to work, nor of the fragmentary and interrupted nature of the record that can be provided in this laborious way. A thorough understanding of the changing vegetational environment of the evolving hominids requires pollen analysis of cores through pollen-rich sediments that have been water-logged since the time of their deposition.

14.7 DISCUSSION

All evidence suggests that the headwater environment of the Nile was relatively dry during the late-Pleistocene, relatively wet during the Holocene. The filling of lakes Victoria and Mobutu Sese Seko, and a major shift in vegetation along the north shore of Lake Victoria and at Mahoma Lake in the Ruwenzori occurred 12 500 years ago. In dryer localities the vegetational shift seems to have been less sudden and later, except possibly at Cherangani, where the sum

of montane forest elements in the microfossil assemblage shows a possibly significant increase about 12 500 B.P. Neither Rutundu nor Sacred Lake on Mt Kenya shows evidence of a marked shift in vegetation before the decline of *Artemisia* between 10 000 and 11 000 years ago. The displacement of grass by shrubs at Muchoya Swamp in Kigezi also seems to have taken place somewhat before 10 000 B.P. A progressive moistening of climate might be expected to lead to the establishment of forest on the wettest mountains first, so it is not surprising that the pollen zones seem asynchronous.

Interpretation of even such moisture-related features as lake level change suffers greatly from the lack of independent information about changes of temperature. We have Osmaston's estimates of close to 5°C temperature difference between Pleistocene and Holocene, but his approach can be used only on high mountains, and these are limited in number. The estimate is not independent of humidity, as we have already seen.

There is a large temperature effect on the rate of amino acid racemization, but the process has been more often used for dating than for palaeothermometry. Where the temperature effect was exploited (Schroeder & Bada 1973), a difference of 5°C was calculated from bone amino acids from Lukenya Hill, Kenya. Isotope palaeothermometry is hampered by uncertainties concerning the isotopic ratio in the hydrosphere and atmosphere during past times. The isotopic composition of water is particularly sensitive to changes in aridity in Africa (Cerling, Hay & O'Neil 1977), and in the global reserve of glacial ice. Palmer (1976) identified fossil African grass cuticles while Teeri & Stowe (1976) suggest a way of using them in palaeothermometry. Perhaps these techniques will soon provide the moisture-independent temperature estimates we now need so badly.

Harvey (1976) and Holdship (1976) found episodes of high lake level during generally dry late-Pleistocene time, but Richardson (personal communication) finds no indication of such episodes during the past 30 000 years in the Kenya Rift lakes. There is a tendency for early Holocene lake levels to be interrupted by a transitory dry period about 7 000 B.P., but only at sites well north of the equator. Apparently climatic changes have not been completely uniform over tropical Africa. Although the Holocene has been generally wet, the late Pleistocene generally dry, the details of climatic change form a mosaic, with individual sites departing from the general trend. This is accordant with the theoretical expectations of Manabe (Manabe & Hahn 1977 and personal communication), who used CLIMAP sea surface temperatures as a boundary condition in his model of the atmosphere and generated an output in which wet anomalies appeared on a background of generally dry climate for tropical Africa under ice-age conditions.

The history of climatic change does seem to offer an explanation for the ichthyogeographical peculiarities of the modern Nile. The modern Nile receives most of its water from the Blue Nile and Atbara, but it is the small, steady discharge from the White Nile headwaters that sustains the river during the season of low flow. During the late-Pleistocene there was no White Nile discharge from Lake Mobutu Sese Seko, and there are many indications that Ethiopia was dryer as well (Gasse 1977; Gasse, Rognon & Street, in this volume; Street & Grove

1976). Even with some possible augmentation from presently dry wadis draining the Red Sea Hills, the lower river must have been seasonally much reduced during the late Pleistocene. As Hugues Faure has pointed out to me in conversation, the response time of a ground water reservoir is long, even comparable to the period of aridity we are considering, so one would expect isolated pools to hold water, even along those parts of the Nile whose discharge dwindled seasonally to zero.

Such a reduced river could not be expected to support so many species of fishes as the large Nile of today. No doubt it contained the 26 species that are now endemic (Greenwood 1976) but perhaps not many more. With resumption of heavy flow during the Holocene an opportunity existed for additional species to live in the river, and this opportunity was apparently exploited largely by fishes that came from well-watered West Africa.

Immigration from such a distant source was facilitated by early-Holocene wetness along the southern fringe of the Sahara, and also, no doubt, by the general flatness of the terrain, where sand-dunes dominate the local relief, and shifting dunes could generate the river captures that are a major mechanism of fish dispersal. Zairean fishes, although much closer, depended on the much rarer accidents of tectonic, volcanic and erosional river capture, and were unable to colonize the expanded Holocene Nile.

14.8 SUMMARY

1. Glacial moraines at altitudes far below the existing glaciers on high mountains of the Nile headwaters show that the climate was formerly much colder than it is today. Prior to the last ice age, which was coming to a close by 14 500 B.P., there were at least two very much older ice ages of comparable extent. On Kilimanjaro four glaciations occurred, the oldest 500 000 B.P.

2. Detailed mapping and statistical analysis of moraines on several mountains suggests a firnline lowering of between 640 and 880 m. If there were no change in humidity, this would imply an ice age 4.2 to 5.8 degrees C colder than modern times. Other lines of evidence suggest that the last ice age was dry. A 25% decrease in rainfall would raise these estimates of ice-age cooling to 6.7 and 8.3 degrees C.

3. Raised strand lines around Lake Rudolf (Turkana) show that it has been much higher many times, especially in the lower Holocene, than it is today. At its maximum height it discharged into the Nile.

4. Cores from the sediment of Lakes Victoria and Mobutu Sese Seko (Albert) show that the levels of both were below their Nile outlets prior to 12 500 B.P. Mobutu Sese Seko has been open from at least 28 000 to 25 000 B.P., from 18 000 to 14 000 B.P. and since 12 500 B.P. Its level fell by at least 56.6 m, leaving no more than 23 m of water in the lake. Victoria was closed from at least 14 500 B.P. until 12 500 B.P. and probably briefly around 10 000 B.P. During the dry period its level fell by at least 75 m, leaving no more than 26 m of water in the lake.

5. Pollen assemblages of Pleistocene age are dominated by grasses at all sites that have been investigated. Grains of forest trees displaced grasses 12 500 B.P.

at Pilkington Bay of Lake Victoria, but at highland sites a variety of small tree and shrub pollen types dominated the assemblages until the rise of tree pollen some millennia later. During the past few thousand years the relative importance of forest pollen types has declined in all localities.

6. The Pleistocene suppression of forest trees seems to have been due to lower rainfall in all localities and lower temperature in at least the highland ones. The rate and timing of the change from Pleistocene to Holocene climatic conditions is still uncertain; most of the evidence suggests a major change at 12 500 B.P., but there are contrary indications of anything from 14 500 to 10 000 B.P. as the beginning of the 'Holocene' climatic era. The forest decline of the past few millennia seems due largely to human influence.

7. Similarity of the Nilotic fish fauna to that of Lake Chad, the Niger and the Senegal may be due to extinction of a large part of the pre-Pleistocene Nilotic fauna during periods when the White Nile was not flowing, and its subsequent replacement by immigrant fishes from West Africa during the early Holocene wet period.

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Quaternary history of the Afar and Ethiopian Rift lakes

Histoire quaternaire des lacs de l'Afar et du Rift Ethiopien

Les lacs de l'Afar et du Rift Ethiopien (Territoire de Djibouti et Ethiopie) sont actuellement indépendants du système du Nil puisqu'ils occupent des bassins fermés. Toutefois, leurs bassins versants ont subi la même évolution climatique que celui de Haut Nil, et des connections se sont établies entre les lacs les plus méridionaux du Rift et le Nil Blanc lors des épisodes humides.

Nous décrivons d'abord succinctement le contexte actuel de la région étudiée. Nous rappelons l'origine des bassins lacustres, liée à l'évolution volcanique et tectonique récente, et expliquant le cadre géologique. Nous insistons sur les variations climatiques altitudinales, responsables des ceintures de végétation. Au point de vue hydrologique, les lacs actuels sont classés en deux groupes principaux: lacs dépendants directement de rivières permanentes descendant des montagnes, lacs alimentés par des eaux souterraines.

De grands lacs se sont développés en Afar au cours du Plio-Plèistocène. Les témoins sont préservés en deux secteurs d'intérêt différent. Tout d'abord, vers l'Ouest, la formation à Hominidès d'Hadar, datée de 3,3 à 2,6 m.a., a permis une reconstitution paléogéographique détaillée. Nous insistons sur l'importance paléontologique de cette formation, contenant *Australopithecus* et *Homo,* et qui constitue un des gisements les plus riches du monde. D'autre part, en Afar Central, l'activité volcanique continue a favorisé la conservation des sédiments, enregistrant plusieurs épisodes lacustres de types très diversifiés.

Le Pléistocène moyen est avant tout une période d'évolution des reliefs. A Melka Kontouré, on note une forte activité fluviale et la construction de terrasses. En Afar, de très vastes glacis se mettent en place aux pieds des escarpements majeurs et recoupent les formations antérieures. Des sables éoliens à ossements s'accumulent localement dans les bassins de l'Afar Central. Bien que divers indices traduisent quelques oscillations humides, le Pléistocène moyen parait être, dans l'ensemble, une période sèche.

Plusieurs épisodes de haut niveau lacustre se succèdent au Pléistocène supérieur. Trois sont connus en Afar, deux ont été reconnus avec certitude dans le Rift Ethiopien. Les lacs successifs s'opposent nettement par leurs caractères écologiques et sédimentologiques. Si les corrélations entre le Rift Ethiopien et l'Afar sont encore hypothétiques pour les épisodes les plus anciens, on peut affirmer que la dernière phase lacustre, la plus importante du Quaternaire supérieur, est synchrone dans ces deux secteurs ($\geqslant$27 000-$\leqslant$20 000 ans B.P.). Cet épisode est partout suivi d'une phase de très grande aridité (17 000-12 000 ans B.P.) dont les témoins constituent un excellent repère stratigraphique pour établir quelques corrélations interrégionales. Il n'est pas possible, pour l'instant, de corréler les fluctuations lacustres et les oscillations des glaciers éthiopiens. Le problème de l'âge des dernières calottes glaciaires est évoqué.

L'Holocène est la période la mieux connue en raison de l'abondance des témoins et de très nombreuses datations au ^{14}C. Nous étudions d'abord les lacs alimentés par des cours d'eau

superficiels. Le parallélisme remarquable entre l'évolution des lacs du Rift Ethiopien et celle du lac Abhé est souligné. Dans les bassins dépendants principalement d'apports souterrains, les courbes de fluctuations des plans d'eau paraissent plus simples: ce type d'alimentation semble avoir amorti les oscillations climatiques brèves ou de faible ampleur. Bien que les informations concernant les bassins versants soient encore très fragmentaires, les données connues s'accordent avec les conclusions paléolimnologiques.

En conclusions, nous soulignons l'importance des faits déduits de l'étude détaillée des lacs éthiopiens pour la compréhension des mécanismes généraux du climat.

15.1 INTRODUCTION

The rift lakes of Ethiopia and Djibouti are situated in the Horn of Africa between 4 and 14°N and 36 to 44°E. At the present day they occupy an enclave of internal drainage separating tributaries of the Blue and White Nile from the rivers flowing towards the Indian Ocean, such as the Webi Shebeli. This region is vital to an understanding of Quaternary events in the Nile system for two reasons: firstly because climatic events in the lake catchments closely reflect those in the adjacent Nile headwaters, and secondly because the southern lakes were linked to the White Nile, via Lake Turkana (Rudolf) during past periods of overflow (Grove et al. 1975).

Looking further afield, we see that the Ethiopian Highlands and the Afar lie at the eastern extremity of the Sahel zone. Both areas have experienced a very similar history of climatic fluctuations which can be correlated with ocean temperature changes and with long term shifts in the West African monsoon. The regional anomalies superimposed on this broad Sahelian pattern closely resemble those recorded by the East African lakes, and may therefore reflect the influence of the Indian Ocean.

The modern lakes occupy very diverse topographic and climatic settings. Recent findings now enable us to compare cirque basins at altitudes exceeding 4 000 m in the highlands with hypersaline lakes lying far below sea level. This enormous altitudinal contrast has also resulted in a broad spectrum of surrounding environments, ranging from Afroalpine moorlands and dense montane forests to rocky deserts and salt plains. Hence, in spite of the marked climatic fluctuations during the Quaternary, favourable habitats for human occupation have always existed within this region. Some of the earliest hominid remains in eastern Africa have been discovered in the Plio-Pleistocene lake basin at Hadar and the lake margins have been foci of prehistoric habitation and foodgathering throughout the Quaternary.

Not surprisingly, the wealth of stratigraphic and archaeological evidence has attracted researchers from a wide variety of countries and disciplines. This has given rise to an extensive but scattered international literature in the fields of geology, palaeontology, limnology, palynology, archaeology and palaeoclimatology. Some lake basins have received scant attention whereas others have been studied in detail over a number of years. It is not yet possible to present a coherent picture for the whole region, so we have tried to concentrate on the periods and the areas which are best known. For example, more information is available

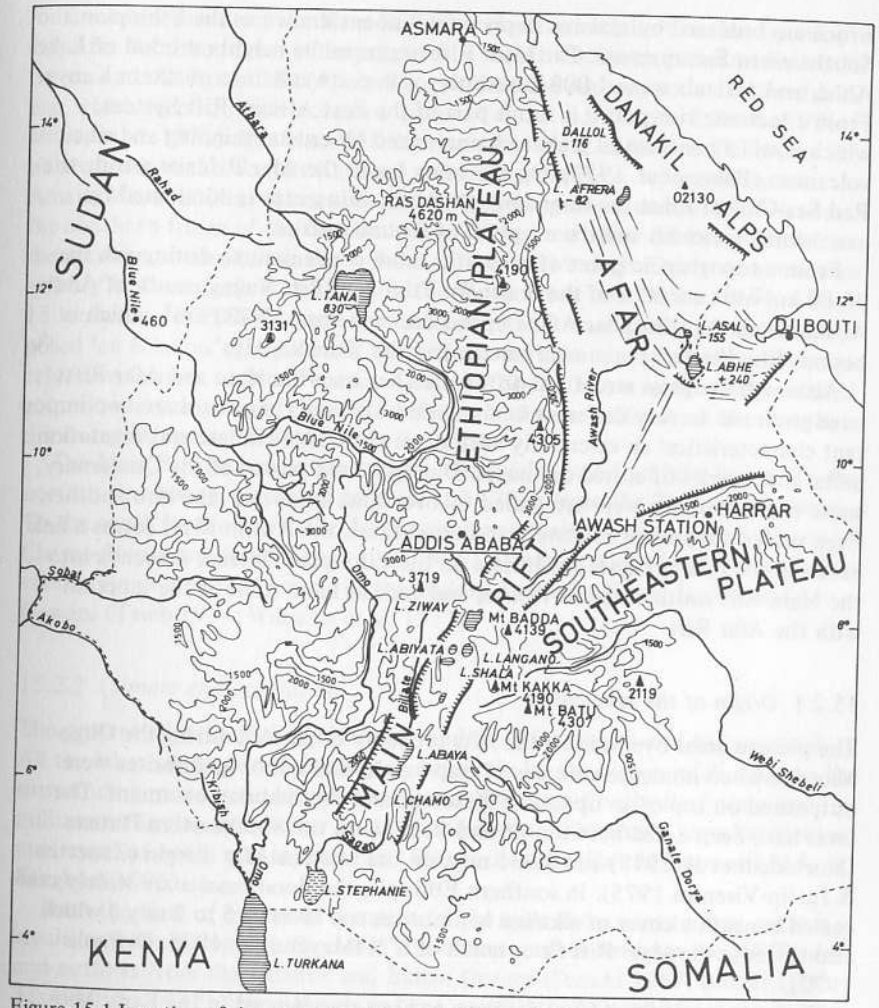


Figure 15.1 Location of the Afar and the Main Ethiopian Rift in eastern Africa.

on the Plio-Pleistocene hominid-bearing formations and the Late Quaternary lake-beds than on the scanty traces of the Middle Pleistocene. The best-studied sites lie in the Central and Southern Afar and in the Ziway-Shala Basin. At every stage the interpretation of these sequences depends on an understanding of modern environments in the region.

15.2 MODERN SETTING

The Ethiopian Highlands, which rise to altitudes in excess of 4 000 m, form an extensive uplifted plateau bisected by the Main Ethiopian and Afar Rifts (Figure 15.1). The lakes discussed here lie within these two megastructures,

which are bordered by massive stepped fault zones known as the Ethiopian and Southeastern Escarpments. The Main Rift begins in the neighbourhood of Lake Abhé, and extends some 1 000 km south-southwestwards into northern Kenya. From a tectonic viewpoint, it forms part of the East African Rift System, which is still a continental graben characterized by crustal thinning and silicic volcanism (Baker et al. 1972). On the other hand, the Afar Rift sits astride the Red Sea-Gulf of Aden sea-floor spreading axis: this sector is dominated by extensional tectonics and the eruption of fissural basalts.

From a topographic point of view, it is more convenient to distinguish the 70-80 km-wide corridor of the Southern Ethiopian Rift Valley, south of Addis Ababa, from the triangular Afar Depression, covering 150 000 km^2, which is bounded by the two main escarpments and the 'Danakil Alps'.

Although the gross structural differences between the Main and Afar Rifts have given rise to very different landscapes, both major regions share two important characteristics: an essentially altitudinal pattern of climate and vegetation belts, and a series of closed drainages. During humid phases of the Quaternary, some of these basins were integrated by overflows from one lake into another. Even under the present relatively arid conditions, the Awash River forms a link between the two rift systems. It rises on the Ethiopian Plateau, descends into the Main Rift south of Addis Ababa, and ends in Lake Abhé at the junction with the Afar Rift.

15.2.1 *Origin of the lake basins*

The plateau areas overlooking the rifts probably originated during the Oligo-Miocene when immense volumes of trap basalts and minor ignimbrites were outpoured on top of an updomed Mesozoic and Precambrian basement. The lavas have been dated between 28 and 21 m.y. on the Southeastern Plateau (Morbidelli et al. 1975) and 32-35 m.y. on the western Afar margin (Zanettin & Justin-Visentin 1975). In southern Ethiopia, the flood basalts are widely concealed beneath a cover of alkaline ignimbrites and lavas (9.5 to 2 m.y.) which also underlie the Main Rift floor north of 6°N (Meyer et al. 1975; Di Paola 1972).

The opening of the Afar Rift seems to have commenced in the Early Miocene (23-25 m.y.) (Barberi et al. 1975). The first lake basins, such as the extinct Mio-Pliocene Chorora Basin and the Plio-Pleistocene West-Central Afar Basin, developed in gently downwarped zones at the foot of the newly created escarpments (Sickenburg & Schönfeld 1975; Johanson et al., in press). These areas have remained relatively stable up to the present day. The interior of the Afar Depression is largely floored by two thick series of stratoid basalts (Barberi et al. 1975). The older of the two is dated from 7-4 m.y., and as a result of crustal spreading, is now only exposed towards the margins. The modern lake Abhé lies in a steepsided fault trough within the more recent series (4-1 m.y.) which now occupies the centre of the Afar. Some neighbouring dry grabens such as Hanlé-Dobi and Der Ela also held lakes during humid phases of the Quaternary. The youngest Afar lake basins are Asal and Afrera, which are situated along the active volcanic axes and are still evolving at the present day.

The development of the Main Rift took place much later than the opening of the Afar Rift. A number of large trachytic shield volcanoes in the Addis Ababa region and the Arussi Mts (4.5-2 m.y.) predate the main episode of downfaulting, which seems to have occurred around 1.8-1.6 m.y. (Mohr & Potter 1976; Meyer et al. 1975). The Main Rift is essentially linear as far as 6.5°S, where it bifurcates into the Ganjuli (Chamo) and Galana Grabens, separated by the Amaro Mts (2 600 m) (Levitte et al. 1974). Both grabens die out at 5°N, near the southern fringe of the highlands. The rift is then offset 50 km west to form the southward-continuing Chew Bahir (Stephanie) trough. Quaternary volcanic activity has been largely confined to the Wonji Fault Belt (Mohr 1967), a 5 to 15 km-wide, NNE/SSW-trending zone of intense normal faulting which is disposed 'en échelon' along the rift floor. Zones of offset are marked by dormant caldera volcanoes such as Fantale, Alutu and Shala. These centres have erupted voluminous quantities of rhyolitic airfall and ashflow tuffs which blanket the rift floor (Di Paola 1972; Meyer et al. 1975).

The Main Rift is compartmented by low divides into four lake basins. To the north is the Awash, separated by a col at 1 670 m from the Ziway-Shala Basin. To the south lie the tiny Lake Awasa catchment and the much larger Abaya-Chamo-Stephanie Basin (Grove et al. 1975). Lakes have also been ponded up at various times along the course of the Middle Awash, at Koka, Besaka and Gawani (Taieb 1974; Williams et al. 1977).

15.2.2 *Climate and vegetation*

The present climate of the Rift Valley and the Afar is semi-arid to hyperarid. All the lakes are sustained directly or indirectly by the high rainfall areas on the surrounding mountains. Mean annual rainfall varies altitudinally from a few millimetres in the areas below sea level and about 300 mm at Chew Bahir, to a maximum of 1 600 mm around the 3 000 m contour (United Nations 1965; Kingham 1975).

Both the time of onset and duration of the rains show a latitudinal pattern, resulting from seasonal shifts in the convergence zones between the NE Trades and airflows from the Atlantic and Indian Oceans (Suzuki 1967; Butzer 1971: 33; Griffiths 1972). From March to June, southeasterly winds from the Indian Ocean bring heavy rain to areas south of 6.5°N. Further north, these 'small rains' are sporadic. Instead, the 'main rains' last from July to September, when moist airstreams from the Atlantic and Indian Oceans meet over the highlands. South of Lake Abaya, rain falls again in September and October as the Northern Inter-tropical Convergence Zone moves rapidly equatorwards.

Air temperatures, and with them, evaporation, decline markedly with altitude, although exposure and windiness exert some modifying influence. The mean lapse rate is estimated to be 6.75°C/1 000 m (United Nations 1973), so that frost is common above 2 000 m (Makin et al. 1975). Annual evaporation from lake surfaces is believed to increase from around 1.6 m at Awasa to 2.0 m at Ziway and 3.0 m at Besaka (Makin et al. 1975, 1976; United Nations 1973). Water losses from the playa lake Chew Bahir and from the Afar lakes must be even higher.

Table 15.1 Present-day characteristics of the Rift and Afar Lakes

Lake	Surface altitude (m a.s.l.)	Max. recorded depth (m)	Area (km^2)	Approx. volume (km^3)	Total dissolved solids (mg/l)	pH	Carbonate alkalinity (meq/l)	Dominant ions[4]	Salinity classification (Gasse 1975)
Afar									
Northern Afar									
Afrera[1]	− 80	n.d.	70	n.d.	159	7.9	1.4	Na > Ca:Cl	Hyperhaline
Central Afar									
Abhé[1]	240	37	350	3	160	10.3		Na:HCO_3 > Cl	Hyperhaline
Asal[1]	− 155	20	55	n.d.	350	n.d.		Na > Ca:Cl	Hyperhaline
Southern Afar									
Besaka[2]	c. 955	n.d.	3.6	n.d.	n.d.	10.0	61-816	Na:HCO_3 > Cl	Mesohaline – hyperhaline
Southern Rift									
Ziway[1]	1 636	8.95	442	1.6	0.32	7.9	3.7	Na > Mg, Ca:HCO_3	Oligohaline
Langano[1]	1 582	47.9	241	5.3	1.27	9.1	14.6	Na:HCO_3 > Cl	Oligohaline
Abiyata[1]	1 578	14.2	176	1.1	8.09	9.4	102.3	Na:HCO_3 > Cl	Mesohaline
Shala[1]	1 558	266	329	36.7	15.68	9.7	162.2	Na:HCO_3 > Cl	Mesohaline – polyhaline
Awasa[3]	1 680	21.6	92	1.3	0.61	8.7	8.4	Na:HCO_3	Oligohaline
Abaya[3]	1 285	13.1	1 070	8.2	0.61	8.0	9.2	Na:HCO_3	Oligohaline
Chamo[3]	1 233	12.7	350	n.d.	0.65	8.6	10.0	Na:HCO_3	Oligohaline
Chew Bahir[3]	520	–	Ephemeral	–	8.10	9.2	51.6	Na:Cl > HCO_3	Mesohaline

1. Gasse & Street (1978a).
2. Pittwell (1967).
3. Grove, Street & Goudie (1975); Vatova (1941); updated from United Nations (1973), Makin et al. (1975) and Bentor (1967).
4. 'HCO_3^-' includes $CO_3^{=}$ and HCO_3^-.

n.d. No data.

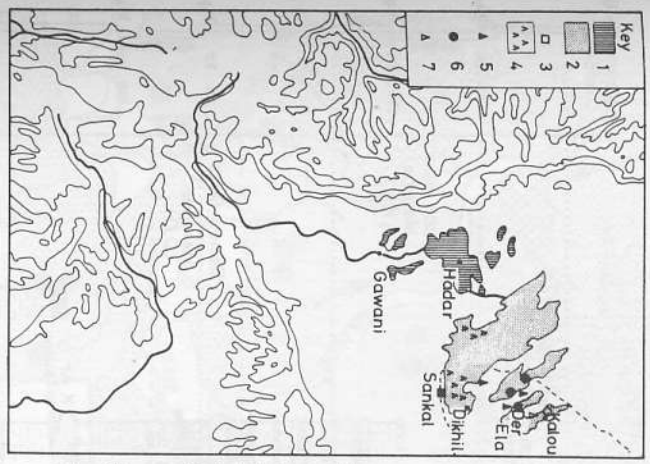


Figure 15.2 The Plio-Pleistocene deposits of Ethiopia: areas of investigation.
1. The hominid-bearing Hadar Formation.
2. Present-day grabens of the Central Afar.
3. Sankal sandstones.
4. Dikkil formation.
5. *Stephanodiscus* diatomites interbedded with the upper part of the Younger Afar Stratoid Series.
6. *Stephanodiscus* diatomites outcropping on the basin floors.
7. Sediments of the Oued Kalou, interstratified with the basalts of the Younger Afar Stratoid Series.

This climatic gradient has resulted in a predominantly altitudinal pattern of vegetation belts, now greatly disturbed by Man. In the driest parts of the Afar, plant life is restricted to sparse tussocks of grass, except for the immediate neighbourhood of drainage lines. Within the Main Rift, the present vegetation ranges from *Acacia* woodland to dry thorn bushland in the more arid areas. Climbing up the mountainous flanks, one successively encounters *Combretum* bush-grassland; remnants of dry *Podocarpus* or *Juniperus* forests, *Hagenia-Hypericum* forest, and finally, beginning at about 3 000 m, ericaceous scrub and Afroalpine heath.

It seems highly probable that these altitudinal life zones have migrated upwards and downwards as a function of Quaternary fluctuations in temperature and precipitation. During the Late Pleistocene, small ice-caps and cirque glaciers developed above 3 700 m on the Arussi Mt summits (Potter 1976; Hastenrath 1977), in the Semien Mts (Hastenrath 1974) and on the Balé massif (Messerli et al.1977). This indicates a substantial lowering of the snowline and significant changes in water availability over the highlands.

15.2.3 *Hydrology*

The present lakes fall into two major groups: those which are fed directly by perennial rivers from the highlands and those which depend on groundwater inflows (Gasse & Street 1978a). The first category includes the Awash and Southern Rift lakes. In these basins, periods of surface water surplus and

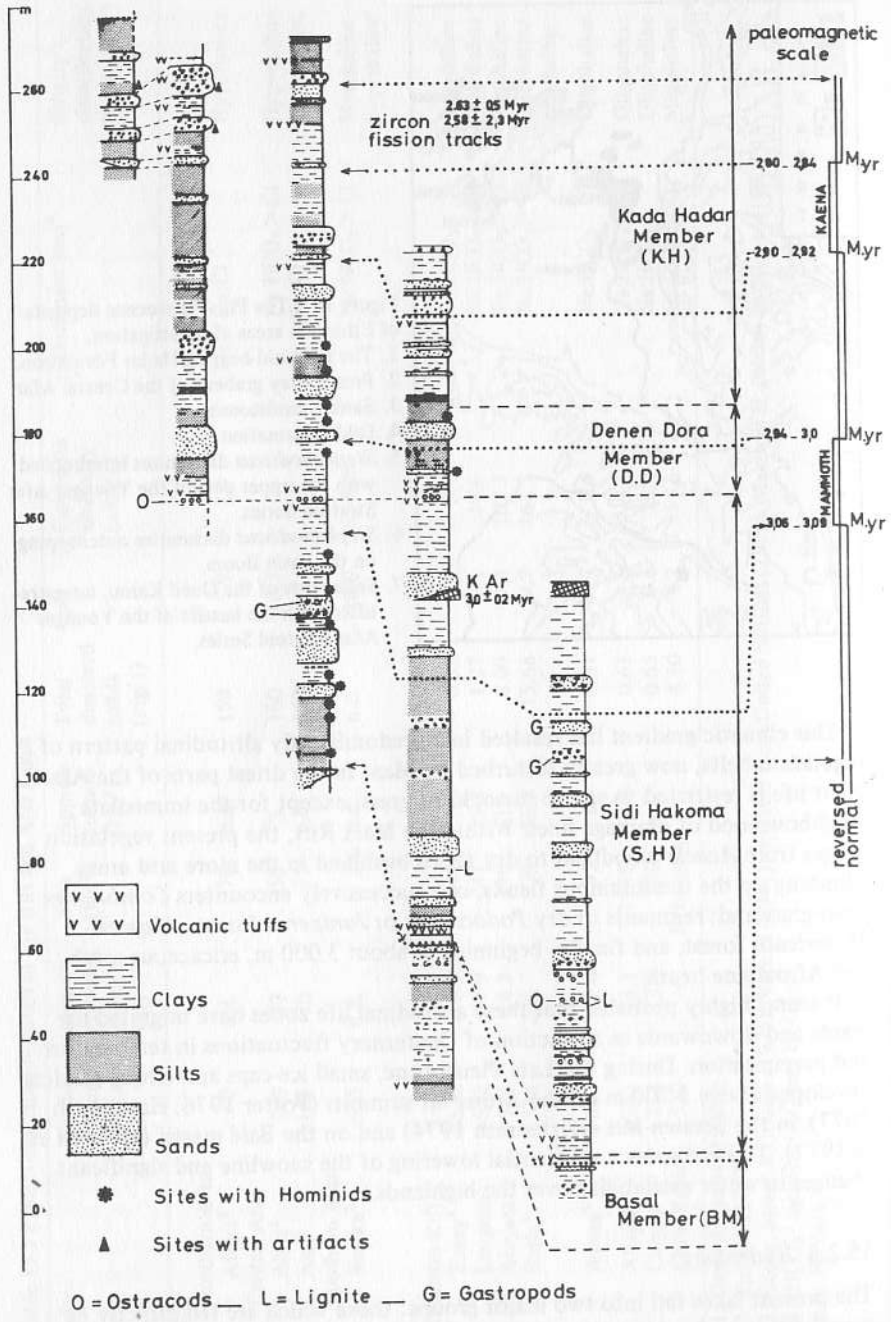


Figure 15.3 Geological sections through the Hadar Formation (from Taieb et al. 1976).

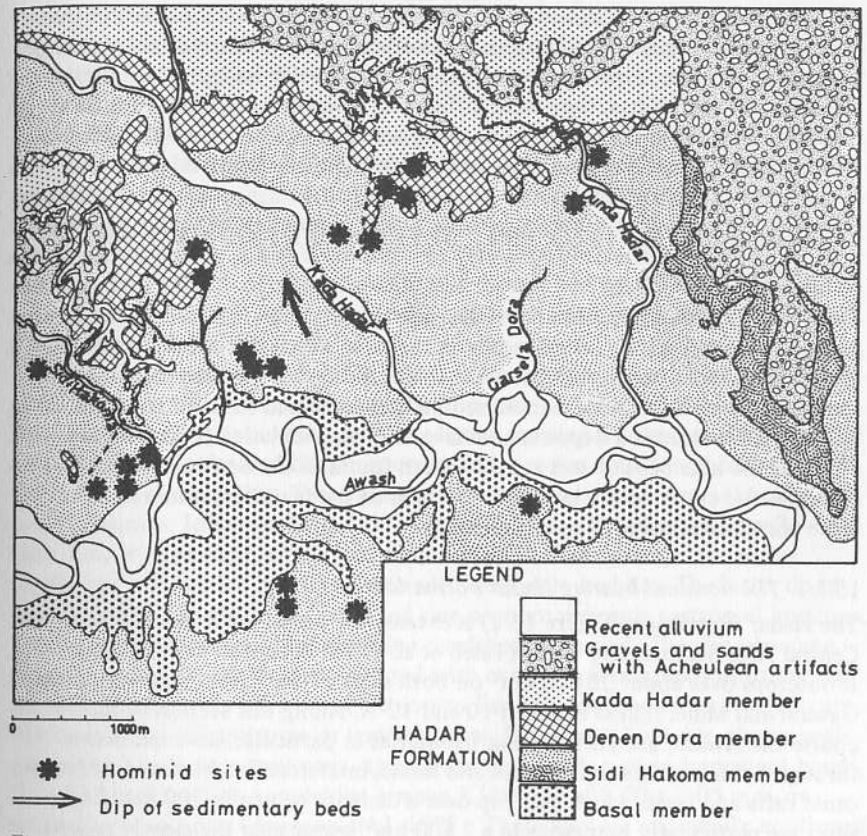


Figure 15.4 Position of hominid sites within the Hadar Formation.

streamflow closely reflect the bimodal rainfall régimes. In the Awash and Ziway-Shala Basins, for example, runoff occurs mainly from March to May and from June to October (Gasse et al. 1974; Makin et al. 1976). Very little reliable data is available from further south despite the existence of major rivers such as the Bilate and the Sagan. In all four basins, overflows from the higher lakes feed the lower ones, which fluctuate sensitively at the present day in response to changing inflows. Similarly, long-term variations in precipitation and evaporation have been amplified by the water-level response of the terminal lakes.

Table 15.1 shows the general tendency for salinity and alkalinity to increase in the direction of the lowest lakes. This trend must have diminished during highstands, when the terminal lakes increased in area until they engulfed lakes further upstream or overflowed across drainage divides.

The groundwater-fed group comprises Lakes Asal, Afrera, Besaka and some palaeolakes such as Hanlé-Dobi. At the present day, the aquifers are recharged by water percolating downwards from the plateaux and escarpment zones. Particularly rapid rates of subsurface flow occur in the Afar basalts because of the

intricate network of faults and open fissures created by crustal extension. But during humid phases of the Quaternary, surface runoff of local origin certainly made a much more important contribution to the water budget of the spring-fed lakes. At such times, they were influenced by both main types of inflow. Asal, Afrera and Besaka are all saline or hypersaline at the present day, and their ionic composition is much more variable than the river-fed lakes.

15.3 THE PLIO-PLEISTOCENE: DEVELOPMENT OF EXTENSIVE LAKES

Since the Plio-Pleistocene boundary has not been defined in Ethiopia, we have grouped together all the lake deposits in the Afar which are interbedded with the younger series of stratoid basalts (4-1 m.y.). Certain undated sediments resting on these lavas show marked sedimentological and floristic affinities with the inter-stratified deposits and have also been included (Figure 15.2).

So far, no lake beds of this age have been found in the Southern Rift. This could be due either to the later development of the main structure or to the more continuous cover of recent deposits.

15.3.1 *The hominid-bearing Hadar Formation*

The Hadar Formation (Figure 15.2) is extensively preserved in the West-Central Afar Sedimentary Basin (Taieb et al. 1976; Johanson et al., 1978). It outcrops over about 20 000 km² on both sides of the River Awash between Gawani and Millé, that is between 10 and 12°N. Along this section of its course the Awash, and its left bank tributaries in particular, have cut down through a thick succession of clays and sands, interstratified in places with volcanic tuffs and lavas, which outcrop over a distance of nearly 200 km. Exposures are particularly numerous in a 2 500 km² sector near the closely spaced confluences of the rivers Gona, Hadar and Ledi (Figures 15.3 and 15.4). At this point the Awash, which flows downstream from Gawani only 15 km from the Ethiopian Plateau, veers away eastward under the influence of its powerful left bank tributaries. The latter have built enormous pediments and fans at the foot of the Ethiopian escarpment, protecting the Hadar Formation from erosion. Recent incision through the gravel capping by the Awash and its tributaries has created such a wealth of exposures that lateral variations in facies within the Hadar Formation can be followed almost continuously. The beds are quasi-horizontal, dipping gently at 2-4° towards the NNW. Younger NNE/NNW faults, which are relatively uncommon here, have throws of 5-30 m at most and do not seriously disturb the continuity of the bedding. Such magnificent exposures are quite exceptional in the Rift and the Afar, and can only be compared with the classic sedimentary sequences of Omo or Olduvai.

15.3.1.1 *Description of the stratigraphic succession* (Figure 15.3). A sequence of four main sedimentary units, with a total thickness of 150-280 m, has been established from the hundred or so sections studied so far. Due to the NNW dip in the Hadar region, the oldest units outcrop to the south of the Awash, which runs E-W. Unfortunately, the upper and lower contacts of the

formation have not yet been observed, because the base is not exposed and the top is always truncated by extensive and much younger Middle Pleistocene pediments. The four members of the Hadar Formation are at present defined by Taieb et al. (1976) as follows:

The Basal Member (BM) has a maximum exposed thickness of about 40 m (according to investigations in 1976). It consists of massive brown clays and grey silts containing small carbonate nodules. Thin intercalations of sand pass laterally into thicker sandstones with a calcareous cement. The detrital sediments are capped by a widespread tuff of very variable thickness: the Sidi Hakoma Tuff (SHT). Attempts to date this marker bed by the K/Ar method, or to relate it to a known phase of volcanism in the Afar, have so far proved abortive (Taieb et al. 1976).

The Sidi Hakoma Member (SH), which is 40-50 m thick in the west, increases in thickness to 130 m eastwards towards the centre of the sedimentary basin. Even here the silty clays with carbonate bands forming the lower half are cut by conglomeratic channel fills or interrupted by major sandstone beds showing marked lateral variability. These sandstones contain abundant animal bones and some hominids. Johanson et al. (1978) interpret them as indicators of a fluviodeltaic environment, which gave way briefly to shallow-water lacustrine conditions represented by clayey silts with carbonate nodules. The latter do in fact include a bed of lignite (SH3) and one or more very rich gastropod horizons. Towards the top, more fully lacustrine conditions returned. The clays become compact, greenish and finely laminated with extensive ferruginous mottling. In the west, close to the foot of the Ethiopian Escarpment, numerous channels are visible as lenses of sandstone or conglomerate. Eastwards, however, clayey sedimentation was more continuous, apart from the eruption of an important basalt flow (2.5 km²), which has yielded a mean K/Ar date of 3.00 ± 0.05 m.y. on unweathered samples (Aronson et al. 1977). These ages are apparently confirmed by the reversed magnetization of the basalt, presumably the base of the Mammoth Reversed Event, which occurred around 3 m.y. according to the authors. At this level, the pig *Nyanzochoerus* also disappears from the fauna, in agreement with the East African evidence (Taieb, personal communication).

The crucial basalt marker bed lies about 20 m below the summit of the Sidi Hakoma Member, which is everywhere delimited by three successive tuff beds (TT 1, 2 and 3). The ashes were deposited in the lake, which had by then probably reached its maximum extent. They are invariably associated with large accumulations of ostracods, presumably as a consequence of the sudden change in water chemistry resulting from the input of pyroclastics (Johanson et al., 1978).

The Denen Dora Member (DD) displays very homogeneous lacustrine facies throughout the region, except in the extreme west. The sediments are 30-40 m thick, tending to revert to regressive facies near the top, where palaeosols with root casts indicate phases of low lake level, and the deposits again become rich in animal and hominid bones. During this period of partial emergence, the 20 to 40 cm-thick Kada Hadar Tuff, which forms the upper limit of the DD Member, was deposited.

The Kada Hadar Member (KH) is characterized near its base by a distinct but

shortlived lacustrine transgression, during which finely laminated grey to green montmorillonitic clays were deposited. It was a little above the Kada Hadar Tuff that the sandy horizon which furnished the partial skeleton of 'Lucy' (a gracile australopithecine) was found (Johanson & Taieb 1976:295). Despite very intensive investigations in 1976, which brought to light 17 hominid fragments in situ in a neighbouring section, Lucy's exact stratigraphic position could not be established.

This uppermost member of the Hadar Formation is 30 to 80 m thick. It again comprises silty clays with carbonate nodules, but these are frequently intersected by lenses of fluvial sands and conglomerates, signs of frequent emergence. The unit ends yet again with volcanics (ashes, tuffs), laid down at a time when fluviodeltaic sedimentation was rapidly gaining ground eastwards (Johanson et al., 1978). But the Hadar Formation is now sharply truncated at the top by an erosional disconformity, overlain by extensive sheets of cobble-gravel dating from the Middle Pleistocene.

According to Aronson et al. (1977) the lacustrine episodes recorded within the Hadar Formation fall within the period between 3.3 and 2.6 m.y. An ash bed near the top of the Kada Hadar Member has recently been dated at 2.63 ± 0.04 m.y. by K/Ar and at 2.58 ± 0.23 m.y. by the fission-track method (Aronson et al. 1977).

15.3.1.2 *Palaeontologic and palaeogeographic importance: one of the richest fossil hominid localities in the world.* Following the 1976 expedition, more than 30 hominid-bearing beds have been discovered within the Hadar Formation (Figure 15.4). In particular, the occurrence of *Australopithecus* with some of the earliest remains attributed to *Homo* justifies the considerable interest aroused by this region, and by the increasingly detailed investigations in the upper part of the formation, especially in 1976-77. These systematic searches led to the finding of three levels with prehistoric artifacts (fractured pebbles, cores, flakes), which could be the most ancient human 'tools' known (estimated age 2.6 m.y.). In addition, the discovery of such an impressive variety of bones, and even a partial skeleton (Lucy) has significantly extended existing knowledge of the anatomy and behaviour of Early Man, and hence of his biological evolution.

The fauna recovered is typical of the savanna regions or of light forest. Elephant remains are extremely abundant: an almost complete skeleton was excavated in 1976. Hippo and rhino, which include a very distant ancestor of the present white rhino (*Ceratotherium simum*), are very common, as are the bovids (the most widely distributed forms), *Hipparion* spp. (including one new species, *Hipparion afarense,* but not *Equus,* given the antiquity of the fauna), the suids and several monkeys. Carnivore remains (canids, hyaenids, a giant weasel and a very primitive otter) are scarcer, as would be expected. And lastly, the rodents have proved of great assistance in the detailed reconstruction of microenvironments.

Along with this terrestrial fauna there are numerous signs of an aquatic fauna (crocodiles, turtles, crabs, gastropods, lamellibranchs, ostracods, etc.). These are associated with the lacustrine and swamp facies.

The Plio-Pleistocene lake may have been initiated by volcanic blockage of the drainage from the Ethiopian Escarpment (Walter et al. 1977). It must have shown certain similarities with present-day lakes of the Sudan and Sahel zones. The deposits of montmorillonitic clay with calcareous nodules recall the modern fluviodeltaic sedimentation in the seasonally flooded plains south of Lake Chad. The coarser-grained character of the channel deposits reflects the proximity of the main Ethiopian Escarpment, but also implies a climate rather on the dry side, since basaltic rocks are generally very susceptible to weathering in a humid tropical climate.

The essentially detrital sedimentation in the Hadar region contrasts with the thick contemporaneous accumulation of volcanics, especially ignimbrite, in the Southern Rift, and with the outpouring of flood basalts in the axial zone of the Afar Rift between 4 and 1 m.y. The protected location of Hadar, on the flanks of the active volcanic sectors, resembles the earlier situation of the Mio-Pliocene Chorora Basin (9-10 m.y.) in the southeast corner of the Afar.

15.3.2 *Plio-Pleistocene lacustrine episodes in the Afar Rift*

Exposures of lake sediments in the Afar Rift are never as deep and extensive as in the West-Central Afar Basin. But the Plio-Pleistocene beds there certainly span a much longer time period than at Hadar, although radiometric dates are still relatively sparse (Gasse 1975).

15.3.2.1 *Fluviodeltaic environments: the Sankal sandstones* (Figure 15.2). In the SE Afar Rift, SW of Dikkil, a clastic succession several tens of metres thick rests on flood basalts which have been dated further south at 4.3 m.y. The deposits are locally capped by a thin basalt flow, probably belonging to the Younger Afar Stratoid Series (4-1 m.y.). Their stratigraphic position is therefore rather similar to the Hadar Formation, which lies above the Older Stratoid Series (7-4 m.y., Varet 1973) and only includes occasional later basaltic flows. However, at Sankal the facies are more definitely fluviatile; quartzose cobbles and sands, silts and clays. But successive sections measured over a distance of several kilometres reveal a northwards trend in grain-size towards lake-marginal facies. At the same time as the sandstones become organized into palaeochannels, a clayey sand facies with occasional coquinas and stromatolites develops. Just like Hadar, these more deltaic deposits contain vertebrate bones, which have not yet been studied.

The main interest of the Sankal formation lies in its demonstration that this region, which is now greatly broken up by faultscarps, was nearly flat at the time. In fact the sandstones contain pebbles and a heavy mineral suite derived from the basement and Mesozoic rocks which outcrop in the Aïsha Horst, several tens of kilometres to the south of Sankal. Today the two areas are separated by numerous faultscarps. Evidently an almost uninterrupted slope stretched from the Southeastern Plateau to the centre of the Afar Rift during this period.

15.3.2.2 *Trend towards increasing desiccation: the Dikkil formation.* East and south of Dikkil, lacustrine sediments about 20 m thick outcrop over an area of

more than 300 km² (Figure 15.2). This 'Dikkil formation' consists of clays and diatomites which pass upwards into gypsiferous deposits. The lake-beds rest on a basaltic boulder-conglomerate of local origin (unlike the Sankal sandstones), underlain by strongly weathered basalt. Several metres of grey lacustrine clays at the base are quite rich in diatoms. The flora already indicates a fairly deep lake. Freshwater conditions probably prevailed despite the presence of a few species which can tolerate brackish waters.

These clays are overlain by several metres of diatomite, characterized by a flora with high dissolved salt requirements and an ability to tolerate wide fluctuations in salinity. The diatomaceous facies gives way to increasingly gypsiferous clays and finally to a thick gypsum crust; an excellent local marker bed. The upward passage into evaporites can probably be interpreted in climatic terms, perhaps corresponding to the period of increasing aridity between 2.5 and 2 m.y. demonstrated by studies of pollen (Bonnefille 1976a) and small rodents (Jaeger & Wesselman 1975) in the Omo Basin.

Sediments with comparable facies and diatom associations have been found in several places in the Central Afar. The similarities with the Dikkil formation are particularly marked in the case of the sediments exposed on the east side of the Gaggade-Der Ela graben. But here the deposits are covered by thin scoriaceous basalts of the Younger Afar Stratoid Series and are tilted SW. If this correlation is confirmed, it means that the recent flood basalts were not poured out uniformly over the Afar Rift, but rather along preferred axes which varied through time. It is worth noting in this connection that the Dikkil formation stretches for more than 50 km along the most marginal graben with respect to the Afar Rift structure.

15.3.2.3 *Development of freshwater lakes: the 'Villafranchian' diatomites.* Another type of ancient lake, with very different ecology from the preceding ones, is represented by thick, and often very pure, diatomites which are found in many parts of the Central Afar (Figure 15.2). At Maydalala these appear to overlie the Dikkil formation (Gasse 1977b). Their flora is characterized by an archaic association dominated by *Stephanodiscus* spp. (*S. niagarae, S. transylvanicus, S. carconensis*). The time-stratigraphic range of these species on a world scale suggests a 'Villafranchian' age for the deposits, quite possibly more than 1.8 m.y. (Gasse 1977b).

In fact these 'Villafranchian' sediments record more than one single transgression. In a section of diatomite in the Der Ela graben, for example, three successive phases can be distinguished using sedimentological and floristic criteria. Other sections, which have not yet been studied in detail, prove that climatic fluctuations during this period were even more complex. It is worth noting the presence of temperate or cold species such as *Stephanodiscus niagarae, Cocconeis disculus, Navicula tuscula*, etc. in the most diatomaceous facies. These indicators of cooler temperatures would support a 'Villafranchian' age, since this period has been defined on the basis of the first significant drop in temperatures in the northern hemisphere.

At present it is still difficult to reconstruct the palaeogeography of these lakes, because their deposits have been greatly disrupted by a later phase of tectonic activity. The outcrops of *Stephanodiscus* diatomites are sometimes situated on the basin floors, where they are not covered by basalt, and sometimes interstratified in the upper part of the Younger Stratoid Series, where they occur perched on top of the horsts which delimit the modern basins (Figure 15.2). These remnants are separated by vertical displacements of up to 300 m or more. However, the widespread extent of this episode in the Central Afar implies that the topography at that stage was still relatively subdued, and that the main faults bounding the present horsts and grabens came into being at a later date (Gasse, Rognon & Williams, m.s. 1976).

15.3.2.4 *Tentative correlation with the sedimentary deposits of the Oued Kalou.* South of Lake Asal, an important sequence of alluvial and lacustrine deposits exists in the Oued Kalou (Clin et al. 1974) (Figure 15.2), interstratified with the basalts of the Younger Afar Stratoid Series. The sediments rest on a basalt flow dated at 2.4 m.y. and are capped by a basalt flow forming the horizontal summit surface and dated at 0.8 m.y. So they fall into the same Plio-Pleistocene time-range as the lake sediments described in the two preceding sections.

During this long period over 220 m of silts and clays accumulated. They contain intercalations of sand and a few conglomerate beds which are particularly common near the base. The presence of diatomites at two or more levels in the section (one in the lower half and the other near the top), indicates that this sector was occupied at least twice by a lake. Lacustrine or swampy conditions are confirmed by other palaeontological evidence (the remains of fish, ostracods, fresh – or brackish – water mollusca, turtles, crocodiles, and hippo). But there is also clear proof that the lake did not cover the area throughout, since two well-developed palaeosols are found at the top. In addition, this section has yielded a varied vertebrate fauna of swamp-dwelling animals, *Elephas recki*, and suids, and even a very primitive stone industry. It may represent an important landmark in the palaeogeographic evolution of the Afar, but no detailed study of the material has so far been published.

The Plio-Pleistocene evidence is therefore preserved in two contrasting areas. In the Hadar region of the West-Central Afar, the extent of exposures spanning the period 3.3-2.6 m.y. has permitted very detailed palaeogeographic reconstructions similar to those made at East Rudolf and Olduvai. Within the Afar Rift, the greater continuity of volcanism has favoured preservation of the deposits of much more varied, but far less extensive, lacustrine episodes.

15.4 THE MIDDLE PLEISTOCENE: EVOLUTION OF THE MODERN DRAINAGE NETWORK

Very little is known at present about this period, which extends from the imprecisely defined limits of the 'Villafranchian' up to the Riss-Würm interglacial. It was a time of great tectonic instability and continuing volcanism in both rifts. Thus in the Southern Rift, the main escarpments bordering the present graben developed around 1.8-1.6 m.y. ago (Meyer et al. 1975), and major calderas,

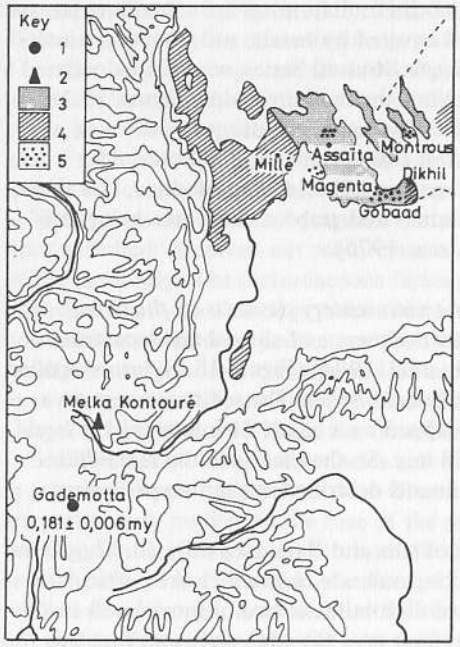


Figure 15.5 The Middle Pleistocene deposits of Ethiopia: areas of investigation.
1. MSA archaeological sites on Gademotta: shoreline remnants.
2. Archaeological sites at Melka Kontouré: fluvial deposits and terraces.
3. Present-day grabens of the Central Afar.
4. Alluvial fans and pediments (Central and Southern Afar).
5. Aeolian sands (Central Afar).

such as Gademotta Ridge, were formed around 1.05 m.y. or shortly after (Laury & Albritton 1975). In the Afar, the topography was greatly modified, and the ancient lake basins were drained and fragmented (Rognon & Gasse 1973). At the moment neither rift has yielded traces of extensive lakes which definitely fall within this period. The only possible exception is the lake which bordered the Gademotta Caldera towards the end of the Middle Pleistocene (Wendorf & Schild 1974; Wendorf et al. 1975; Laury & Albritton 1975) (Figure 15.5). Excavations of four Middle Stone Age living sites on the outer flanks of the caldera, which is situated in the Ziway-Shala Basin near the western shore of Ziway, yielded the first proof, in the form of hippo bones within a channel fill, of the existence of permanent water (probably the ancestral Lake Ziway) nearby. The fill has been tentatively correlated with the oldest occupation level, dated at 0.181 ± 0.006 m.y. by K/Ar on sanidine from an adjacent tuff.

Traces of an important phase of gully erosion, followed by aggradation, occur higher in the sequence, just below a second tuff dated at 0.149 ± 0.013 m.y. Laury & Albritton (1975) attribute the cut and fill cycle to increased surface runoff, followed by a rise in lake-level. Their argument gains some support from the presence of rhyolitic beach pebbles contouring the ridge at altitudes ⩾100 m above Lake Ziway. Unfortunately the stratigraphic position of these gravels remains ill-defined, and several further problems of interpretation arise. Incision could equally well have resulted from a fall in lake-level, as it did during the terminal Pleistocene and late Holocene (Gasse & Street 1978a). However, the inter-linkages between climate, vegetation and gully incision are very complex,

and do not lend themselves readily to simple climatic interpretations (Cooke & Reeves 1976). The elevation of the ancient beach ⩾65 m above the present drainage divide to the north, implies substantial warping of the Rift floor. Furthermore, the K/Ar dates themselves remain highly controversial, since they revise most previous ideas on the antiquity of the MSA tradition (Wendorf et al. 1975).

Apart from Gademotta, we have no absolute chronology from this period at our disposal. The succession of events remains based on palaeontology and prehistory, so that dating is often hypothetical (for example the lower limits of the Acheulian and the Middle Stone Age). It is therefore difficult to fit the scattered traces of the Middle Pleistocene into a reliable framework. The deposits originate in the main from sheetwash, river or aeolian activity. Such variations in process probably reflect climatic fluctuations as well as tectonic instability. Even though this period was seemingly unfavourable for the development of lakes, it is of interest here for an understanding of the origins of the present relief and drainage network.

15.4.1 *The fluvial deposits and terraces at Melka Kontouré*

Melka Kontouré lies just at the crest of the western escarpment of the Main Rift at 2 000 m above sea level and 150 km downstream from the sources of the Awash (Figure 15.5). The upper valley had already assumed roughly its present form by the Middle Pleistocene. The discovery of numerous stratified archaeological sites has allowed the only detailed climatic sequence for this period to be established by means of pollen studies (Bonnefille 1976b; Chavaillon 1976).

Prior to the Middle Pleistocene, the climate of the Oldowan levels (Gomboré IB and IC) tentatively ascribed to around 1.75-1.6 m.y. is believed to have been moister and relatively cool. Although the local vegetation must have been light montane forest (more than 55% of Gramineae pollen), the most strongly represented trees (4/5 of the arboreal pollen) are *Podocarpus* and *Juniperus.* The humid character of the climate is confined by the great abundance of hippo in the fauna.

During the Middle Pleistocene there was a marked decline in montane forest species, whose present lower limit lies around 2 500 m. *Olea, Juniperus* and *Hagenia* totally disappeared. A few *Podocarpus* remained, but the arboreal flora consisted essentially of *Acacia* and *Combretum.* Chenopods increased and the percentage of Gramineae lay around 75-80% of the total. The overall impression is one of very thinly wooded savanna. These warmer and drier tendencies are more pronounced in some levels than others.

During the Developed Oldowan occupation (Garba IV, around 1.5-1.3 m.y.) the trend towards increasing aridity was already clearly evident in the fauna. Antelope were very frequent and equids common, whereas hippo became rare.

During the Middle Acheulian period the first remains of *Homo erectus* appear at site Gomboré II around 0.7 m.y. (Schmitt et al. 1977), in association with abundant hippo, large bovids, giraffe and numerous equids. The climate became moister, and a full *Acacia* savanna developed. This is confirmed by the pollen assemblages from the Garba II, and above all, Gomboré III levels.

Finally, during the Late Acheulian (around 0.2-0.3 m.y.?), the climate again became considerably drier than at present, based on the pollen from Garba I.

According to the curve presented by Bonnefille (1976b:72), the moist periods of the Oldowan and Acheulian were similar to the present, and much less humid than the Late Pleistocene wet phase around 40 000 B.P. The majority of the Middle Pleistocene was therefore much drier than the present.

The gravels transported by the Awash during this period often consist of cobbles. Terraces of very coarse material line the whole course of the Awash. The river descends into deep gorges at Koka and above Awash Station. In the lower gorge, a high terrace attributed to the Middle Pleistocene lies some 60 m above the bed, with a well-developed middle terrace at ca. 40 m (Taieb 1974: 213). The latter has yielded a few artifacts including a pebble-tool.

15.4.2 *Alluvial fans and pediments in the Afar*

Below the mouth of the gorge at Awash Station, the Awash constructed an enormous alluvial fan, more than 5 km long, during the course of the Middle Pleistocene (Taieb 1974:75). Today this fan is perched more than 30 m above the river-bed. It consists of large accumulations of cobbles, 10-15 m thick, resting on 10-15 m of finer-grained deposits. According to boreholes drilled at the distal end of the fan, the total thickness of silts, sands and cobble-beds is of the order of 100 m. But no means of dating them is available.

In the Western Afar, to the west and especially to the north of Hadar (11-12°N), the foot of the Ethiopian escarpment is bounded by enormous stepped pediments, covered by coarse gravels. These were first described by Büdel (1954), who attributed them to the Middle Pleistocene. Later work by Roubet & Taieb (1976), who found numerous Acheulian artifacts, has confirmed his dating. The tools have always been found close to the surface, but it is clear from the sections that several beds of cobbles occur in alternation with ash-beds, and rest disconformably on lacustrine deposits of Plio-Pleistocene age (Taieb 1974:288-298). The very poor sorting of the interbedded sands reflects deposition by infrequent flash floods, and rapid rates of erosion in the headwaters. Today these gravel sheets define an old erosion surface descending from the mountain-front towards the Afar, and perched some 25-30 m above the modern streams.

Extensive gravel spreads lying well above the present channels are also found on the margins of the Afar Rift, in particular north of the Gulf of Tadjurah where they cover vast areas, and in the south, on the southern side of the Dikkil Basin, where there is a series of staged pediments of polygenetic origin. Here again Acheulian artifacts have been found in situ in the overlying deposits.

Pediments and related fan-gravels of Middle Pleistocene age have not so far been described from the Main Rift south of the Awash catchment. Possibly this results from a lack of information, but it could also reflect emerging climatic contrasts between the Afar and the Rift. Traces of a former gravel spread may, however, occur within the Rift at the north end of Lake Langano (Gèze, personal communication 1975). Abundant evolved Acheulian bifaces were found in an isolated outlier of deeply weathered basaltic cobble-gravels, perched on the

eastern rim of the O'itu caldera (Figure 15.5). The lithology and westward dip of the deposit suggest a source on the present plateau (E.F.Lloyd, personal communication 1975). Major graben subsidence has clearly occurred along the Wonji Fault Belt to the east in the 0.2-0.3 m.y. since Late Acheulian hunters occupied the Rift (Wendorf et al. 1975; Clark 1975).

The Middle Pleistocene begins to emerge as a time in which the basic elements of the present relief were shaped. During this period the Awash cut its major gorges, while the escarpments further down-stream were effectively eroded and their debris spread over vast pediment surfaces. One might imagine these processes taking place under a humid climate. However, the downcutting along the gorges merely implies high flood discharges armed with a heavy bedload of cobbles, and the action of very intense but infrequent rainstorms would suffice to cut the pediment surfaces. So there is no contradiction between this picture of 'rapid' topographic evolution and the indications of drier climatic conditions at Melka Kontouré. Middle Pleistocene aridity was also expressed in the occurrence of extremely arid conditions at lower altitudes in the Afar Rift, although these are still poorly dated.

15.4.3 *The accumulation of aeolian sands in the Afar Rift*

On the distal margins of the pediments the Middle Pleistocene is represented by finer and essentially sandy sediments. Like the Plio-Pleistocene lake-beds at Dikkil, the sands are chiefly preserved between Gobaad and Magenta in the basins furthest from the axis of the Afar (Figure 15.5). Chronologically, they postdate the Dikkil formation and predate the Late Pleistocene lacustrine transgression. They therefore clearly belong in the Middle Pleistocene (Gasse 1975:115-120).

In thickness, these sands range from 2-3 m up to 10 m. Beginning with fluvial deposits at the base (coarse sands and pebble-beds), they pass upwards into very characteristic aeolian facies with excellent sorting about a modal diameter of 125-200 μm. They accordingly reflect the transition from sheetwash deposition under semi-arid conditions to a dune-building episode. As they contain abundant mammalian bones (*Elephas recki, Hippopotamus gorgops* etc.), this suggests that the aeolian phase was interrupted by moister episodes when a savanna habitat (suited to equids, rhino and antilope) dotted with expanses of swampland, was re-established.

Besides their distribution on the southern margins from Gobaad to Magenta, wind-blown sands also occur in the centre of certain basins. In general their grain-size distribution is typically aeolian. But near Assaïta, the sands are capped by a carbonate horizon, again containing a mammal fauna in association with mollusc species typical of deep tropical lakes. The existence of permanent water is confirmed by remains of silurid fishes, crocodile and hippo. Beds of fine quartz and basalt gravel near the top indicate that alluvial fans were still supplying clastic sediment to the centre of the basin. It seems that at Assaïta the erg was invaded by marshes during the final, more humid, phase of its existence. More recent analogues of these interdune deposits are widespread in the Saharan ergs (Rognon 1967; Conrad 1969). The fauna does not provide a precise age, but the presence of the antelope *Tragelaphus* sp., a true *Phacochoerus* and a

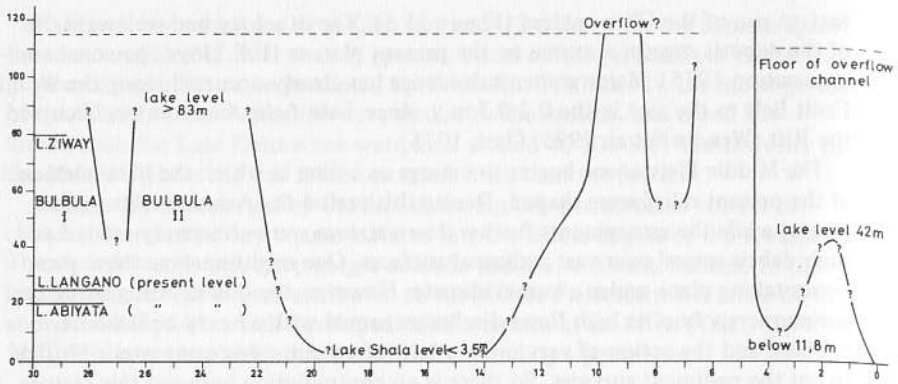


Figure 15.6 Late Quaternary lake-level fluctuations in the Ziway-Shala Basin (Main Ethiopian Rift) (from Gasse & Street 1978a). Vertical axis is metres above Shala datum; horizontal axis is ^{14}C age in thousands of years.

tetraprotodont hippo indicates that it is distinctly more recent than that at Hadar.

Finally, in the Gaggadé-Der Ela Basin, the Oued Montrous formation begins with about 10 m of aeolian sands, overlain by fluvial sands, and passing upwards into gypsiferous lacustrine clays. This thick succession (50 m) rests disconformably on 'Villafranchian' lake-beds, and is covered by lacustrine sediments of Late Pleistocene age. Research currently in progress will provide a much more detailed picture of Middle Pleistocene palaeogeography.

15.5 THE LATE PLEISTOCENE: SUCCESSIVE LACUSTRINE HIGHSTANDS

The Late Pleistocene is better known than the preceding period for the good reason that for the last 40 000 years at least, the chronology is firmly based on ^{14}C dating. Only the ancient lakes of the Central Afar (Gasse 1975, 1977a; Gasse & Delibrias 1977) and the Ziway-Shala Basin (Grove et al. 1975; Street in press) have so far given rise to detailed investigations. These have enabled us to correlate the principal episodes in the evolution of both sectors (Gasse & Street 1978a, b). On the other hand, the scattered results from the Southern Afar fit quite neatly into the same pattern. The Late Pleistocene is thus the earliest period for which it appears valid to derive a climatic sequence from the lake-level fluctuations, with some confidence that the climatic record has not been obscured by volcanicity or tectonism.

15.5.1 *The Central Afar and the Southern Rift*

The limnological evolution of the Afar and the Southern Rift has mainly been reconstructed from two type sections which represent almost continuous sequences (Figures 15.6 and 15.7). In the Central Afar, a 50 m core from the edge of the present Lake Abhé (Figure 15.8) has revealed the succession of habitats in the centre of the basin. Three lacustrine highstands, named respectively Abhé I,

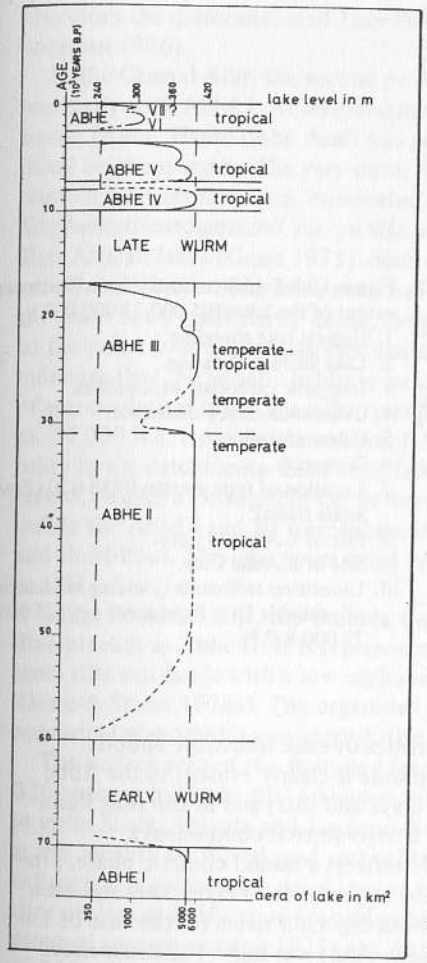


Figure 15.7 Late Quaternary lake-level fluctuations of L.Abhé (Central Afar) (from Gasse 1977a).

Abhé II and Abhé III are seen to have occurred. In the Main Rift, the 30 m-thick type section 0738-B20 is located along the gorge of the River Bulbula, between Lakes Ziway and Abiyata. Its base lies at 42 m above the present terminal lake (Shala). Two lacustrine episodes, Bulbula I and Bulbula II, have been demonstrated. Although correlations between the lower part of these two sections remain hypothetical, the correspondence of phases Abhé III and Bulbula II is firmly established by radiometric dates. In both regions the extent of successive lakes and the vertical amplitude of their regressions have been inferred from the study of several marginal sections. In the case of the Central Afar, the history of Lake Abhé (Figure 15.7) can be matched with that of the adjacent grabens (Hanlé-Dobi, Asal). Since the details of the sedimentological analyses and diatom floras have already been published in the papers cited, the following

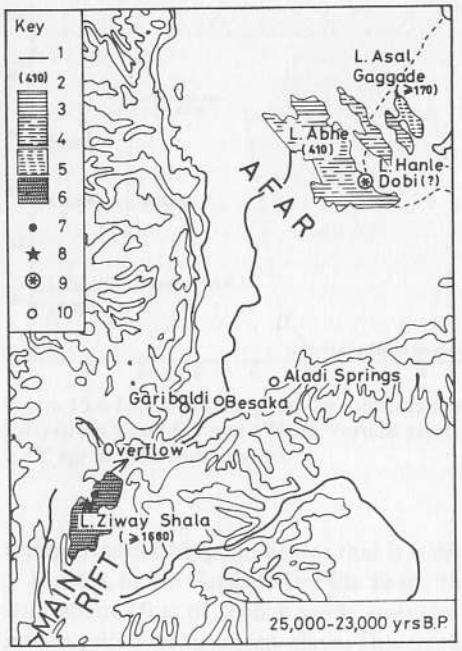


Figure 15.8 Evidence for the Late Pleistocene extent of the lakes (25 000-23 000 B.P.).
1. Highest lake shoreline.
2. Lake surface elevation.
3. Inorganic carbonate precipitates.
4. Calcareous clayey diatomite.
5. Calcareous silts.
6. Diatomite.
7. Location of type section 0738-B20 (Ziway-Shala Basin).
8. Site of L.Abiyata Core.
9. Site of L.Abhé Core.
10. Lacustrine sediments (yielding MSA artifacts), of probable Late Pleistocene age (25 000-23 000 B.P.?).

summary is limited to the main characteristics of each lacustrine episode.
In the Central Afar, the first lacustrine episode is clearly evident in the Abhé Basin (where it is chiefly represented by clays and silts) and in the Asal Basin (where it is recorded by diatomites with a large detrital component).

In the Afar at large, the Abhé I episode reflects a humid climatic phase, probably with an irregular rainfall regime. The importance of clays, silts and even sands shows that sediment transport by both highland rivers (in the case of Lake Abhé) and local streams (in the case of Lake Asal) was high. Their suspended load was carried right to the centre of the lakes, which were consequently turbid. During the time of highest level, the planktonic diatom floras reflect tropical conditions. The plankton in LakeAbhé was rich in *Nitzschia aequalis* and *N. stricta*. *Melosira agassizii* var. *malayensis* is dominant in the Asal diatomites.

The Abhé I episode was followed by a phase of desiccation which is recorded in the centres of the basins by fluvial sands, and on the margins by extensive pediments with a thin sedimentary cover.

In the Southern Rift, the existence of deposits older than Bulbula I is evidence for a lacustrine phase of presumed lower Late Pleistocene age, although its equivalence to Abhé I remains entirely hypothetical. A very finely laminated diatomite, 6 m thick, outcrops on the NE side of Lake Shala below the silts and diatomites of upper Late Pleistocene and Holocene age (Grove et al. 1975: Figure 6). It rests on a pumice bed, draped over an ignimbrite flow which appears too young to be dated by the fission-track method. Since zircon has been used elsewhere to date rocks as young as 0.1 m.y. it is likely that the ignimbrite, and

therefore the diatomite, is of Late Pleistocene age (F.J.Fitch, personal communication 1976).

In the Central Afar, the second or Abhé II lacustrine highstand contrasts quite markedly with Abhé I. At lake maximum, sedimentation in the Central Afar basins (Abhé, Hanlé-Dobi, Asal) was purely biogenic in mid-basin but biochemical on the margins. The very pure, finely laminated deepwater diatomites contain a planktonic flora, dominated by *Nitzschia aequalis, N. stricta* and *Stephanodiscus hantschii* var. *pusilla,* and rich in species endemic to the large East African lakes (Gasse 1975). Such a community is characteristic of very transparent waters. The rains must have been sufficiently fine and regular, or the plant cover sufficiently dense, for the clastic load of streams to be reduced to the point where only dissolved material entered the lakes. The diatom flora indicates that the aquatic habitats were distinctly alkaline, very productive and of warm tropical type. The subsequent regression can be accurately situated at ca. 31 000 B.P. from the Abhé core. It marks a breakdown of geomorphic stability in the catchments. Lake level fell and the waters became more concentrated, despite a perceptible fall in temperatures (Gasse & Delibrias 1977). But unlike the Abhé I and III regressions, the drop in level in Lake Abhé was partial and short-lived. The lake never dried up completely between Abhé phases II and III.

In the Southern Rift, the Bulbula I episode may possibly fall within the same time-bracket as Abhé II. It is represented in the type section by reworked volcanic silts and sands with a low carbonate content, typical of inshore conditions (Gasse & Street 1978a). The organisms present (diatoms and ostracods with only occasional planorbids) also suggest littoral, brackish waters.

The surface area of the Bulbula I lake is unknown. However the height of the B20 outcrop indicates that lake-level reached at least 1 605 m, which is sufficient to unite Shala, Abiyata and Langano into a single lake. The regression is recorded at this locality by fluvial sand and pebble-gravel which truncate the lacustrine sediments. A palaeosol is developed in the uppermost 20 cm of the sand. It contains abundant artifacts of probable early Late Stone Age type (H.Kurashina, personal communication 1975) and dispersed charcoal fragments dated at 27 050 ± 1 540 B.P.

Traces of the third or Abhé III lacustrine episode are found in all the main grabens in the Central Afar. Thirteen radiocarbon dates obtained from the Abhé and Hanlé-Dobi Basins range from 27 000 to 17 000 B.P. The maximum extent occurred between 25 000 and 23 000 B.P. (Figure 15.8).

During the Abhé III episode, lake-level reached 410 m, the highest elevation it attained during the Late Quaternary. However, the sedimentation always remained largely detrital (calcareous clayey diatomite in the centre of Lake Abhé, diatomaceous silts in Hanlé-Dobi, calcareous silts in Asal). The climatic régime was therefore very different from Abhé II; more like Abhé I, in fact. We believe that the rivers feeding the lakes were subject to intense flood peaks. The lake waters must have been turbid with suspended sediment, except for certain marginal embayments where chemical precipitation prevailed. Whereas diatoms of temperate and oligotrophic waters (particularly *Cyclotella ocellata*) are abundant at the base of this unit, Lake Abhé supported tropical plankton during the

time of highest lake level, when *Melosira granulata* var. *valida,* accompanied by several other East African *Melosira* spp. (*M. nyassensis* and its variety *victoriae, M. goetziana*) was clearly dominant. But the persistence of temperate elements seems to indicate that their habitat was cooler than either the Abhé II phase or the present day.

Lake levels fell rapidly from 20 000 B.P. onwards. Lake Abhé was dry, or nearly so, by 17 000 B.P. During this regression, silts and marls dominated the sedimentation right to the centre of the basins. In the Abhé core, the diatom flora seems to register a marked drop in water temperatures, as it did during the Abhé II regression. However, the proportion of temperate and cool species remained small, because the rise in salinity during the regression effectively masked the effects of temperature on the diatom flora.

In the Southern Rift, the Bulbula II phase is represented by thick, noncalcareous diatomites in the centre of the basin. On the other hand, the nearshore sediments are quite rich in carbonate. The Bulbula II deposits are dated in the B20 section at 24 000 ± 750 B.P. near the base, and 22 050 ±650 B.P. at 35 cm from the top. In view of the age of the underlying palaeosol, we think that the transgression and regression of the lake at this elevation took place around 26 500 and 21 000 B.P. respectively (Street in press).

The highest lacustrine sediments which definitely relate to this episode outcrop at 1 641 m. Although we have no firm proof, it seems likely that the strandline remnants (calcreted rhyolite shingle) at 1 680 m west of Ziway Town date from this phase. If so, it means that the lake reached 1 680 m – which would be 10 m higher than its early Holocene level, as in the case of Lake Abhé. All four lakes, Ziway, Langano, Abiyata and Shala, would therefore have been united, with an outlet into the Awash and ultimately into Lake Abhé.

The diatom flora, like the mollusca (Gasse & Street 1978a) indicates that the lake was tropical and oligohaline. The *Melosira*-dominated phytoplanton belongs to the same stock as in Lake Abhé III. The two lakes must have had closely comparable water chemistry. This ecological similarity is also met with in the Holocene, and may well be related to the existence of an overflow linking the two systems. However, differences in water temperature resulting from the altitudinal gradient do seem to be reflected by the diatoms. Temperate elements are in fact much more diverse and reach much higher proportions (especially *Cyclotella ocellata*) in the sediments of Lake Ziway-Shala.

Colder conditions again manifested themselves during the regressive phase, judging from the appearance of the palaearctic bivalve *Pisidium subtruncatum* Malm (Gasse & Street 1978a). The Bulbula II regression, like its Abhé III counterpart, appears to have been associated with general cooling.

15.6 TERMINAL PLEISTOCENE ARIDITY

A phase of pronounced aridity followed the episode of very high lake levels. Evidence for accentuated aridity is extremely clear in the Ziway-Shala Basin as well as in the Afar. In the Central Afar the arid phase made itself felt in every basin, whether fed by major rivers from the highlands, by local wadis or by groundwater seepage.

At the Abhé core site, steppe vegetation became established after 17 000 B.P. A soil with a horizon of carbonate accumulation, containing montmorillonite and attapulgite produced by in situ weathering, can be seen between 13.77 and 8.90 m in the core, and proves that Lake Abhé was practically dry. The soil is dated 17 000-16 000 B.P. (Gasse & Delibrias 1977). The overlying volcanic ash and silt (dated at 16 500 ± 400 B.P.) were laid down in a few centimetres of water at the most, judging from the diatom flora. This contains some cool water elements, and is comparable with the uppermost assemblages in the Abhé III sediments.

Laterally, and in the adjacent grabens, the arid episode is recorded by vast scarpfoot pediments, which are covered by several metres of large basaltic blocks and still form an important element in the landscape. These pediments were presumably cut during intense but infrequent local storms (Rognon 1975). The rainfall régime was too irregular for a closed vegetation cover to become established. The presence of fixed dunes north of Assaïta (Figure 15.9), and aeolian sands southeast of Asal, neither of which are firmly dated, however, would argue for an almost complete absence of vegetation in these sectors.

In the Ziway-Shala Basin, a pumice deposit up to 13 m thick separates the sediments of phase Bulbula II from the lower Holocene lacustrine marls and silts. The pumice beds are thought to be ash-fall deposits. Apparently they accumulated on the exposed lake floor under very dry and possibly cold conditions which were unfavourable for pedogenesis. However, the pumices do show traces of reworking by ephemeral streams. So there were a few active gully systems in the Rift during this episode. Observations on the ancient channels allow us to state that Lake Abiyata lay close to its present level towards the end of this period.

The terminal Pleistocene arid interval now emerges as one of the most distinctive climatic events in the Quaternary history of either region. However, it was manifested differently in the Rift from the Afar. Pediments and debris fans developed in many parts of the Afar, whereas in the Rift the characteristic sediments are much finer; mainly air-fall or fluvially reworked pumice deposits.

15.7 INTERREGIONAL CORRELATIONS

15.7.1 *Evidence from archaeological sites*

The archaeological sites in the Southern Afar have not yet been studied in detail from a limnological viewpoint. Because of this, the data is less precise than in the previous examples, and highly scattered. The very characteristic terminal Pleistocene arid phase has nevertheless been distinguished with fair certainty in various localities and seems to form an excellent basis for correlations across Ethiopia.

At Aladi Springs, which is situated at the foot of the Southeastern Escarpment (Figure 15.9), the arid phase is recorded by a sterile gritty brown clay. The clay is directly overlain by a spring tufa containing shells dated at 11 070 ± 160 B.P., and is underlain by 1.5 m of calcareous green clay loam, which fur-

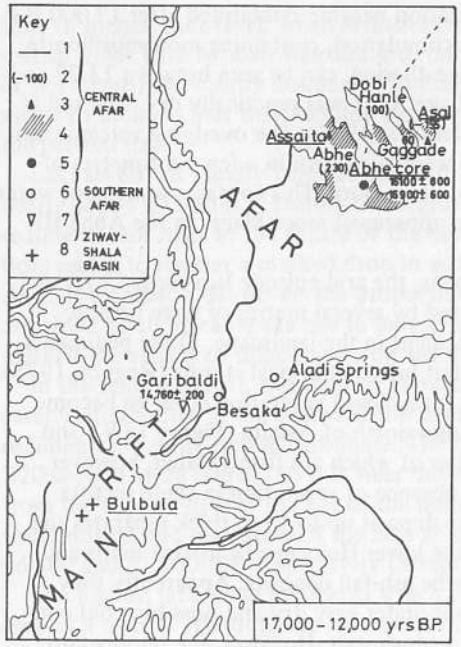


Figure 15.9 Evidence for terminal Pleistocene aridity (17 000-12 000 B.P.).
Central Afar
1. Basaltic escarpments bounding the grabens.
2. Altitude of dried-up or nearly dried-up graben floor.
3. Aeolian sands.
4. Pediments covered by basaltic blocks.
5. Soil with attapulgite.

Southern Afar (non-lacustrine sediments indicating drier conditions)
6. Palaeosols or colluvial deposits.
7. Alluvial loam, dated at 14 670 ± 200 B.P. on ostrich eggshell near the top.
8. Air-fall pumice deposits.

nished abundant artifacts (of later Middle Stone Age affinities) from its upper 10-20 cm. This possibly lacustrine clay loam confirms the occurrence of at least one humid episode during the Late Pleistocene (Williams et al. 1977).

In one of the calderas of the K'one (Gariboldi) complex (Figure 15.9), Clark & Williams (in press) have described the following stratigraphic succession:

The ignimbrite substratum of the caldera floor is overlain by several metres of pyroclastics (silt-sized ash and pumice gravel). On top of these rest 12 m of cracking clays and tuffaceous loams, deposited at the distal end of a low-angle alluvial fan. From the base up, they comprise a brown pedal clay, a palaeosol (Lower Vertisol), a brown loam (Lower Loam), a palaeosol (Middle Vertisol), a brown loam (Upper Loam), a palaeosol (Upper Vertisol).

The Middle and Lower Vertisols yielded Middle Stone Age artifacts, whereas the transition from Middle to Late Stone Age occurs within the calcareous Upper Loam, immediately beneath the Upper Vertisol. A date of 14 670 ± 200 B.P. on ostrich eggshell comes from this loam, which is, therefore, the local manifestation of the terminal Pleistocene arid phase. The Middle Stone Age levels and the Upper Vertisol seem to reflect marshy conditions, more humid than those of the present day (Williams et al. 1977).

Finally, on the margins of Lake Besaka, a small saline lake beside the Middle Awash, diatomites dated at 11 430 ± 380 B.P. and 11 200 ± 160 B.P. rest directly on a palaeosol containing Late Stone Age artifacts (Williams et al. 1977). The latter therefore marks the terminal Pleistocene lowstand. Beneath it again lie fossiliferous lacustrine clays of probable Late Pleistocene age.

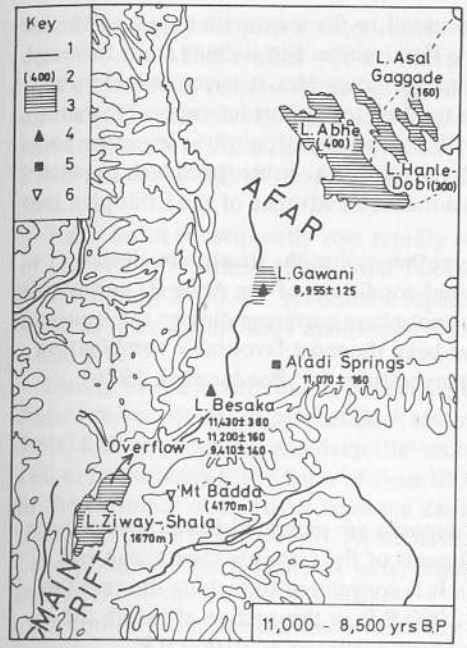


Figure 15.10 Evidence for the early Holocene extent of the lakes (12 000-8 500 B.P.).
1. Highest lake shoreline (9 500-8 500 B.P.).
2. Lake surface elevation.
3. Diatomaceous marl.
4. Isolated ^{14}C date on lake sediments (shorelines not reconstructed).
5. Spring tufa.
6. Mt Badda peat bog.

15.7.2 *The mountain icecaps*

Small icecaps and cirque glaciers developed on the highest Ethiopian summits during the Late Quaternary. In the Arussi Mountains, their moraines have been mapped from aerial photographs (Potter 1976; Hastenrath 1977). We now know that the ice-cap on Mt Badda, which was the most extensive, covered ca. 140 km². On Mt Chilalo (4 005 m), ice covered 19 km². Mt Kakka (4 190 m) and Mt Enkwolo (3 850 m) were capped by smaller glaciers (18 km² and 2 km² respectively). Their development is an important event in the climatic history of the Late Quaternary, but their age remains problematical. We will, however, make some tentative suggestions.

A 3 m-long peat core, collected by A.Street at 4 000 m in a small cirque basin on Mt Badda (Figure 15.10), has yielded a minimum age for the final retreat of the glaciers. The basal 10 cm have been radiocarbon-dated at 11 500 ± 200 B.P. (G.Delibrias, personal communication 1977). The analysis of the pollen (Hamilton 1977) and diatoms (F.Gasse 1978) from the core confirms that the ice had completely disappeared by 11 500 B.P. These results also show that unlike the New Guinea Highlands (Bowler et al. 1976) and Mexico (Heine 1977) the climate of the early Holocene in Ethiopia was unfavourable for glacier readvance despite the return of more humid conditions. The development of glaciers would have required not only heavy precipitation but also substantial cooling compared with the present.

It is not impossible that the icecaps formed during the terminal Pleistocene

arid phase. And this does, in fact, correspond to the maximum extent of the ice-sheets in high latitudes of the Northern Hemisphere. But judging from the very low levels of the lakes downstream from the Arussi Mts, it seems that the precipitation at that time must have been too low to support ice-caps on the summits. There is also convincing evidence for an acceleration of the lower tropospheric circulation on the equatorward margins of the subtropical high pressure belts (Rognon & Williams 1977), which makes an advance of the Ethiopian ice seem even more unlikely.

We therefore suggest, purely as a hypothesis, that the maximum glacial advance occurred during the more humid conditions of the Abhé III episode. It may even have taken place during the cool phase corresponding to the lacustrine transgression. This would seem to have been the most favourable combination of high net accumulation and lower temperatures (cf. Bowler et al. 1976).

15.8 THE HOLOCENE

Throughout Ethiopia, Holocene lake deposits are separated from those of Late Pleistocene age by the distinctive sediments of the terminal Pleistocene arid phase (20 000-17 000 to 12 000 B.P.). It is convenient to include the re-establishment of wetter conditions after 12 000 B.P. in this section although the lower boundary of the Holocene is conventionally set at 10 000 B.P.

The Holocene climatic history of Ethiopia was complex. Conditions fluctuated widely. As a result, detailed regional correlations are often difficult, because the timescale of the fluctuations is of the same order as the standard error of the ^{14}C dates. We are fortunate that the lakes are proving to be sensitive climatic indicators, at least in those areas where limnological studies have been carried out in sufficient detail. However the number of water-level oscillations recorded by individual lakes is dependent to a certain extent on their hydrological régimes (Gasse & Street 1978a, b).

15.8.1 *Lakes fed by surface runoff from the highlands*

The resemblance between the independently-derived lake-level curves for Shala and Abhé is truly remarkable (Figures 15.6 and 15.7). Both lakes expanded rapidly at the end of the terminal Pleistocene arid phase. The precise timing of the rise is difficult to establish. In the Ziway-Shala Basin, ages of 11 870 ± 300 B.P. and 10 450 ± 180 B.P. have been measured on charcoal and soil humus from a palaeosol directly underlying Holocene marls at +56 m (Shala datum) (Street 1978). The basal lake sediments yielded dates of 9 810 ± 170 B.P. in a core from the shore of Lake Abiyata (+22 m) and 10 010 ± 150 B.P. around Lake Shala (+82 m) (Street, unpublished).

In the Abhé Basin, the oldest ^{14}C date on Holocene deposits, which already corresponds to the maximum level, is 9 380 ± 130 B.P. (Gasse 1975). It would therefore seem that the main transgression took place around 10 000 B.P.

The lakes maintained their early Holocene highstand from 9 400 to 8 500-8 400 B.P. During this period Lakes Ziway, Langano, Abiyata and Shala

formed a single lake with a water surface at 1 670 m, 112 m above Shala datum. Lake Abhé reached 400 m, which is 160 m higher than its present level.

A pronounced regression then affected both palaeolakes. Its amplitude exceeded 50 m in Ziway-Shala, and was about 160 m around Abhé. The lacustrine minimum is difficult to fix precisely, but occurred somewhere between 8 400 and 7 600 B.P. in the Abhé Basin and 8 500 and 6 500 B.P. in the Main Rift.

Water-levels subsequently rose rapidly to a second maximum. The high level of Lake Abhé remained stable from 7 000 to 6 500 B.P. A small negative oscillation around 5 800 B.P. preceded a rapid drop from 4 000 B.P. onwards, whereas Lake Ziway-Shala maintained its highstand (1 670 m) from 6 500 to 4 800 B.P.

During the early and middle Holocene, the palaeolakes Ziway-Shala and Abhé evolved almost in parallel. Both became very extensive (2 690 km^2 and ca. 5 500 km^2 respectively) and deep (the increase in surface elevation was 112 and 160 m respectively). The form of their lake-level curves differs somewhat, due to the existence of an outlet from the Ziway-Shala Basin. This explains the truncated peaks (Figure 15.6). As we have suggested for the Late Pleistocene, Lake Abhé received the surplus water from the Ziway-Shala system whenever the latter overflowed into the Awash.

In contrast, the late Holocene was a dry period interrupted only by short humid pulsations. At Lake Abhé, a lacustrine phase dated from 2 700 to 1 000 B.P. culminated around 1 500 B.P., when the water-level reached 310-320 m. The multiple strandlines formed after 1 000 B.P. reflect a very unstable lake-level, which makes it difficult to draw up a meaningful curve. In the Ziway-Shala Basin, relatively fresh shorelines surround the present lakes below 1 595-1 600 m. They testify to a recent transgression which postdates 2 500 B.P. It was insufficient to unite Ziway with the three southern lakes. More recently, the level of Lake Shala has risen to +6 m and fallen again, probably during the last few centuries (Gasse & Street 1978a).

In the Main Rift as well as in the Afar, the lake environments of early Holocene and middle Holocene time were closely comparable. Although local factors clearly had considerable influence, the two large palaeolakes show various common characteristics which seem to reflect regional conditions.

Beyond the influence of wave action, their sediments are typically fine and calcareous. In Lake Ziway-Shala, low-Mg calcite marls or calcareous diatomites were laid down in confined marginal embayments: thin fine-grained clastics (diatomaceous silts and clays) and carbonate precipitates accumulated in deep water. In Lake Abhé, although transgressive and regressive phases are recorded by montmorillonitic clays, precipitation of high-Mg calcite became dominant throughout the lake during the highstands. These facies and deposition rates seem to imply low rates of mechanical erosion in the catchments.

The lakes were oligohaline and very productive during their maxima. The planktonic diatom assemblages are of the same ecological type. In Lake Abhé, there was an almost monospecific population of *Stephanodiscus astraea* var. *minutula*. The deposition rate of *Stephanodiscus* can be evaluated at 50 x 10^8 frustules/cm^2/yr, which is a measure of the high primary productivity (Gasse

1977a). The flora of Lake-Ziway-Shala was more diverse, although *Stephanodiscus astraea* was repeatedly dominant, in association with abundant *Melosira*. Cooler water temperatures than in Lake Abhé, resulting from the higher altitude, are reflected in greater frequencies of *Cyclotella ocellata* (up to 50%) and the presence of several species living preferentially in cooler waters, such as *Cocconeis disculus* and *C. thumensis* for example (C.Descourtieux, personal communication 1977). Around the shores of these large waterbodies, the associations of epiphytic diatoms conjure up a picture of dense aquatic vegetation. A freshwater fauna of sponges, gastropods, lamellibranchs, ostracods, crabs and fish was correspondingly well developed. Freshwater fish were particularly abundant in Lake Shala, which is now saline (Table 15.1).

Such favourable habitats were never to be restored during the late Holocene, although isotopic analyses of littoral carbonates deposited between 2 700 and 1 000 B.P. around Lake Abhé show that its waters were largely of highland origin, as in the preceding episodes (Fontes & Pouchan 1975). But the sedimentation remained clayey or silty in mid-basin. Conditions have deteriorated markedly during the last few centuries, while organisms have tended to die out as the result of an excessive rise in pH and salinity.

After descending the Ethiopian Escarpment, the Awash follows the Main Rift corridor along its foot, entering the vast Gawani Plain, with a mean altitude of 550 m, at about 10°N. The plain is today covered by marshes, principally fed by the flood peaks of the river, and varying seasonally in area from 700 to 1 100 km² (United Nations 1965). Along the edge of the marshy area, outliers of lake sediments (diatomites, shelly sands and limestones, and stromatolites) betray the existence of an early Holocene lake. A date of 8 955 ± 125 B.P. was obtained on *Melanoides* shells collected from one of these outcrops (Taieb 1974: 299). The evolution of the Holocene lake has not been reconstructed in detail. We only know from the lateral extent of the deposits that its maximum level approached 570 m and that its width must have been 20-30 km (Taieb 1974: 303). At the present day, the river suffers significant percolation and evaporation losses along the Gawani floodplain. The magnitude of the seepage losses, due to the permeability of the alluvium and the highly fractured substratum, is responsible for the downstream attenuation of the Awash flood peaks (Gasse et al. 1974).

Similar lakes appear to have existed further upstream at Koka (Lake Galila) and possibly at Wonji (Taieb 1974:230-234), in another present-day zone of groundwater recharge (United Nations 1974:40). During the early Holocene, seepage losses were undoubtedly even more significant. Passage through Lakes Galila and Gawani must have considerably damped the seasonal variations in river flow, which helps to explain, at least in part, the stability of the water-level in the contemporary Lake Abhé. The subsurface waters presumably flowed, as they do at the present day, towards the lowest grabens east of Abhé (Dobi, Hanlé, Gaggade, Der Ela and Asal) which are thus indirectly linked to the Awash system.

We will now turn our attention to the Rift Valley lakes, starting with the Abaya-Chamo-Chew Bahir Basin. Little is known in detail about changing conditions in this southernmost basin of the Main Rift. However it is clear that the

level of the present terminal playa, Chew Bahir, has varied by at least 20 m during the Holocene. Mohr (1962:203) found *Etheria* shells up to 52 m above its floor. Algal stromatolites are well-developed on rocky cliffs and spits up to +20 m, and indicate the past existence of a transparent, oligohaline, and only moderately alkaline, permanent lake. A single radiocarbon date of 5 600 ± 110 B.P., from an *Etheria elliptica* shell (Grove et al. 1975), reveals that the 20 m highstand was contemporary with the middle Holocene maximum of Ziway-Shala and Abhé.

A prominent overflow channel is visible on LANDSAT-1 imagery, running from the south end of Chew Bahir into East Turkana. Although there is no conclusive proof, it appears very likely that the palaeo-lake Chew Bahir overflowed into the expanded Lake Turkana, which had an early and mid-Holocene outlet into the White Nile via the Lotigipi mudflats and the Sobat drainage (Butzer 1976). An integrated network of lakes and rivers therefore linked the present White Nile to the headwaters of the Bilate River on the Ethiopian Plateau (Grove et al. 1975).

15.8.2 *Lakes fed by groundwater*

The spring-fed lakes can be subdivided according to the source area of the underground water. The first group, in the Central and Southern Afar, is fed by circulation through the fissured basalts of the Awash catchment towards the lowest basins. Such is the case for Lake Besaka and the fault-troughs east of Abhé. In the north of Ethiopia, rain falling on the highlands runs mainly towards the Nile. Lake Afrera, situated within the confines of the Northern Afar, depends almost entirely on waters which are recharged along the foot of the Ethiopian Escarpment and then flow towards the centre of the Danakil Depression (United Nations 1973). Afrera is therefore totally independent of the Awash system and represents a second group of spring-fed lakes.

15.8.2.1 *Lakes depending indirectly on the Awash system.*

Lake Besaka lies close to the middle course of the Awash (Figure 15.10). Two Holocene transgressions are evident from the stratigraphy, but their extent and age have not been easy to establish (Williams et al. 1977).

The first lacustrine phase is recorded by silty diatomites, dated on shell at 11 430 ± 380 and 11 200 ± 160 B.P. (Williams et al. 1977). A further measured age of 9 410 ± 140 B.P., on apparently reworked *Melanoides* shells collected from the overlying clay unit, probably refers to the same episode (Williams, personal communication 1977). The water level must have risen at least 10 m above its January 1974 level (Williams et al. 1977). However a preliminary examination of two samples of diatomite indicates that conditions were definitely littoral and brackish (shown by abundant *Anomoeoneis sphaerophora* and its varieties, *A. costata, Mastogloïa elliptica, Rhopalodia gibberula* and *Cyclotella meneghiniana*). This assemblage recalls present Ethiopian soda lakes such as Abiyata (Gasse 1975), although it would be unwise to assume for an instant that the whole of the diatomite bed was deposited under such conditions.

The lower diatomite is overlain by a black organic clay, laid down during the gradual retreat of the lake and the transition to a shallow marsh.

In some sections, a second diatomite records a final lacustrine transgression to ⩾9 m (Williams et al. 1977). This event is bracketed by the ^{14}C dates of 3 460 ± 280 B.P. (on charcoal from an overlying soil) and 9 400 B.P. (which gives a minimum age for the top of the lower diatomite) but it cannot yet be pin-pointed more exactly. Since 3 460 B.P. the lake has never risen above +4.2 m.

The Hanlé and Dobi grabens (Figure 15.10), which descend to 100 m a.s.l., are at present dry. During humid periods, they received enhanced inflows from a variety of sources, which sustained a large lake. In additon to local rainfall, the lake was fed by resurgences of groundwater originating from the Awash system, and by the Oued Hanlé, which drains the mountainous foothills of the Southeastern Plateau. This former watercourse was never as important as the Awash, however.

A lake developed in the early Holocene (Gasse & Street 1978a). By 10 870 ± 220 B.P. it had already risen to 160 m a.s.l., and rapidly reached 300 m, maintaining this maximum level throughout the early and middle Holocene (Figure 15.10). During this time Lake Hanlé-Dobi had an area of 1 100 km² and a depth of 200 m. A second transgression flooded the graben during the late Holocene, probably between 2 500 and 1 500 B.P. Although its amplitude was smaller, the lake attained a depth of at least 135 m.

The lacustrine environments in these two successive lakes were of the same type as in Lake Abhé. We find essentially the same sequence of sedimentary facies and diatom floras. This ecological similarity presumably reflects the influence of the highland runoff carried by the Hanlé River. It is worth noting here that a higher level of Lake Hora, on the Southeastern Plateau margin, has been dated at 6 890 ± 115 B.P. by Williams et al. (1977).

Lake Asal, as we saw earlier, lies at 155 m below sea level but only 10 km from the sea. It is currently fed both by the resurgence of meteoric waters from the catchment and by seawater springs on the SE shore.

Following the terminal Pleistocene arid phase the lake rose rapidly, reaching at least 120 m a.s.l. by 9 900 B.P. Studies of the bottom deposits indicate that the transgression started well before 10 000 B.P. The highest shoreline, which appears to have been stable between 10 000 and 6 000 B.P., lies at 160-170 m a.s.l. This is 300 m above the present water surface. Lake Asal was the deepest Holocene lake in the entire Afar, communicating with the Gaggade Graben (Figure 15.10) to form a single waterbody some 1 000 km² in area (Gasse & Street 1978a).

The main regression began at 6 000 B.P. It took place very rapidly, since the sediments at −100 m had already acquired a littoral character by 5 600-5 300 B.P. A major consequence was the resumption of seawater seepage as soon as the surface dropped below sea level. These inflows have tended to stabilize the water level, and are likewise responsible for the distinctive subsequent history of the lake (Gasse & Stieltjes 1973).

During the late Holocene, the altitude of the water surface has always remained well below sea level. Nevertheless the lake experienced a small transgression of 20 m amplitude, so far undated, which may be contemporary with the 2 700-1 000 B.P. phase demonstrated in Lake Abhé.

Throughout its phase of maximum extent, Lake Asal was characterized by the precipitation of at times almost pure high-Mg calcite. The planktonic diatom flora (dominated by *Melosira* and *Synedra*) indicates that the lake was tropical, oligohaline, and richer in silica than Abhé. This episode was preceded and followed by periods when the waters were higher in dissolved salts and when clastic elements played a greater role in the sedimentation.

The mid-Holocene regression brought about a profound environmental change, so that the evolution of Asal diverged markedly from the adjacent lakes. Very pure aragonite began to precipitate in the centre of the basin. Then, when lake-level fell to −100 m, a belt of gypsum was deposited. The small late Holocene transgression gave rise to a second bench of gypsum situated 20 m above present level. Finally, the lake entered the domain of halite precipitation, which today occurs in a broad crescentic plain on the NW side of the residual lake.

15.8.2.2 *Comparison with the river-fed lakes Ziway Shala and Abhé.* The evolution of the lakes maintained by groundwater originating in the Awash catchment differs noticeably from that of Ziway-Shala and Abhé, which were directly fed by highland runoff (Gasse & Street 1978a). The available radiocarbon results imply that Lakes Besaka, Hanlé-Dobi and Asal reached high levels at a considerably earlier date. We can suggest two possible explanations. To begin with, it is very likely that the proportionally higher influx of HCO_3-rich groundwater into these lakes resulted in larger apparent ^{14}C ages. However it is not inconceivable that the change to a precipitation surplus, around 12 000-10 000 B.P., initiated the recharge of aquifers depleted during the arid phase, so that the spring-fed lakes were the first to respond.

Another difference is that the groundwater-dependent lakes do not show a a clearcut regression separating early and mid-Holocene highstands. Shorter climatic fluctuations seem to have been damped by the slow response of the groundwater reservoirs, so that only arid intervals of long duration (terminal Pleistocene, present day) have been registered.

Finally, the complex hydrological régime of these lakes explains their distinctive geochemical characteristics, the most striking case being Lake Asal, which has been dependent on marine inflows since the middle Holocene.

15.8.2.3 *A lake independent of the Awash system: Lake Afrera.* The fluctuations of Lake Afrera are illustrated by Figure 15.10. Just like Hanlé-Dobi and Asal, and probably for the same reasons, a high level was maintained from 10 000 to 6 000 B.P. However the regression which took place at 8 000 B.P. in Lake Abhé was evident in attenuated form.

In other ways, Lake Afrera stands apart from the Central Afar lakes. It remains small and shallow throughout. Several factors operated here. First of all, the subdued topography is unfavourable for the development of a deep lake. Secondly, the catchment is small, and the climate of the Northern Afar much hotter and drier than the Central Afar. Finally, we should recall that Lake Afrera did not benefit from rainfall over the Ethiopian Plateau, which drains towards

the Mediterranean, but was fed by groundwater percolating down along the Ethiopian escarpment.

The lacustrine environment was equally distinctive. The sedimentation remained essentially chemical (pure calcite) even during the transgressive and regressive phases. The geochemistry of the Holocene lake differed from the Central Afar lakes, as the diatom floras clearly show. The abundance of forms requiring a high salinity, particularly NaCl, is remarkable (Gasse 1974). Lake Afrera never became truly oligohaline. Its salinity can be explained by the flow-path of the groundwaters, which circulate through marine evaporites (gypsum and halite) forming the substratum of the basin. In this way Lake Afrera inherited, during the Holocene, certain distinctive marine characteristics.

15.9 PREVAILING CONDITIONS IN THE CATCHMENTS

We possess very few clues to environmental changes in the catchments. The results of pollen and soil analyses are still very fragmentary. However several indicators record the major humid phase of the early Holocene, and some information can be extracted from palaeolimnological studies.

15.9.1 *The interval 12 000-10 000 B.P.: a little known period of climatic instability*

This transitional period between the terminal Pleistocene phase of accentuated aridity and the humid peak of the early Holocene is still difficult to understand on the basis of present information, which is partly contradictory. We have put forward one hypothesis which suggests that the aquifers were recharged from 11 500-11 000 B.P. onwards, initiating the expansion of the spring-fed lakes Besaka, Hanlé-Dobi and Asal. At Aladi Springs (Williams et al. 1977), a gravelly brown clay believed to have been deposited during the arid phase is capped by a shelly tufa dated at 11 070 ± 160 B.P., testifying to the resumption of spring activity. It seems however that markedly arid conditions still reigned on Mt Badda at this time (Hamilton 1977). A small glacial cirque (Figure 15.10) which was quite dry at 11 500 B.P. was only transformed into a marsh around 10 000 B.P. (Gasse 1978). According to our other hypothesis, this apparent conflict can be explained by errors in dating carbonates from spring-fed environments. Alternatively, it may simply result from random errors in the ^{14}C dates or from an insufficiency of data. The increase in moisture undoubtedly did not take place in a regular fashion, but with numerous minor oscillations. These were probably short, and were therefore not registered in environments supplied by ground water. So far they have only been detected in basins fed directly by rainfall (Mt Badda) or by surface runoff (Lakes Ziway-Shala and Abhé).

15.9.2 *Environments of the early and middle Holocene*

15.9.2.1 *Increased runoff.* In both the Main Rift and the Central Afar basins, many of the small watercourses which are now dry or intermittent carried water

very actively during this period. A date from Erer Springs, at the foot of the Southeastern Plateau, shows that there was permanent water in present-day ephemeral channels at 6 670 ± 110 B.P. (Williams et al. 1977). Many local streams incised their valleys down to base-level, which was the lake surface of the time. These gullies end at an altitude of 1 670 m in the Ziway-Shala Basin (Grove et al. 1975), 400 m in the Lower Awash, and 300 m in Hanlé-Dobi (Gasse 1975). Surface runoff of local origin was therefore very significant, although many of the small catchments became inactive from 6 000 B.P. onwards. The level at which precipitation equals potential evapotranspiration, currently situated above 1 700 m (United Nations 1973), must have been substantially lower if rain falling within the Central Afar was able to feed lakes in the depressions.

15.9.2.2 *Low overall erosion rates.* In all the lakes studied so far, detrital elements played a very minor role in deepwater sedimentation during the phases of maximum extent. The deposits are biochemical (carbonates) in the Afar, and predominantly clastic, but thin and fine-grained, in the Rift. Suspended sediment inputs by rivers, whether highland or local, were apparently low. The rains may not only have been greater in total, but also finer and more regularly distributed throughout the year, so that the slopes were protected by an increase in vegetation cover. A preliminary interpretation of the pollen results from Mt Badda (Hamilton 1977) shows that montane forest expanded significantly on the Arussi Mts, while greater geomorphic stability during the early Holocene is indicated by the widespread development of a brown calcimorphic palaeosol in the Main Rift (Haynes & Haas 1974; Laury & Albritton 1975).

15.9.3 *Minor climatic oscillations during the late Holocene*

Limnological studies have not up till now enabled us to reconstruct the climatic changes of the early Holocene in any detail. The unstable conditions and the multiplicity of shorelines, which are difficult to date, make the results hard to interpret. Further complexity is introduced by the domestication of cattle, sheep and goats around 3 500 B.P. (Clark, personal communication 1977) and by the onset of forest clearance on the Arussi Mts after 1 850 B.P. (Hamilton 1977), both of which probably had an impact on runoff (Bormann et al. 1968). Work in progress on the pollen and diatoms from the Afroalpine site on Mt Badda will shed new light on climatic fluctuations during this little known period.

15.10 CONCLUSIONS

Less than ten years ago, Quaternary stratigraphers working in Africa were still trying to fit the African 'pluvials', as defined by the occurrence of high lake levels, into the glacial-interglacial sequence of the Northern Hemisphere. South of the Sahara, 'pluvials' were being matched up with interglacials (Balout 1952; Tricart 1956). The first reports of Holocene lakes in East Africa (Butzer et al. 1972) and the Afar (Gasse et al. 1974) only reinforced this view.

In Ethiopia, the early and middle Holocene saw a great extension of lacustrine conditions. Deep freshwater lakes occupied basins in which residual soda lakes or playas maintain a precarious existence at the present day. River floodplains, now reduced to marshland areas, were themselves covered with several tens of metres of water. In total, Lakes Ziway-Shala, Galila, Gawani and Abhé, along the course of the Awash alone, covered an area of the order of 10 000 km^2, which is about equal to the modern Lakes Turkana and Abaya combined. The palaeolakes supported a varied and abundant flora and fauna. The early and middle Holocene therefore provided a rich variety of habitats for human occupation.

From 4 000 B.P. onwards, the general deterioration in climatic conditions, despite the occurrence of several moister interludes, has progressively brought about the present situation in which the availability of surface water is a major factor limiting settlement.

In contrast, the discovery, first in the Afar, and then in the Main Rift, of larger and more persistent lakes in the middle of a glacial (from ⩾40 000 to ⩽20 000 B.P. with a slight regression around 30 000) has led to a major modification of ideas about tropical climatic and ecological changes during the Würm (Rognon 1976). These lakes seem to fall within the interstadials of the Middle Würm. But it is noteworthy that lakes of tropical character still existed at 23 000 B.P. in the Afar and the Main Rift, at levels higher than those reached during the Holocene, when Europe was experiencing the onset of the Late Würm glacial advance. One major outcome of research on these lakes has been to challenge earlier oversimplified views. Since then, a similar picture has been emerging from Australia, the other large tropical desert (Bowler et al. 1976; Rognon & Williams 1977). The way is now open for discussion of the mechanisms underlying this complex climatic evolution. Because Ethiopia is situated at the convergence of the Atlantic and Indian monsoons, its climatic past may prove more difficult to explain than in West Africa or Australia. However initial comparisons between Ethiopia and Chad reveal an almost identical climatic sequence from 40 000 to 0 B.P., apart from slight palaeotemperature differences.

Looking further back in time, Ethiopia is no exception to the general scarcity of African lake deposits of Middle Pleistocene age. This period was marked by major earth movements and volcanic activity. Landscape evolution seems to have occurred under dry conditions. The best evidence has been preserved on the Ethiopian Plateau margin at Melka Kontouré, away from the active sectors. Similar deposits may await discovery at the southern end of the Main Rift, which has also been less disturbed by recent tectonics, especially the Wonji Fault Belt. The ancient connections between Lake Chew Bahir, Lake Turkana and the White Nile are particularly in need of investigation.

On the other hand the Plio-Pleistocene lake sediments, though far older, underlie much larger parts of the Afar. Climatic interpretations for this early period are of a different order from the Late Quaternary. Emphasis must be placed on floristic and faunal indicators because fluctuations in lake level, or even the drainage of whole basins, may have been due to volcanic or tectonic events which cannot now be reconstructed (Bishop 1971).

The discovery of large tropical lakes at Hadar from 3.3 to 2.6 m.y. has confirmed the picture emerging from East Africa (Olduvai, Omo, East Turkana, etc.). The site has yielded an exceptionally fine collection of fossil remains, all of which indicate, as in East Africa, a Sudanian or Sahelian climate. Studies at Hadar have shown the continuity of these lakes and of their general climatic setting through nearly a million years. This period contrasts strikingly with the following one. Aridity set in between 2.5 and 2 m.y. in the Omo (based on the pollen and rodents) and in the Afar, where it probably marks the onset of desert conditions. This change seems to coincide with the development of major ice-sheets in the Northern Hemisphere and with the first appearance of a flora adapted to summer drought in the Mediterranean (ca. 2.2-1.6 m.y. in the south of France according to Ildefonse et al. 1975). The climatic zonation that we know today seems to have become established in this period (see also Cerling et al. 1977). Shortly afterwards, the development in the Afar of extensive lakes with an archaic temperate flora suggests an initial correlation with the Early Pleistocene lakes of the Hoggar, where these diatoms are associated with an eastern Mediterranean montane flora also reported from Tibesti and Upper Egypt (Rognon 1967; Butzer & Hansen 1968:515-20). From this point onwards, the climatic evolution of Ethiopia bears an increasing resemblance to that of the Sahara. This probably holds for the shorter lake level oscillations whose extreme complexity only becomes apparent in the Late Quaternary.

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Part Three: Prehistoric occupation
Troisième partie: Occupation préhistorique

Confronted with widespread evidence of ecological deterioration in those vast, sparsely populated, marginal lands on the edge of the desert, we cannot justifiably shirk the problematic issue of man's impact upon his environment.

One school of thought places the blame for desert encroachment upon man and his herds. Overgrazing, devegetation, albedo increase, reduced rainfall, are all part of this vicious 'biogeophysical feedback' circle. Another, less extreme approach is that of the Quaternary geologist who is content to establish the reality of long- and short-term climatic changes in continents with 40 000 years of prehistory as in Australia, or four million years as in Africa – changes which cannot convincingly be attributed to man's activities. Nonetheless, the interaction between man and milieu is a problem worthy of scholarly investigation, beginning with the earliest evidence that allows us to reconstruct prehistoric economy, habitat and society with appropriate precision.

The Egyptian Sahara was arid towards the end of the Pleistocene and became less arid during the Early Holocene, when temporary lakes occupied deflation hollows scoured out by the wind during the preceding arid phase. Wendorf and Hassan describe the prehistoric sties associated with the Terminal Palaeolithic and early Neolithic occupation of these playas between 9 400 and 7 700 B.P. The Neolithic communities of the Western Desert grew barley and sorghum, raised cattle and sheep/goats, and continued the hunting and plant collecting traditions of their forebearers.

In Predynastic times, sizeable sedentary communities of farmers and herdsmen occupied slightly elevated localities adjacent to the Nile floodplain. Hassan analyses the economy of these settlements, concluding that agriculture made possible the storage of food for use in times of minimum availability of wild food resources.

The remarkable similarities between the Early Holocene lacustrine or 'aqualithic' cultures of the central and southern Sahara and those of the Nile valley are again evident in the Middle Holocene Neolithic tradition, discussed here by A.B.Smith. In contrast to Europe and the Near East, ceramics appear in the Sahara several thousand years before the first signs of domesticated plants and animals. Smith goes on to describe the herders' response to increasing Saharan desiccation after about 4 500 B.P. The ensuing southward migration

of nomadic pastoralists along major rivers like the Niger and Tilemsi culminated in the colonisation of the West African savanna and in the introduction of domesticated cattle into that region.

There are obvious parallels between the response of prehistoric pastoralists to increasing aridity, and that of the modern nomadic inhabitants of the Sahel when confronted with severe drought. Susan Smith's account of the Kel Tamasheq of southern Mali is accordingly useful both for the light it sheds upon the life-style of a nomadic community today, as well as for the insights it affords us when trying to visualize the life-style of Neolithic pastoralists.

The problematic nature of the archaeological record and the attendant difficulties involved in trying to determine when and where certain cereals were first domesticated are the subject of Ann Stemler's review. She concludes that all the available evidence points to the comparative recency of plant domestication in Africa, namely 1 000 B.C. for cultivated *Pennisetum* in Mauritania and 300 A.D. for cultivated *Sorghum* in central Sudan.

In the concluding chapter, J.Desmond Clark returns to the themes raised by Ann Stemler, Susan Smith and earlier contributors. After noting the first signs of prehistoric movements from the Maghreb across the western Sahara as far as the Egyptian Nile during Mousterian times, and the emergence of two clear cultural divisions north and south of the Hoggar during the Aterian, he reviews the evidence for increasing economic specialisation and cultural diversification during the past 20 000 years. The Sahara ecological boundary denoting the respective limits of winter and summer rains seems also to have been a well-defined Early Holocene cultural boundary. Clark attributes the development of plant and animal domestication in the Sahara and Nile valley to the constraints imposed upon the hunter-gatherer way of life by progressive desiccation from about 2 000 B.C. onwards. Rapid adoption of exotic cultigens like wheat and barley implies a sedentary Nilotic population already accustomed to harvesting the local plant resources. Clark concludes that the most pressing need in North African prehistory today is for an intensive study of Holocene settlement and of the origins of domestication in the Nile valley.

En face des nombreux signes de dégradation écologique dans ces vastes pays peu peuplés à la lisière du désert, nous sommes amenés à aborder le problème épineux des influences humaines sur les milieux désertiques.

Certains disent que l'homme et ses troupeaux sont à l'origine des avancées du désert. Le surpâturage, la dégradation végétale, l'albedo qui s'accroît, la diminution de la pluviosité, font tous partie de ce cercle vicieux du 'feed-back biogéophysique'. D'autres, moins extrémistes, comme les géologues quaternaristes, se contentent d'établir la réalité des variations climatiques. Il est difficile d'admettre que l'homme est la cause des variations climatiques quaternaires quand on retrouve les mêmes variations en Afrique et en Australie, car l'homme habite l'Afrique depuis quatre millions d'années, mais l'Australie depuis 40 000 ans seulement. Néanmoins, les relations entre l'homme et son milieu devront êtres étudiées de façon très précise, en commencant par les données les plus anciennes qui nous permettent de reconstituer le milieu, l'économie, la société, avec un détail suffisant.

Vers la fin du Pléistocène, le Sahara égyptien était aride. Puis, à l'Holocène inférieur, il est devenu moins aride, et des lacs temporaires ont occupé les cuvettes érodées par le vent au cours de la phase aride précédente. F.Wendorf et F.A. Hassan décrivent les gisements préhistoriques du Paléolithique terminal et du Néolithique ancien fouillés dans ces cuvettes ou playas et datant de 9 400 à 7 700 B.P. Les populations néolithiques de cette région cultivaient l'orge et le sorgho, pratiquaient l'élevage des bovins et des ovins/caprins, et continuaient la tradition de chasse et de cueillette de leurs aïeux.

Aux temps prédynastiques, d'assez grandes populations sédentaires de cultivateurs et de pasteurs ont occupé les petits reliefs proches de la plaine d'inondation du Nil. F.A.Hassan fournit une analyse économique de ces populations d'agriculteurs qui conservaient des réserves de vivres pour les utiliser aux saisons où les ressources alimentaires sauvages étaient rares.

Les ressemblances entre les cultures lacustres ou 'aqualithiques' du Sahara central et méridional et celles de la vallée du Nil pendant l'Holocène inférieur sont encore évidentes pendant le Néolithique, décrit ici par A.B.Smith. A la différence de l'Europe et du Proche Orient, les céramiques apparaissent au Sahara plusieurs milliers d'années avant les premiers vestiges de culture des

plantes ou de l'élevage. Smith donne une analyse des mouvements de populations pastorales du Sahara vers le sud après l'assèchement amorcé vers 4 500 B.P. Ces migrations le long des grands fleuves comme le Niger et le Tilemsi ont introduit les bovins domestiqués dans l'Afrique de l'Ouest pendant la colonisation Néolithique de cette région.

Face à une sécheresse sévère, les nomades du Sahel réagissent de la même façon que les pasteurs préhistoriques. L'étude faite par Susan Smith des Kel Tamasheq du Mali méridional est donc utile pour les reseignements qu'elle nous apporte sur le style de vie d'un peuple nomade contemporain, ainsi que pour les aperçus qu'elle nous fournit lorsque nous essayons d'évoquer la façon de vivre des pasteurs néolithiques.

Les problèmes d'interprétation des informations fournies par les gisements préhistoriques, et surtout la difficulté de pouvoir discerner où et à quelle époque étaient cultivées certaines céréales sont repris par Ann Stemler. D'après les données disponibles, il semble que la culture des plantes à une histoire assez récente en Afrique: 1 000 B.C. pour la culture du *Pennisetum* en Mauritanie et 300 A.D. pour la culture du *Sorghum* au Soudan central.

Dans le dernier chapitre, J.Desmond Clark revient aux thèmes de Ann Stemler, de Susan Smith et des auteurs précédents. Les premiers indices de migrations préhistoriques du Maghreb à travers le Sahara jusqu'au vallée du Nil en Egypte datent de l'époque moustérienne. Pendant l'Atérien qui suit, deux grandes unités culturelles sont apparues, l'une au nord et l'autre au sud du Hoggar. La spécialisation progressive des économies préhistoriques, et leur diversification culturelle au cours des derniers 20 000 ans sont le sujet principal de cette synthèse. La limite écologique entre les régions à pluie d'hiver et celles à pluie d'été semble avoir été aussi une limite culturelle bien définie. Clark pense que la culture des plantes et la pratique de l'élevage au Sahara et dans la vallée du Nil provenaient des contraintes imposées par l'assèchement progressif dès 2 000 B.C. sur le mode de vie des chasseurs-cueilleurs. L'adoption rapide des espèces cultivées exotiques telles le froment et l'orge implique une population nilotique sédentaire déjà accoutumée à la récolte des plantes locales. En conclusion, Clark suggère que le besoin le plus urgent pour la préhistoire de l'Afrique du Nord est une étude approfondie des sites holocènes et des origines de l'agriculture dans la vallée du Nil.

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16

Holocene ecology and prehistory in the Egyptian Sahara

Ecologie holocène et préhistoire du Sahara égyptien

Pendant la période allant de 9 500 à 6 700 B.P. (années marquées au ^{14}C), le Sahara égyptien (désert de l'ouest égyptien) a été exposé à des précipitations plus importantes. Les chotts prouvent cet événement, jusqu'à Nabta vers le Sud et l'oasis de Siwa vers le Nord – les précipitations dans la partie sud du Sahara semblent avoir été plus importantes que celles dans le Nord.

Les sites du Paléolithique terminal avaient été établies dans le Sahara égyptien durant cette période humide et peuvent être observées à Nabta Playa, El-Korbein, El-Beid, Gilf El-kebir, L'Oasis de Kharga et l'Oasis de Siwa. L'économie néolithique a commencé dès 8 000 B.P. dans La chott de Nabta. Les assemblages d'outils en pierre du Paléolithique terminal dans le Sahara égyptien présente des caractéristiques régionales, mais présente des éléments communs avec d'autres industries de la même période provenant d'autres regions d'Afrique du Nord, y compris la vallée du Nil.

Les gisements néolithiques les plus anciens au playa de Nabta comprennent un mélange de traits caractéristiques du Paléolithique terminal ainsi que des traits Néolithiques proprement dit. La plupart des gisements Néolithiques sont datés de 8 200 ± 100 B.P. à 7 710 ± 70 B.P., et sont peu comparables aux assemblages nilotiques du même age. Avec leurs armatures de flèche à la base concave ils ont des affinités avec le Néolithique du Fayum, et leur céramique trempée au sable a un style décoratif semblable à celui de la tradition dite 'Early Khartoum', qui est datée de 8 000 à 7 000 ans B.P. dans la basse vallée du Nil Blanc au Soudan central.

Les données paléoécologiques indiquent une flore steppique à l'Holocène inférieur, avec des buissons épineux et des acacias éparpillés dans le désert. La couverture végétale la plus dense était surtout concentrée autour des lac temporaires. L'économie du Paléolithique terminal était fondée sur la chasse et la cueillette des plantes sauvages et les peuples Néolithiques ont continué à faire la chasse et à cueillir les plantes sauvages, bien qu'ils pratiquaient la culture des plantes (orge) et l'élevage (bovins, ovins/caprins). La culture de l'orge dans le Sahara égyptien semble être la plus ancienne culture connue jusqu'à présent en Afrique.

16.1 INTRODUCTION

The name of Egypt calls to mind the verdant green strip of land bordering the Nile, and the splendid civilization which rose from the mud of the Nile, which has had an indelible influence on the early history of world civilizations. Yet, the land of Egypt is mostly desert – barren, rainless, and almost uninhabited.

To the west of the Nile Valley, starts the Sahara. Within the borders of Egypt, the desert west of the Nile is often called the Western Desert. Sometimes, this desert is considered a part of the Libyan Desert which extends west of the Nile to the mountains of Ennedi and Tibesti. The Western Desert of Egypt is vast, extending over 680 000 km², slightly under 20 times the area of the Nile Valley in Egypt and the Delta combined. It is a tableland which has remained tectonically inert during the geologic eras, representing a stable cratonic shelf, which was repeatedly invaded by the ancestral Mediterranean (Tethys) seas. On the surface, the Cretaceous to Miocene strata are the most striking. In the south, the Nubian Sandstone slopes gradually from the summit of Gebel Uweinat to the Gilf El-Kebir plateau and ends in the great plateau in which Kharga and Dakhla Oases are situated (Figure 16.1). The landscape changes north of the Dakhla-Kharga region to a limestone plateau of Cretaceous to Eocene age. In this plateau lie the depressions of the Farafra, Baharia, and Fayum Oases. The plateau slopes gradually towards the Mediterranean, and north of the Fayum, the Miocene limestone plateau begins. At the northwestern end of this plateau lies Siwa Oasis bordering to the east one of the most formidable depressions in the world, the Qattara depression, which has a maximum depth of 134 m below sea level.

The Western Desert of Egypt is a land of harsh beauty. The inhabitants of the Nile rarely venture into its sands and barren rocks, but many explorers have dared the desert and they invariably produced evidence of previous prehistoric occupations of that wilderness (Hassanein Bey 1924; Prince Kamal el-Dine 1928; Bagnold 1931, 1933; Bagnold, Myers, Peel & Winkler 1939; Sandford 1935; Shaw 1936). However, until the 1960s systematic research remained restricted to the pioneer studies by Caton-Thompson (1952) in the Kharga Oasis. In 1963 and 1964, James Hester and Philip Hobler undertook a study of the Dungul and Kurkur Oases (Hester & Hobler 1969) and explored Bir Sheb and Bir Nakhla to the South. In 1962, the 'Combined Prehistoric Expedition' led by Fred Wendorf initiated a systematic study of the Prehistory and Quaternary geology of the southern part of the Western Desert. Two years later, Fekri Hassan began to work in the northern part of the Western Desert at Siwa Oasis. This paper summarizes the initial results of our on-going research, specifically that which deals with the Holocene (see also Wendorf et al. 1976; Schild & Wendorf 1977; Hassan 1976a, b; Hassan, in press).

16.2 PREVIOUS WORK

The work undertaken by Caton-Thompson (1952) in the Kharga Oasis introduced two Holocene archaeological entities, the 'Bedouin Microlithic' and the 'Peasant Neolithic'. The Bedouin Microlithic is characterized by a predominance of microlithic artifacts consisting for the most part of microlithic blades, frequently notched and backed. Geometric pieces are very scarce.

The collections described by Caton-Thompson (1952) also included transverse arrowheads, both V-shaped and long-stemmed, as well as many other arrowhead types, tanged and winged. The Ounan points are also represented. The arrowheads were pressure flaked. Lanceolate bifacial knives were also recorded. In addition, the collections included ostrich eggshell fragments, some

of which were worked into beads. No ceramics were present, but hand-milling stones were in evidence. During 1975, the combined Prehistoric Expedition revisited the area and obtained a radiocarbon date of 7 289 ± 90 B.P. (SMU-273) on ostrich egg shells.

The Peasant Neolithic displays a tool kit with flaked axes, 'chisels', 'planes', 'bifacial knives'. Ceramics are limited to wind-blasted fragments and arrowheads are rare. They include the concave-base arrowheads known from the Fayum.

Hester & Hobler (1969) recognized what they called the 'Libyan culture' – an 'incipient Neolithic', characterised by transverse points, stemmed arrowheads, endscrapers, burins, perforators, including double-backed perforators. They also recorded bifacial knives, and bifacially pressure flaked points. Ostrich eggshell beads and hand-milling stones and metates were also noted. Hester & Hobler (op. cit.) obtained a radiocarbon date of 7 900 ± 120 B.P. on the Libyan culture.

McHugh (1971, 1974) in a study of the collection made by Oliver Myers during the Bagnold expedition to Gilf El-Kebir and Gebel Uweinat, indicated that the material in the largest collection, from Wadi el-Bakht, consists predominantly of notched flakes and blades, endscrapers, and perforators which suggested to him a close affinity with the Kharga 'Bedouin Microlithic' and the 'Libyan culture'. The collection, however, contained pot sherds which led McHugh to conclude that the Wadi el-Bakht assemblage postdates these two entities. The site at Gilf el-Kebir was revisited by the Combined Prehistoric Expedition. The observations made indicate that in the area of the site, falling dunes formed a wall which dammed a wadi and created a pond. The pond was eventually filled with sediments and the dam was breached. A Neolithic site with ceramics overlying the dune surface yielded a date of 6 280 ± 90 B.P. (SMU-273) on ostrich eggshells.

The discovery of stone artifacts and rock-drawings in the Western Desert indicated that the environmental conditions were perhaps not as harsh in the past as they are today. Evidence for somewhat greater rainfall and spring activity was obtained from the study of sediments by Said in Dungul and Kurkur Oases (in Hester & Hobler 1969), by Reed (1964) and also by Butzer (1964), and Butzer & Hansen (1968) in Kurkur Oasis.

16.3 HOLOCENE GEOLOGY AND PALAEOCLIMATE

During the period contemporaneous with the Main Würm in Europe, arid conditions prevailed in the Egyptian Sahara. It was a period of deflation and scouring. Numerous basins were formed, and the older Quaternary deposits were stripped off. There is no evidence during this period for fluvial or lacustrine conditions. During the early Holocene, relatively moist conditions prevailed. Rainfall was sufficient to sustain ephemeral lakes (playas) and ponds in numerous places such as Nabta, El-Kortein, El-Beid, Gilf El-Kebir, and Siwa Oasis. Spring discharge at Kharga Oasis was also enough to sustain a pond.

At Nabta a huge playa more than 100 km² occupied a shallow deflation basin 100 km west of Abu Simbel (Figure 16.1), Quaternary deposits overlie the deflated surface of the Nubian Sandstone.

During the early Holocene, the deflated basin was invaded by dunes, presu-

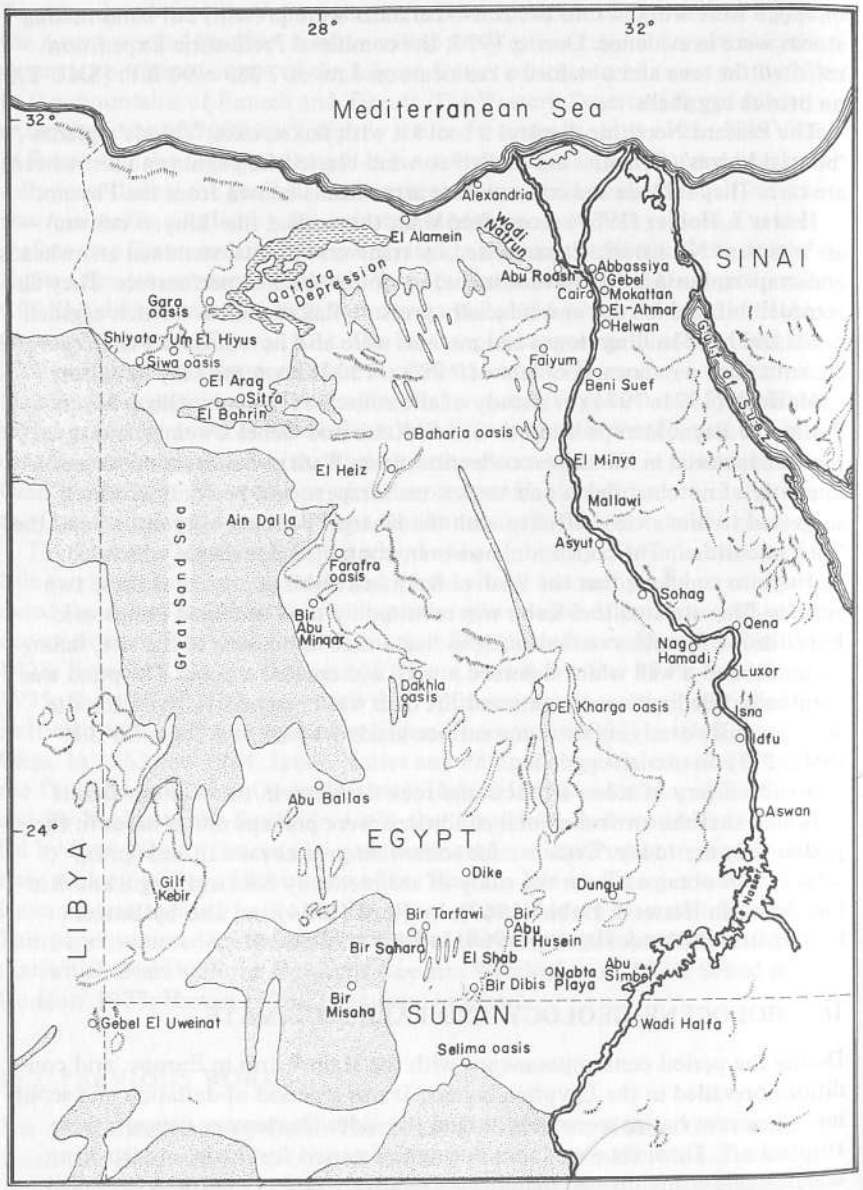


Figure 16.1 Location of Terminal Palaeolithic and Neolithic sites in Egypt

mably under conditions not much different from those prevailing today. By ca. 8 500 B.P. the climate was still sufficiently moist to support some vegetation on the dunes. Then alternating rainy spells and drier conditions led to an intercalation of dune and playa deposits. These conditions were followed by a moist

phase and extensive playa deposits were formed. The first Terminal Palaeolithic occupation dates to that time. Sheet wash deposits accumulated next, and it was on the stabilized surface of these deposits that another Terminal Palaeolithic settlement was established. Another unit of sheetwash sand covered this occupation. On top of this second sheetwash cover, a Neolithic site was found. This Neolithic site is in turn covered by sheetwash sand, followed by lenses of clay and then by the main part of the playa loamy silt.

The Terminal Palaeolithic occupations are dated by two radiocarbon determinations:

9 360 ± 70 B.P.	(SMU-200)	Charcoal
7 850 ± 80 B.P.	(SMU-257)	Ostrich eggshell

The Neolithic occupation yielded five radiocarbon dates:

8 200 ± 110 B.P.	(SMU-181)	Ostrich eggshell
7 710 ± 70 B.P.	(SMU-191)	Ostrich eggshell
8 120 ± 100 B.P.	(SMU-199)	Charcoal
8 010 ± 80 B.P.	(SMU-203)	Charcoal
8 018 ± 240 B.P.	(SMU-240)	Charcoal

The playa sediments contained in the Nabta basin reached a maximum elevation of about 6 m higher than the earliest Neolithic settlement. This was followed by a major reduction in the size of the playa. Older deposits were exposed and subaerial desiccation and deflation occurred. Later, the playa expanded again, probably to about the size of the previous phase. Another Neolithic occupation is recorded in association with this new phase of playa expansion. The ceramics of this Neolithic occupation are closely related to those which are present in the earlier Neolithic site. There are two radiocarbon dates on the second playa phase: 7 150 ± 130 B.P. (SMU-242) and 6 700 ± 50 B.P. (SMU-261). There were several minor fluctuations in the extent of the playa during this second interval. Arid conditions following the second playa expansion were signaled by the rapid accumulation of dune sands along the margin of the playa. A Neolithic settlement with ceramics closely similar to those from the Nile Valley in Nubia occurs in these dune sands. This Neolithic settlement has not yet been dated, but the pottery would suggest an age around 5 500 B.P.

About 20 km north of Nabta, two smaller basins with playa deposits display a similar sequence to that of Nabta. These were named El-Kortein and El-Beid playas. At El-Kortein playa, two Terminal Palaeolithic and one Neolithic site were excavated to the underlying Nubian Sandstone. The Nubian Sandstone is overlain by a thick bed of aeolian sand (over 4 m) with a dense mat of plant root casts at the top. Terminal Palaeolithic artifacts associated with stone-lined and stone floored cists were found in the dune top (Site E-77-3). The artifact assemblages resemble those of Site E-75-6 in Nabta Playa. Water-laid playa silt covers the site and fills the topographic lows of the dune top. The playa silt reaches a thickness of over 3 m. That period of playa expansion left well defined beach features along the foot of the Nubian Sandstone hills which border the basin on the north. A Terminal Palaeolithic settlement (Site E-77-6) was contemporaneous with the deposition of the upper part of the playa silt. The artifact assemblage is similar to those recovered from two sites farther north, one near Kharga, the

other to the south of Dakhla. The occupational remains of the site were churned up by the desiccation of the playa deposits, a phenomenon attributed to seasonal wetting followed by drier conditions. A Neolithic settlement was discovered still higher up in the playa silt (Site E-77-5). It consists of a relatively small, dense occupation containing early Khartoum pottery and at least two slab-lined houses. The top of the remnants of the playa silt is covered by a relatively thin layer of wadi gravel and coarse sand. Subsequent wind erosion, still continuing today, defines the present morphology of the basin.

The stratigraphic sequence at El-Beid is similar to that to the north of Nabta. The basin includes both Terminal Palaeolithic and Neolithic sites. One of the Terminal Palaeolithic sites was excavated (Site E-77-7). The artifacts were found embedded in laminated playa silt. The silt is underlain by aeolian sand with intercalations of playa silt. The sand overlies the Nubian Sandstone bedrock.

At Kharga Oasis, spring-fed pond deposits containing Neolithic artifacts overlie an older unit of pond deposits which yielded a few typical Aterian artifacts. The Neolithic artifacts occur in several layers. The uppermost of the occurences yielded sherds of a simple, sand tempered, plain pottery. Playa sediments are associated with Graeco-Roman, Neolithic, and Terminal Palaeolithic sites near the Kharga airport. A Neolithic Site (E-76-7) yielded a date of 9 195 ± 65 B.P.

South of the Dakhla Oasis, midway between Bir Sahara and Bir Tarfawi, sandstone 'dykes' are characteristic of an extensive area. The dykes are associated with shallow deflation basins filled with sand. The accumulation of sand seems to be related to local internal drainage. Terminal Palaeolithic sites are associated with the sand deposits.

In the region of Siwa Oasis, Holocene deposits are preserved in a very few places, mostly in pans. Where these deposits occur, the older Quaternary deposits were totally deflated. At Hatiet Um El-Hiyus, where numerous sites were located, a small shallow deflation basin is filled with sands, silty sand, and loamy sand deposits. A charcoal date from a hearth in these deposits yielded a date of 8 570 ± 110 (WSU-1674). Dates on ostrich eggshell associated with Terminal Palaeolithic artifacts near the surface of the pan deposits are 8 119 ± 64 B.P. (SMU-281) and 7 980 ± 160 B.P. (WSU-1697).

Following a period of deflation at or shortly after 7 000 B.P., small hummocky dunes formed in the pan, presumably around sparse vegetation cover. A drop in water table afterwards led to considerable shrinkage if not total desiccation of the spring-fed salt lakes which even now exist in the Siwa region. Salt from the desiccated lakes was windblown and deposited as dune sand. Subsequently, phytogenic dunes accumulated in many places overlying the fossil dunes of the previous periods.

The distribution of playa and pan deposits in the southern and northern part of the Egyptian Sahara clearly indicates that a period of greater rainfall dates from ca. 9 500 to 6 700 B.P. (Figure 16.2). This mid-Holocene moist phase was preceded by an early Holocene dry period during which dunes invaded the depressions in the south of the Egyptian Sahara. In the north, at Siwa, such dune deposits are not found; indicating that deflation rather than accumulation of aeolian sand was going on in the northern depressions. The period of playa deposition does not represent a period of uniform climatic

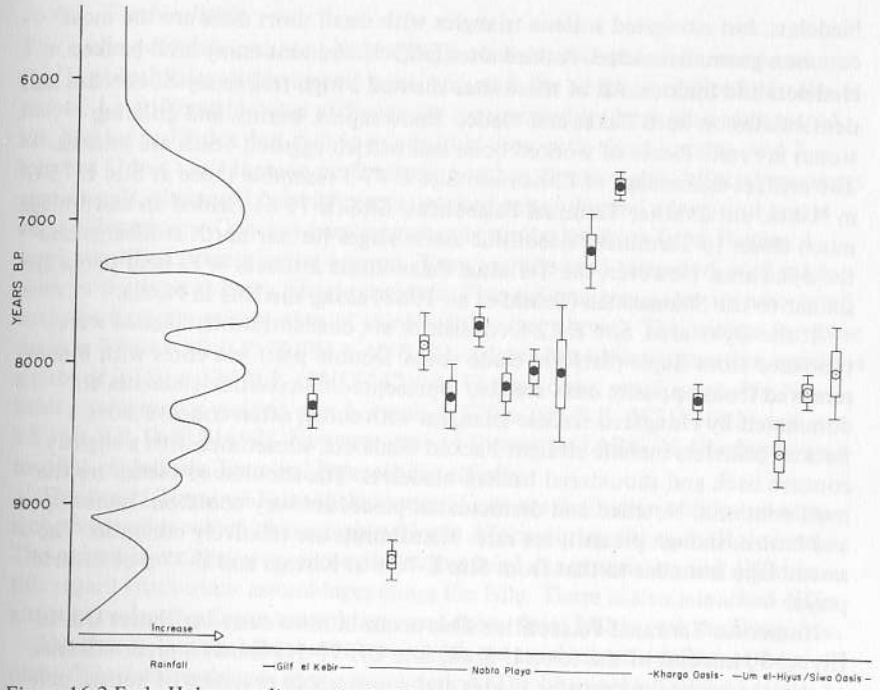


Figure 16.2 Early Holocene climates in the Egyptian Sahara.

conditions. Initially, the climatic conditions were characterized by frequent fluctuations with an alternation of dry and wet conditions, followed by a period of predominantly moist conditions. The moist phase was followed ca. 6 700 B.P. by dry conditions which prevailed perhaps with minor interruptions, such as during Roman times to the present.

16.4 ARCHAEOLOGICAL SITES AND ARTIFACT ASSEMBLAGES

16.4.1 *The Terminal Palaeolithic*

Terminal Palaeolithic sites are found in many places in the Western Desert. We have studied these in detail in the Nabta and Dyke areas in the southern part of the desert and at El Arag and Gara Oases in the Siwa Oasis region, northwestern part of the Desert.

The sites at Nabta are characterized by microlithic elements. The blanks are produced from cores struck from a single platform or changed orientation platforms. One site (E-75-6) shows an emphasis on pointed bladelets with straight to slightly arched backs. Geometrics are usually isosceles triangles with two concave and markedly convergent sides. Ounan points (or a closely related form) occur in several varieties. Another site (E-75-7) contains many straight-backed

bladelets, but elongated scalene triangles with small short sides are the most common geometric shape. A third site (E-75-9) contains many arch-backed bladelets and lunates. All of these sites showed a high frequency of notches and denticulates on both flakes and blades. Endscrapers, burins, and grinding stones are rare. Pieces of worked bone and ostrich eggshell beads are present. The artifact assemblage at El-Kortein Site E-77-3 resemble those at Site E-75-6 in Nabta, but another Terminal Palaeolithic Site (E-77-6) yielded an assemblage much closer to Terminal Palaeolithic assemblages further north at Kharga and the dyke area. However, the Terminal Palaeolithic artifacts at El-Beid playa are similar to the Shamarkian (Schild et al. 1968) along the Nile in Nubia.

At the Dyke area, Site E-72-5 consists of six concentrations. Blanks were produced from single platform blade cores. Double platform cores with blades removed from opposite ends are also represented. Microlithic elements are dominated by elongated scalene triangles with short, often concave sides. Backed bladelets include straight backed bladelets, sometimes with a slightly concave back and shouldered backed bladelets. The shouldered pieces are the most common. Notched and denticulated pieces are very common. Endscrapers and burins, though present, are rare. Microburins are relatively common. The assemblage is similar to that from Site E-76-6 at Kharga and E-77-6 at El-Beid playa.

Numerous Terminal Palaeolithic sites occur in Siwa oasis. At Hatiet Um El-Hiyus, 30 km east of the town if Siwa, Site UH-75-5/6 shows a predominance of straight backed microlithic blades and a noticeable presence of burins, perforators and microburins. Site UH-75-31, on the other hand is markedly rich in burins, represented by dihedral, double and single varieties. Both snapping and truncation in preparing the burin facets were practised. Endscrapers, perforators, denticulates, and microburins, as well as microlithic backed blades are common. Site UH-75-5/6 yielded a date of 8 119 ± 64 on ostrich eggshell (SMU-281) and one site situated on a plateau overlooking the depression UH-78-31 yielded a date of 7 980 ± 160 B.P. (WSU-1697), also on ostrich eggshell.

At Gara oasis, 130 km northwest of Siwa town, a site complex of seven major concentrations was studied. In one of the sites (G-75-27), the tools are dominated by burins, denticulates, perforators, and backed microlithic blades. Microburins are absent. Endscrapers, scaled pieces, and notches are rare. There is also an abundance of arrowheads. A radiocarbon date on ostrich eggshell from this site is 8 219 ± 72 B.P. (SMU-300).

At El Arag Oasis, 97 km east of Siwa and 100 km south of Gara, several Terminal Palaeolithic sites were located on the eastern and southern part of the area on the edge of the plateau overlooking the depression.

The largest of the sites (ARG-76-24) shows a predominance of burins. Backed microlithic elements follow in abundance. They consist of straight-backed, arched-backed and shouldered varieties. Endscrapers, notched and denticulated pieces, microburins, and points are rare. A date on ostrich eggshell from this site yielded an age of 7 980 ± 160 B.P. (WSU-1694).

16.4.2 *The Neolithic*

The earliest Neolithic sites at Nabta playa contain artifacts similar to those of the Terminal Palaeolithic assemblages, but with the addition of Neolithic elements. Later Neolithic sites at Nabta are represented by large sites with a tool kit, lacking in blades, but rich in microlithic crescents, short lunates, and J-lunates. Other tools include perforators, notches, denticulates, bifacial stemmed arrowheads, elongated bifacial pieces, pecked celts, chipped adzes, and transverse sidescrapers. Concave-base arrowheads similar to those from Fayum A were identified. Ceramics are present. They include sand-tempered, well made ware in the typical Early Khartoum style. Five radiocarbon dates are associated with the earlier manifestation of the Neolithic (see above). The average for these dates is 7 944 ± 40 B.P. (5 994 ± 40 B.C.). A later Neolithic occupation provided a date of 7 150 ± 130 B.P. (SMU-242). At El Arag oasis, small, probably Neolithic, occurrences yielded ages between 6 520 ± 105 B.P. (WSU-1691) and ± 5 150 B.P. (WSU-1692). However, one of these sites (ARG-76-19) displays a tool kit of definite Terminal Palaeolithic affinity.

The desert Terminal Palaeolithic assemblages are definitely within the same techno-complex which characterizes North Africa during the early Holocene. The assemblages, however, show distinctive local characteristics and differ in this regard from other assemblages along the Nile. There is also a marked difference between the Siwan assemblages and those from Nabta and the Dyke area.

The desert Terminal Palaeolithic assemblages are distinctly different from many Nilotic assemblages of the same period. The Shamarkian (Schild et al. 1968) dating around 7 000 B.P. is dominated by backed microlithic blades and geometrics. Pointed backed bladelets both with straight and arch backs are common. Some show a truncated base. Geometrics consist predominantly of lunates (segments). The Qarunian is overwhelmingly dominated by backed blades, backed microlithic blades, and notches and denticulates. Straight-backed bladelets are slightly more frequent than arch-backed forms. The Qarunian ranges in age from 8 100 to 7 140 B.P. (Wendorf et al. 1970). The Qadan (Shiner 1968) which ranges from ca. 15 000 to 6 000 B.P. does not show a clear predominance of any single class. Backed flakes and blades, geometrics, sidescrapers, points and truncations are common. The geometrics are represented by lunates, J-lunates, and the so-called 'CC geometrics'. The points are predominantly of a leaf-shaped, small form with slight retouch. The Kabian (Vermeersch 1970), dating ca. 8 000 B.P., displays an anomalous abundance of microburins. Backed microlithic elements are next in frequency. They consist of the straight-backed and arch-backed pointed varieties. Trapezes are present, but rare.

The assemblages from Nabta playa share with the Nilotic assemblages the rarity of endscrapers and burins, and the abundance of backed microlithic blades. It is, however, distinguished by scalene and isoceles triangles and the Ounan-related points. The Dyke assemblage is distinguished by the abundance of notches and denticulates and by its geometrics and microburins. The geometrics are similar to those of Nabta in the abundance of triangles. Like the assemblages from Nabta and the Nile Valley, the Dyke assemblage is impoverished in endscrapers, but shows a modest frequency of burins. Perforators,

however, are lacking. In the Shamarkian, the Qarunian, and the Kabian perforators are represented by more than 5%.

The Siwan assemblages stand out because of their unusual richness in burins. They share with the southern assemblages of the Western Desert and Nilotic assemblages the abundance of backed blades, microlithic blades and the rarity of endscrapers. However, they differ from the Nabta and dyke assemblages in their lack of geometrics and the scarcity of notches and denticulates. Microburins are also rare. They also display a distinctive presence of perforators, especially of the '*mèche de forêt*' type. Perforators are shared with the Kabian, Qarunian, and Shamarkian. The '*mèche de forêt*' perforators are present in the Qarunian and the Kabian. These assemblages, however, show a pronounced presence of geometrics which the Siwan assemblages lack. It is interesting to note here that the Siwan Terminal Palaeolithic assemblages share with the 'Libyco-Capsian' and the 'ante or proto-Neolithic of the Haua Fteah (McBurney 1967) the abundance of burins and the relative low frequency of notches and denticulates.

The Neolithic sites in the Western Desert show some interesting similarities with Early Khartoum and the Fayum. The Nabta Neolithic pottery is sand-tempered, well made, and usually has a densely stamped surface in the typical Early Khartoum style. The Neolithic from the El-Kortein playa is similar to that from Nabta. Arkell (1976) refers to 'Early Khartoum' as 'Khartoum Mesolithic', a preagricultural culture based on fishing and hunting. The presence of grinding stone suggests to Arkell (1976:20-21) that wild cereals were exploited. The tool kit of the Khartoum Mesolithic is characterized by barbed bone points with grooved butts, crescents and lunates, scrapers, and borers. A date of 8 370 ± 350 B.P. (I-1485) on shell was reported recently from the Tagra site in the lower White Nile valley (Adamson et al. 1974:120). Another date from the same section of 8 130 ± 225 B.P. (SUA-68) indicates an age of ca. 8 250 B.P. for the Khartoum Mesolithic. It is noteworthy that the later Khartoum-related Neolithic assemblages at Nabta are characterized by lunates and crescents, which are present in the Khartoum Mesolithic. It should also be noted that the Qadan Final Palaeolithic and Terminal Palaeolithic assemblages are characterized by microlithic lunates and crescents.

The Nabta Neolithic sites also show the presence of several concave based arrowheads similar to those found in the Fayum A Neolithic which is dated to ca. 5 860-5 388 radiocarbon years B.P. (Wendorf et al. 1970).

The Neolithic assemblages from Kharga and Gilf Kebir do not contain Early Khartoum-like pottery and thus may belong to a different entity.

16.5 SUBSISTENCE AND SETTLEMENT

A large collection of faunal remains was obtained from the Terminal Palaeolithic and Neolithic sites at Nabta Playa. The Terminal Palaeolithic sites yielded numerous bones of Cape hare (*Lepus capensis*), Gazelle (*Gazella rufifrons*?), and ostrich eggshells. The Neolithic sites also contained abundant hare and gazelle bones, in addition to a few rare bones of the Egyptian mongoose (*Herpetes ichneumon*), African wildcat (*Felis libyca*), and hedgehog. The Neolithic

sites also yielded a few bones of cattle, which are believed to be domestic. At Kharga, the Neolithic sites yielded a few scraps of bone, mostly the teeth of a large bovid, which is believed to represent domestic cattle. Other faunal remains included sheep/goat and gazelle (*Gazella dorcas*?) (A.Gautier, ms.).

Macrobotanical remains at Nabta are abundant. This contrasts with the lack of pollen encountered both in the northern and southern parts of the Western Desert. The plants identified at Nabta include, *Acacia ehrenbergiana, Salsola baryosma,* tamarisk (*Tamarix* sp.), dom palm (*Hyphaena thebaica*), date palm (*Phoenix reclinata*), two varieties of barley, one domestic, the other wild, and four weeds common in cultivated and similar disturbed, moist areas: *Medicago* sp., *Tribulus logipetalus, Vicia* sp., and *Calendula* sp. In addition, one rachis of grass has been tentatively identified as sorghum (N.Hadidi, ms.). The domestic barley is the earliest confirmed domestic plant of Africa.

The Terminal Palaeolithic and Neolithic sites are located at the edge of, or in, playa deposits indicating that the settlements were governed by the availability of water and ground moisture. The Terminal Palaeolithic sites are small and scattered by comparison to the Neolithic sites, which are extensive.

One of the Terminal Palaeolithic sites in the Dyke area (Site E-72-5) consists of six concentrations, two of which are adjacent to each other. One of these concentrations, which has been excavated, consists of a very dense cluster of artifacts, almost circular, measuring 7 m in diameter. Numerous heavy sandstone slabs were scattered around the perimeter of the cluster. No internal patterning was detected. At Shyiata, 37 km northwest of Siwa town, a circular structure with limestone slabs around the perimeter of a light circular scatter of artifacts, measured 11.7 m in diameter. There was a definite patterning of cores, a hearth, ostrich eggshells, debitage, and tools. The ostrich eggshells yielded a date of 8 817 ± 77 B.P.

The Western Desert during the early Holocene can be seen now in a new light. It was not the kind of paradise with lush vegetation and teeming game that the first exploration of the Sahara has tempted many to picture (cf. Shaw 1976). The vegetation was most likely thin and concentrated around ephemeral lakes. It was an arid open desert steppe with wild grasses, thorn bushes, and a few acacia and tamarisk trees. The Libyan hare is a small hare which inhabits open grassy flats. The red-fronted gazelle (*Gazella rufifrons*) inhabits open arid habitats with thorn bushes. The Dorcas gazelle, which is slightly smaller than the red-fronted gazelle lives on sand dunes and in flat stony terrain and is well adapted to desert conditions. The African wildcat, which is conspecific with the European species, *Felis sylvestris,* inhabits all types of savanna. It is nocturnal and remains hidden in thick bush, tall grass, or rock crevices during the day (Dorst & Dandelot 1970). The ostrich inhabits sandy deserts, as well as areas with low bushes and thorn trees (Bannerman 1964).

The subsistence strategy of Terminal Palaeolithic peoples judging from their tool kit and their ecologic setting consisted most likely of hunting and plant gathering. Since the resources were scarce, it is envisaged that the people lived in small, flexible and mobile bands. However, since the resources were localized (but not necessarily fixed from year to year), certain places were repeatedly visited and inhabited. This reconstruction is consistent with present-day

observations of the Bushmen economy (Yellen & Harpending 1972).

The Neolithic inhabitants of the Egyptian Desert, though in possession of domestic animals and plants, continued to hunt wild animals and to collect wild plants. This is understandable since at the early stage of food production and under uncertain weather conditions, dependence on any single source of food would be foolhardy. The economic units were most probably still small, but cultivation could have led to more frequent occupation of those areas where agricultural land was available. Sites located near such areas would reflect such a settlement pattern, which would be associated with a lateral shift through time, evidenced by an extensive occupational area.

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17

Prehistoric settlements along the Main Nile

Les gisements préhistoriques le long du Nil

L'occupation humaine sur les bords du Nil remonte au début de la période Paléolithique. Les sites sont situés au bord de la plaine d'inondation, sur les terrasses du bas désert ainsi que sur les collines résiduelles du plateau désertique. Les dimensions des sites sont très variables. Quelques sites du Paléolithique inférieur couvrent une superficie allant jusqu'à 550.000 m^2, représentant probablement une occupation répétitive avec changement latéral dans le temps. Les sites du Paléolithique moyen et supérieur sont aussi assez étendus, mais à partir du Paléolithique moyen les sites de petite taille sont les plus répandus.

L'emplacement des gisements est fortement influencé par la disposition linéaire de la végétation le long du Nil. L'étroite plaine alluviale rend possible la location des sites au bord de cette plaine pour profiter en même temps des ressources du Nil ainsi que celles du désert. Pendant le Paléolithique inférieur et moyen, quand les précipitations étaient beaucoup plus importantes qu'à présent, les gisements étaient situés plus loin du Nil ainsi que dans le Sahara égyptien.

Les activités de subsistance avant la période prédynastique se concentraient surtout autour de la chasse au bétail sauvage et aux bubales et, de temps à autre, des gazelles, des ânes sauvages et des lièvres. La chasse à l'hippopotame semble avoir été pratiquée régulièrement et la pêche existait au moins depuis le Paléolithique moyen. Les ressources locales en plantes, provenant du Nil, de la plaine alluviale, et du désert, étaient probablement exploitées. Les changements dans la stratégie de subsistance semblent avoir été liés aux oscillations du Nil ainsi qu'aux changements du climat local. Pendant le Pleistocène terminal la vallée du Nil offrait une variété de traditions technologiques, un nombre de sites de plus en plus important et un dynamisme stylistique considérable. L'exploitation des céréales sauvages devient évidente à cette époque. L'économie agricole, par contre, ne suit pas immédiatement cette phase, peut être à cause d'une série d'inondations catastrophiques. Ce n'est qu'à partir de 7 000 B.P. que l'agriculture et la domestication deviennent le mode de subsistance dominant. Au cours de cette époque l'accent à été mis sur l'élevage. Vers 5 150 B.P. la civilisation dynastique de l'Egypte commence à remplacer les traditions préhistoriques.

17.1 INTRODUCTION

The prehistoric record along the Main Nile is long and diverse. Thanks to recent explorations and excavations, a great deal of information on the nature of prehistoric settlements has been obtained altering many of the beliefs on the prehistory of the Main Nile which were current before the 1960s. This chap-

ter presents an overall view of the prehistoric record from the Lower Palaeolithic to the end of the Neolithic with an emphasis on settlement patterns, seasonal occupation of the sites, and population size and mobility. The discussion will proceed in chronological order from the Lower Palaeolithic onward. The area covered includes the stretch of Nile from Sudanese Nubia to the Delta (Figure 17.1).

17.2 THE LOWER PALAEOLITHIC

Artifact scatters attributed to the Lower Palaeolithic have been reported from many places along the Main Nile in Nubia, Upper Egypt and the Delta. These artifacts were first reported at the turn of the century by Arcelin, Schweinfurth, Hamy, Lenormant, and de Morgan (Massoulard 1949; Smith 1974). The discovery of these artifacts provided the first evidence for a human past in Egypt that extended beyond Pharaonic times and served in addition to show that this prehistoric past goes back to one of the earliest periods of human antiquity. Surveys on the Nile from Nubia to Lower Egypt by Sandford & Arkell (1929, 1933, 1939) and Sandford (1934) provided further evidence for Lower Palaeolithic occupation. Sandford and Arkell also attempted to relate the position of Lower Palaeolithic artifacts to old Nile terraces. They recognised what they referred to as 'primitive' and evolved Chellean, and Chellean-Acheulian including flakes of 'Clactonian' manufacture associated with the 30 m Nile terrace. The Acheulian artifacts were found on the surface of the 30 m terrace, and in association with the 15 m terrace.

One of the better known localities where lower Palaeolithic artifacts were located is the Abbassia plain, Cairo, where Bovier-Lapierre (1925) discovered a sequence of artifact assemblages associated with sands and gravels exposed in a sand pit. According to Bovier-Lapierre, the sequence consisted of 'Pre-Chellean', Chellean, Acheulian and Micoquian levels. The artifacts, however, were rolled and reworked with the gravel and sand.

During the Nubia campaign, one of the first habitation sites (Arkin 8; Figure 17.2) was discovered (Chmielewski 1968). The site is situated near the edge of a low wadi terrace resting on Nubian Sandstone bedrock and the artifacts were covered by 20-30 cm of wadi gravel. The artifacts were scattered over an oval area 40 x 15-20 m (about 550 m^2). The artifact density averaged 6.2 artifacts/m^2. The total number of artifacts is 3 409. The site consists of eight concentrations, each covering an oval area 6 to 8 m in diameter (about 25-50 m^2). Near the edge of one concentration big blocks of Nubian Sandstone form an irregular circle about 4 m in diameter. The artifact assemblage is composed of cores, flakes, choppers, chopping tools, discs and half-discs, ovates, handaxes and tools made on flakes. The cores consist of discoidal and oval cores. Flakes are smaller than 120 mm in length and many of the flakes are decortication flakes. The platforms are cortical, unfaceted, or multifaceted. The handaxes are small (less than 100 mm) and cordiform. Less frequent types include suboval, amygdaloidal, and lanceloate types. Tools made on flakes consist mostly of side-scrapers and retouched flakes. Burins and borers are rare. The assemblage

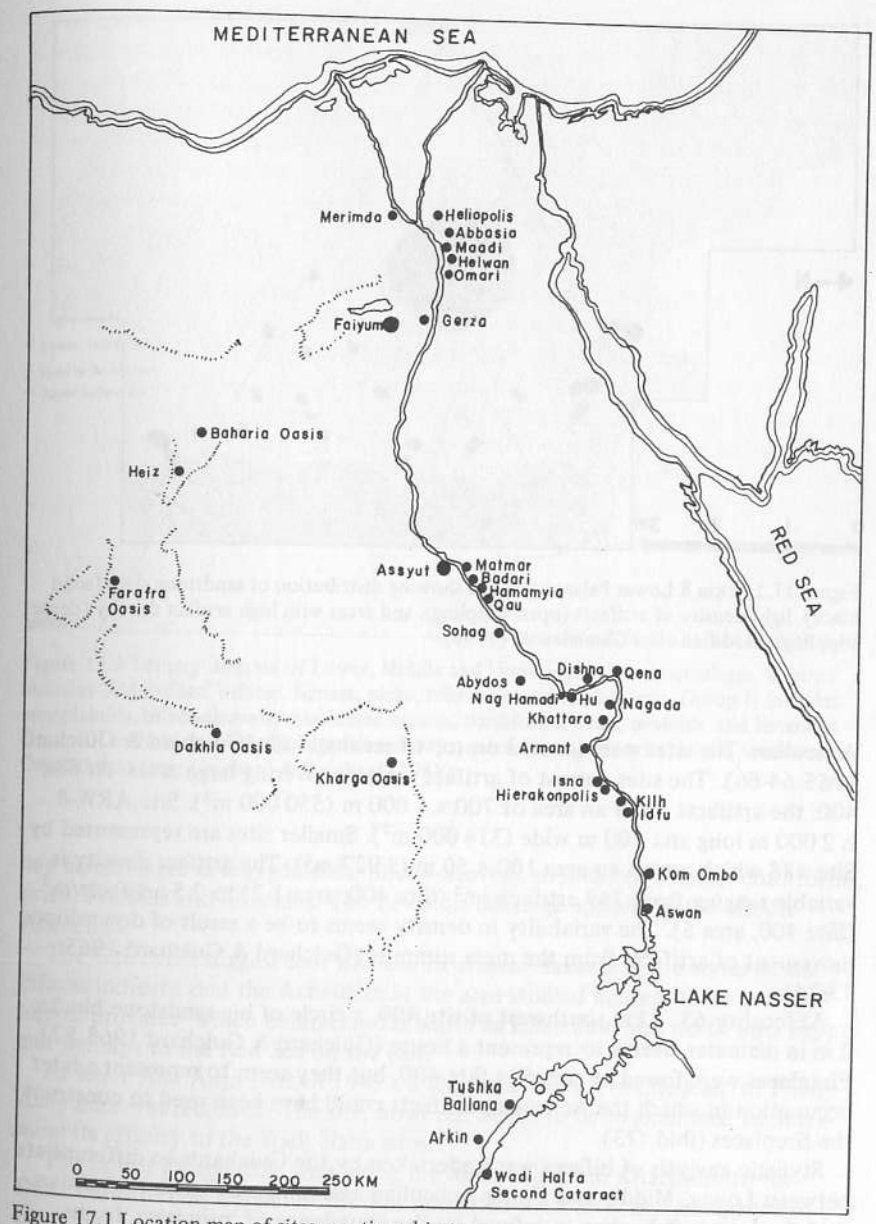


Figure 17.1 Location map of sites mentioned in text.

is regarded as Lower Acheulian. Other Lower Palaeolithic sites, mostly of reworked and wind-abraded artifacts, were found in the area of the Arkin 8.

Acheulian sites were also found by the Guichards (1965, 1968) in Nubia near Wadi Halfa. They classified the sites into Lower, Middle and Upper

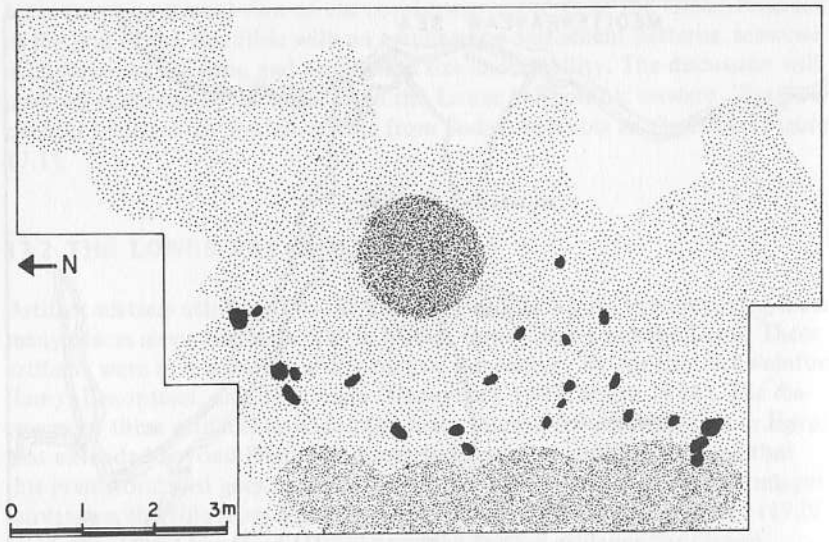


Figure 17.2 Arkin 8 Lower Palaeolithic site showing distribution of sandstone slabs (solid black), light density of artifacts (open stippling), and areas with high artifact density (dense stippling). Modified after Chmielewski (1968).

Acheulian. The sites were located on top of residual hills (Guichard & Guichard 1965:64-66). The sites consist of artifact scatters covering large areas. At Site 400, the artifacts cover an area of 700 x 1 000 m (550 000 m²). Site ARW-8 is 2 000 m long and 200 m wide (314 000 m²). Smaller sites are represented by Site 438 which covers an area 100 x 50 m (3 927 m²). The artifact density is variable ranging from 249 artifacts/m² (Site 400, area 1-2) to 2.5 artifacts/m² (Site 400, area 5). The variability in density seems to be a result of downslope movement of artifacts from the mesa summits (Guichard & Guichard 1965: 73-74).

At locality 63, 1 km southwest of site 400, a circle of big sandstone blocks, 2 m in diameter, seems to represent a house (Guichard & Guichard 1965:82). Fireplaces were found at area 5 in Site 400, but they seem to represent a later occupation in which the Acheulian artifacts could have been used to construct the fireplaces (ibid.:73).

Stylistic analysis of bifaces was undertaken by the Guichards to differentiate between Lower, Middle and Upper Acheulian assemblages. Figure 17.3 shows that the Lower Acheulian is defined by the abundance of 'primitive' forms; 'Abbevillian' bifaces, ficrons, picks, trihedrals, and nucleiforms, and a low frequency of 'refined' forms; lanceolates, lageniforms, Micoquian forms, pelecyforms and reniforms. The Upper Acheulian shows the reverse with the 'refined' forms amounting to about 60% of the finished bifaces. The Middle Acheulian assemblages are intermediate with their frequencies. Both the Middle Acheulian and Upper Acheulian show a slightly higher frequency than the Lower Acheu-

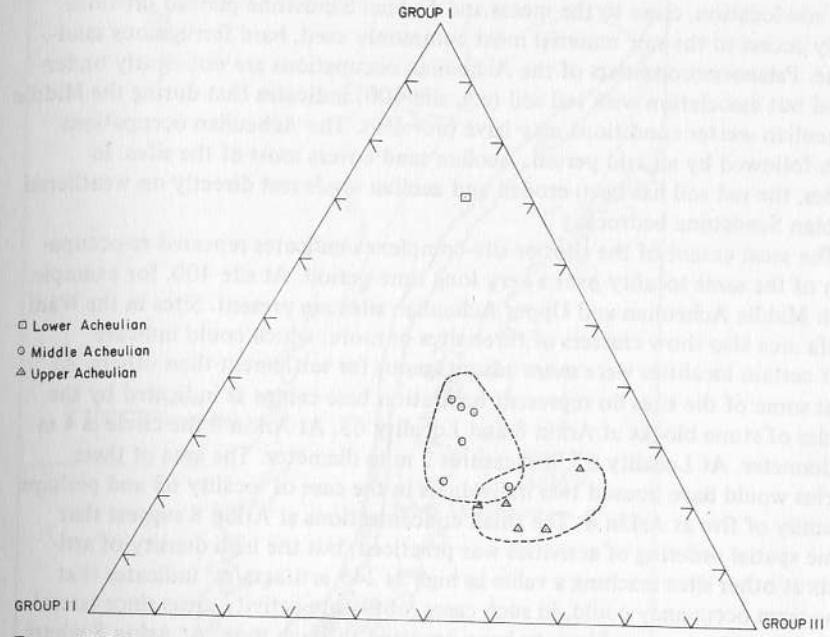


Figure 17.3 Ternary diagram of Lower, Middle and Upper Acheulian assemblages. Group I includes 'Abbevillian' bifaces, ficrons, picks, trihedrals, and nucleiforms. Group II includes amygdaloids, biface-cleavers, shouldered bifaces, cordiforms, ovals, ovaloids, and limandes. Group III includes lanceolates, lageniforms, Micoquian forms, pelecyforms and reniforms. Original data from Guichard & Guichard (1968).

lian assemblages in amygdaloids, biface-cleavers, shouldered bifaces, cordiforms, ovals, ovaloids and limandes. The Levallois debitage appears in the Middle Acheulian.

The Guichards suggest that the lack of cleaver-flakes and the styles of the bifaces indicate that the Acheulian in the area studied belongs to an archaeological province which extends as far south as Khartoum and north into Egypt, and perhaps to the Red Sea on the east.

At Khor Abu Anga (Arkell 1949), a sequence from 'Pre-Chellean' to Final Acheulian was recorded. The site, however, needs to be re-examined to determine its affinity to the Wadi Halfa sites.

The Lower Palaeolithic sites along the Main Nile from Khartoum to the Delta indicate that the Main Nile was inhabited soon after the emergence of *Homo* sp. in East Africa and Ethiopia. The distribution of sites in the Wadi Halfa region from the Lower to the Middle Acheulian within an area 10 x 2 km and the stylistic continuity observed there indicates that there could have been a certain degree of regional continuity of technological tradition over very long time spans. The sites are about 1 to 5 km from the Nile channel indicating that they probably availed themselves of the resources of the Nile. Proximity to major wadis may also indicate the utilization of wadi animal and plant resources.

The site location, close to the mesas and Nubian Sandstone plateau provides ready access to the raw material most commonly used, hard ferruginous sandstone. Palaeoenvironments of the Acheulian occupations are not clearly understood but association with red soil (e.g. site 400) indicates that during the Middle Acheulian wetter conditions may have prevailed. The Acheulian occupations were followed by an arid period. Aeolian sand covers most of the sites. In places, the red soil has been eroded and aeolian sands rest directly on weathered Nubian Sandstone bedrock.

The areal extent of the sites or site-complexes indicates repeated re-occupation of the same locality over a very long time period. At site 400, for example, both Middle Acheulian and Upper Acheulian sites are present. Sites in the Wadi Halfa area also show clusters of three sites or more, which could indicate that certain localities were more advantageous for settlement than others. At least some of the sites do represent habitation base-camps as indicated by the circles of stone blocks at Arkin 8 and Locality 63. At Arkin 8 the circle is 4 m in diameter. At Locality 63, it measures 2 m in diameter. The area of these circles would have housed two individuals in the case of locality 63 and perhaps a family of five at Arkin 8. The small concentrations at Arkin 8 suggest that some spatial ordering of activities was practiced, but the high density of artifacts at other sites reaching a value as high as 245 artifacts/m^2 indicates that long-term occupancy could, in such cases, obfuscate activity areas since lateral shift in activity areas is likely to have occurred through time. At Arkin 8 where the density is about six artifacts/m^2 the recognition of the small concentrations could be attributed to lack of excessive spatial overlap through time.

17.3 MIDDLE PALAEOLITHIC

The earliest work on the Middle Palaeolithic of Egypt was done by Caton-Thompson (1946, 1952), Caton-Thompson & Gardner (1934), and Sandford & Arkell (1929, 1933, 1939). However, most of the Middle Palaeolithic sites known at the time yielded few artifacts and in many cases the artifacts were not in primary context. Consequently, their original geological position is uncertain. Caton-Thompson (1946) recognized three stages of what she called Mousterian along the Nile and a sequence of Acheulo-Levalloisian, Levalloiso–Khargan, Khargan, and Aterian in the Kharga Oasis, Western Desert. More recent work by Guichard & Guichard (1965, 1968), Chmielewski (1965, 1968), and Marks (1968a) provided a much more detailed body of information. Middle Palaeolithic sites have also recently been located in the Western Desert of Egypt, associated with lacustrine deposits and fauna (Wendorf & Schild 1976b). This new phase of research led to a rejection of the earlier chronology and terminology of Caton-Thompson for the Middle Palaeolithic. The Middle Palaeolithic studied by the Guichards was termed the Nubian Middle Stone Age and was subdivided into two main groups: (1) those with crude bifacial foliate objects, believed to resemble the Middle Sangoan of Sub-Saharan Africa, and (2) those with more refined bifacial foliates, bilateral sidescrapers with rounded tips, and distinctive point cores resembling the Aterian of North Africa and

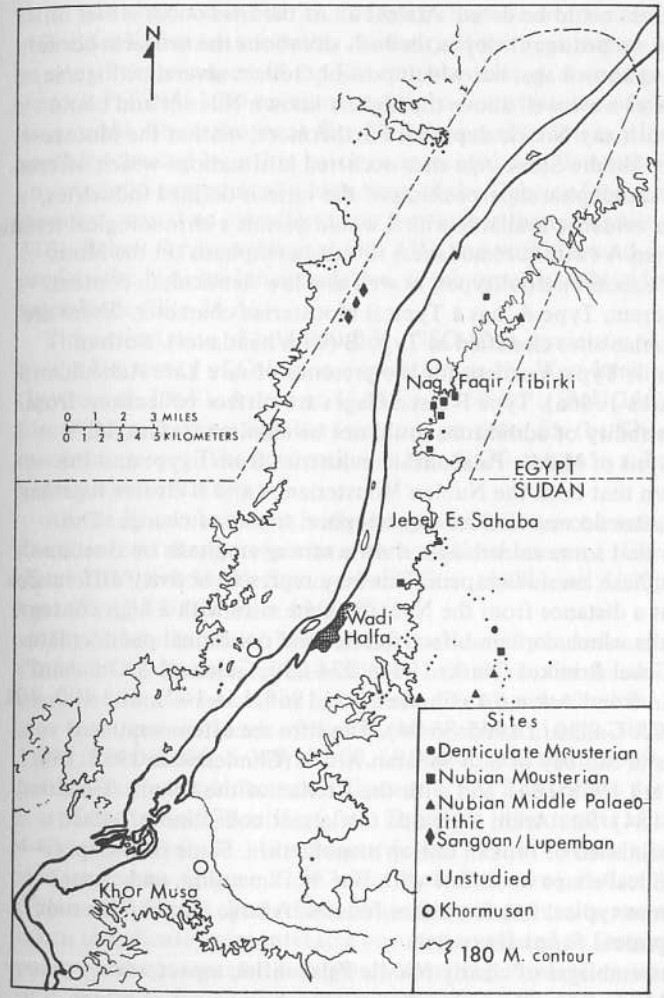


Figure 17.4 Location map of Middle Palaeolithic sites in Nubia, after Marks (1968a, 1968b).

some Stillbay assemblages of East Africa. All of the Nubian Middle Stone Age sites were located on the tops of mesas and buttes, and they could not be related stratigraphically to the sediments in the Nile Valley.

Chmielewski (1965, 1968) described two Middle Palaeolithic sites (Arkin 5 and Arkin 6A), both located on the west bank of the Nile (Figure 17.4) and also well above the highest known Nile silt. Both of these resemble the Nubian Middle Stone Age industry of the Guichards, and strong Sangoan affinities were also noted.

Marks (1968a) defined two major groups: Nubian Mousterian and Denticulate Mousterian. The Nubian Mousterian was further subdivided on the basis of presence or absence of bifaces into two subgroups, A and B. Unfortunately, none

of the Mousterian sites could be dated. Almost all of the sites occur either on the top of buttes or on pediment slopes. In both situations the artifacts occur within red soils of unknown age, but which possibly reflect several pedogenic events. All of the sites were well above the highest known Nile silt and could not be correlated with any Nilotic deposits. Furthermore, neither the Mousterian nor the Nubian Middle Stone Age sites occurred in situations which offered evidence of clear stratigraphic superposition of the various defined industries, nor was there other evidence available which would permit a chronological seriation.

Nubian Mousterian A (without handaxes) shows an emphasis on the Mousterian and Upper Palaeolithic tool types, as well as a low denticulate content. The Nubian Mousterian, Type A, has a Typical Mousterian character. There are two Nubian Mousterian sites classified as Type B (with handaxes). Both of these closely resemble Type A except for the presence of rare Late Acheulian type handaxes (Marks 1968a). Type B assemblages are surface collections from buttes, and the possibility of admixture could not be eliminated. Graybill's (1975) cluster analysis of Middle Palaeolithic industries from Egypt and the Near East has shown that both the Nubian Mousterian A and B cluster together.

The Mousterian sites do not disclose any temporal trends of change. The tools indicate only that some assemblages show a strong emphasis on denticulates, others an emphasis on sidescrapers. This may represent activity differences. In Nubia, mostly at a distance from the Nile, there are sites with a high content of Levallois elements which contain biface foliates and occasional pedunculates. Among these are Gebel Brinikol (Marks 1968a:274-280; Guichard & Guichard 1965:86-89), Arkin 5 and Arkin 6A (Chmielewski 1968:134-147), Site 400, 401, and 415 (Guichard & Guichard 1965:86-94). The sites are often compared with the Sangoan and Stillbay of Sub-Saharan Africa (Chmielewski 1968:146; Guichard & Guichard 1968:184), and with the Aterian of the Sahara (Guichard & Guichard 1968:184). Site Arkin 5 yielded the largest collection of biface foliates, mostly unfinished or broken during manufacture. Some of the specimens are elongated leaf-shape in outline with fine workmanship, and cannot be distinguished from typical Aterian biface foliates. A large number of crude, handaxe-like amygdaloid forms also occur.

Two stratified assemblages of clearly Middle Palaeolithic aspect were recovered at Site 440 in Khor Musa near Wadi Halfa. A fragment of biface foliate from the surface collection suggests that these assemblages may belong to the Aterian complex.

Marks (1968b) also studied a number of sites he grouped in an industrial complex named the Khormusan. Although they displayed many Middle Palaeolithic traits, both in their technology and typology, they were designated as Upper Palaeolithic in age for three reasons: (1) two radiocarbon dates, one at Site 1017 of 20 750 B.C. ± 250 years (WSU-203), and the second at Site ANW-3 of 15 850 B.C. ± 500 years (WSU-215) (Marks 1968b:318), (2) the general geological reconstruction which placed the Khormusan bearing sediments within the Debeira-Jer and Ballana Formations, believed to be Terminal Pleistocene in age, and (3) the relatively high Upper Palaeolithic Index, mainly consisting of burins.

Drastic changes in the interpretation of the Khormusan industry by Wendorf & Schild (1976b) are suggested by three new radiocarbon dates. One of those

dates was obtained at Site 34, Industry D, which overlies the layer containing a still older Khormusan industry. Industry D was regarded on typological grounds as one of the youngest of the Khormusan series. A date of greater than 41 490 years B.P. (SMU-106) on humates from a sandy residue of a hearth is regarded as minimal. The industry at Site 34-D occurred in situ in a loose fluvial sand partially covered by a thin patch of truncated silts. It was believed that the covering silts represented a high stage of the Debeira-Jer aggradation which, however, was at an elevation some 6 m higher than elsewhere (Marks 1968a: 318). Below the assemblage at Site 34D, and within a sand dune assumed to predate the Debeira-Jer aggradation, is the typologically oldest Khormusan assemblage (Site 34-A).

The second date of >36 000 B.P. (GSO-409), comes from Site 6G30, excavated by the University of Colorado expedition on the West bank opposite Wadi Halfa (Irwin et al. 1968). A date of 33 800 ± 3 350 B.P. (SMU-245), Site 1017, reinforces the suggestion that the two younger dates for the Khormusan could be much too recent. The occupation at Site 6G30 occurs in a dune sand sandwiched between two silt units.

All the Khormusan sites with abundant fauna are characterized by the predominance of *Bos primigenius* with occasional bones of *Gazella rufifrons* (Sites 1017 and 34-D), *Equus asinus* (Sites ANW-3 and 1017) and a large antelope (Site 34-D) (Gautier 1968:98).

The Middle Palaeolithic sites vary considerably in area and artifact density (Table 17.1). The minimum area is 16 m^2 and the maximum 31 415 m^2. The increase in the mean radius for the site area classes, obtained by averaging the area for the sites in each of the following classes: 10-20, 50-100, 100-500, 500-1 000, 1 000-5 000, 5 000-10 000, 10 000-25 000 and 25 000-50 000 m^2, shows a patterned allometric increase (Figures 17.5A, B). Artifact density varies from 5 artifacts/m^2 to 273 artifacts/m^2. There are three modes of artifact density: 4-47 artifacts/m^2, 77-117 artifacts/m^2 and 174-273 artifacts/m^2. The increase in artifact density (Figure 17.5C), like that of site area, is also allometric (Figures 17.5D, E). Both the increase in artifact density and site area can be taken to indicate more intensive occupation related to longer duration of occupancy, perhaps repeated occupancy assuming constant group size. The intensity of occupation can be measured by multiplying the area of the site by the density of artifacts. This provides an index of the intensity of occupation.

The increase in the intensity of occupation seems to have been regular and patterned. The cumulative percentage of sites plotted against their index of the intensity of occupation following the technique devised by Berry (1961) shows a continuous log-normal distribution (Figure 17.5F). This may indicate that the sites represent a continuum with a homogeneous organizational pattern. None of the sites seems to represent a major centre of specialized activity. This is intriguing because these sites belong to different stylistic traditions and some presumably represent workshops. It must be recalled, however, that debitage, even at habitation base camps would be the most frequent artifact category because it has a greater chance of abandonment and a very low chance for reuse (cf. Schiffer 1976). Tools on the other hand, should be expected to be present in very low frequencies, even at habitation sites, because they are of

Table 17.1 Area and density of artifacts – Middle Palaeolithic sites along the Main Nile

Site	Area (m^2)	Density (artifacts/m^2)
Arkin 5	1 767	97
Brinkol	400	
400 = 1-1	27.5	117
415	1 884	
401D	3 680	
415A	16	47
420	16	
Abu Simbel, 1	12 140	
36	31 415	
1000	1 000	87
36B	200	77
1010-8	50	86
1035	100	23
1036	200	42
1037	60	273
1038	200	174
1033	1 000	210, 177
6	500	5
121	40	25

greater value ensuring a longer life span of use, a higher probability of retrieval when dropped or mislocated, and are likely to be used outside the area of the site where they would be lost, dropped or discarded.

The area of the sites seems to obey the following rule:

$$A_{n+1} = k(A_n)$$

where k equals ½. A_n is the area of the nth site in the series 1, 2, 3, . . . n, in which sites are arranged in descending order by area, and A_1 is the largest site. It is not clear what specific factors are responsible for this order (cf. Haggett 1966), but re-occupation might be a major factor.

Site areas up to 250 m^2 would seem to represent occupation by a group consisting of one to five families. Sites larger than 500 m^2 are less likely to have been occupied by a multi-unit group. This is especially the case in those sites which are greater than 3 680 m^2. Sites with very large areas thus would indicate multiple re-occupation of the site area with considerable lateral shift in the areas of activities through time. This seems to be the case in sites Arkin 5, 1000, and 1033 which are characterized both by a very large area and a high artifact density. Small sites 16 m^2 to 200 m^2 with high artifact density, on the other hand, would seem to indicate that the site was continuously occupied over a long time period. Such sites include 400-1-1, 36-B, 101-B, 1037 and 1038. Small sites of similar area but relatively low artifact density, such as 1036, 1035, and 415A would seem to represent continuous occupation of a site for a shorter time period. None of the sites has an artifact density low enough to qualify as a transient or ephemeral occupation.

Evidence of multiple re-occupation of a site locality or prolonged occupation of a site would indicate that such sites were favoured because of proximity to

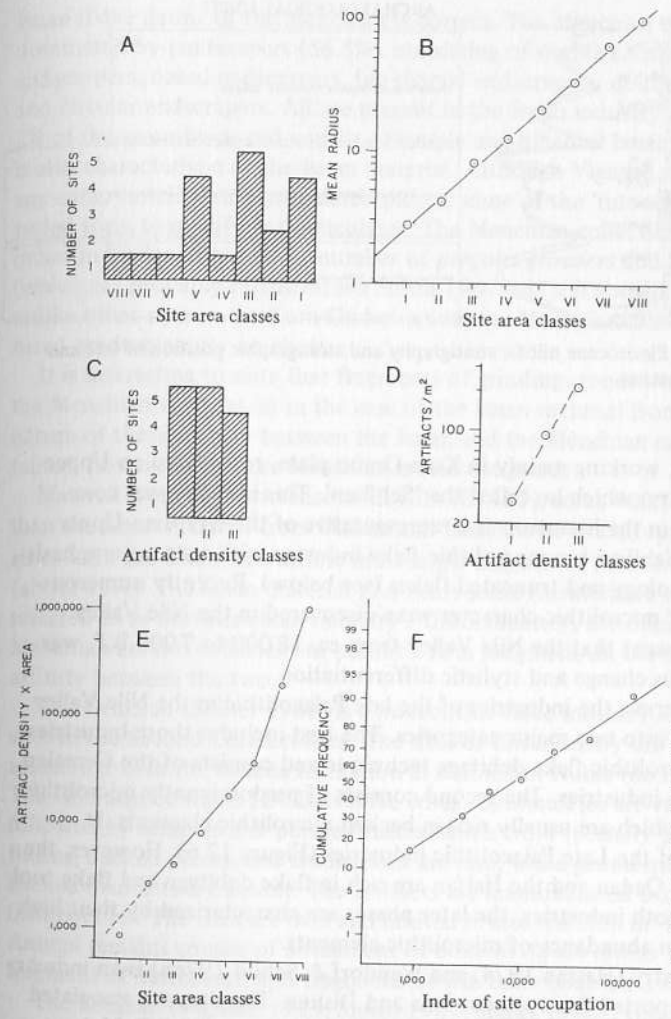


Figure 17.5 Size and density of Middle Palaeolithic sites:
A. Number of sites in the following classes: I (10-50 m^2), II (50-100 m^2), III (100-500 m^2), IV (500-1 000 m^2), V (1 000-5 000 m^2), VI (5 000-10 000 m^2), VII (10 000-25 000 m^2), VIII (25 000-50 000 m^2).
B. Mean radius for site area classes.
C. Artifact density classes: I (4-47 artifacts/m^2), II (77-117 artifacts/m^2), III (174-273 artifacts/m^2).
D. Mean density (artifacts/m^2) versus artifact density classes.
E. Site area classes versus artifact density multiplied by site area.
F. Cumulative frequency of sites plotted using normal probability scale.

key resources (food and others) and would also indicate that some cultural continuity was involved.

17.4 THE LATE AND TERMINAL PALAEOLITHIC

The results of early investigations on the Palaeolithic of Egypt have led many archaeologists to regard the Nile Valley during the Palaeolithic as an isolated enclave where the old techniques of the Middle Palaeolithic continued to be pursued with very few modifications. These Late Palaeolithic industries, rich in their content of Levallois flakes, were called the 'Epi-Levalloisian' (Caton-Thompson 1952).

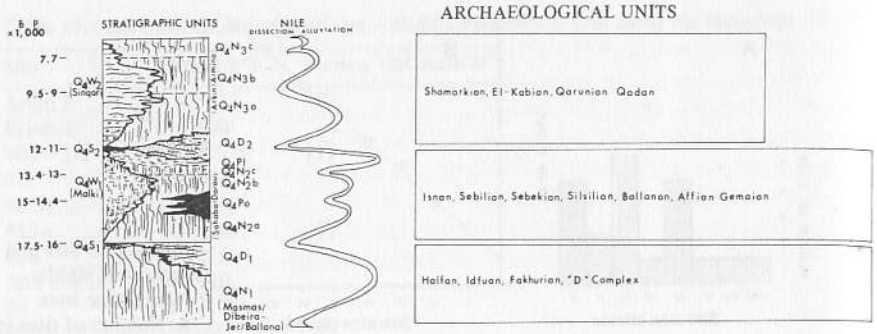


Figure 17.6 Terminal Pleistocene nilotic stratigraphy and stratigraphic position of late and final Palaeolithic industries.

Vignard (1923), working mainly in Kom Ombo plain, recognized an Upper Palaeolithic industry, which he called the 'Sebilian'. This industry was commonly referred to in the literature as a representative of the Egyptian Upper Palaeolithic. The Sebilian is a macrolithic flake industry with a strong emphasis on Levallois technology and truncated flakes (see below). Recently numerous blade industries of microlithic character were discovered in the Nile Valley and it seems at present that the Nile Valley from ca. 18 000 to 7 000 B.P. was a region of vigorous change and stylistic differentiation.

In very broad terms, the industries of the late Palaeolithic in the Nile Valley can be subdivided into two major categories. The first includes those industries which share a macrolithic flake debitage technique and consists of the Gemaian, Sebilian and Isnan industries. The second consists of predominantly microlithic blade industries, which are usually rich in backed microlithic elements. It includes the rest of the Late Palaeolithic industries (Figure 17.6). However, the early phase of the Qadan and the Halfan are rich in flake debitage and flake tool elements, but in both industries, the later phases are characterized by their high blade index and an abundance of microlithic elements.

The Isnan industry (Hassan 1974; and Wendorf & Schild 1976a) is an industry which has been reported from sites at Isna and Dishna. The sites are associated with the Sahaba silt (Figure 17.6) and date to ca. 13 000-12 500 B.P. Major core types consist of single platform, double platform and discoidal cores. The debitage consists mainly of flakes. Levallois flakes are practically absent. Endscrapers are very common, followed by burins, and denticulates and notches. A few backed pieces and truncated pieces are present. At Isna, the artifact assemblages include grinding stones and it is likely that processing of wild grain was undertaken at these sites.

Other archaeological material which seems to be somewhat related to the Isnan is the 'Menchian industry' (Smith 1966:336, 1967:147), first recognized by Vignard (1955) at Menchia in the northern part of the Kom-Ombo Plain and called 'middle Aurignacian'. The collection is contemporaneous with Sebilian II of Vignard (Smith 1967:147) and would thus fall within a range of about 14 000-11 000 B.P. The Menchian is therefore contemporaneous with the

Isnan if the dating of the Menchian is correct. The Menchian artifacts are dominated by endscrapers (56.5%), consisting of simple endscrapers, carinated endscrapers, nosed endscrapers, fan-shaped endscrapers, double endscrapers, and circular endscrapers. All are present in the Isnan industry. Burins constitute 2% of the assemblage and consist of simple and dihedral burins. The assemblage is also characteristic of the Isnan material. Although Vignard does not report any other notched or denticulated pieces, some of the 'retouched' blades illustrated seem to qualify as denticulates. The Menchian collection seems to be richer in blades. It has also a number of *perçoirs grossiers* and Sebilian elements (which are probably intrusive; see Smith 1967:147). It should be noted that unlike other sites in the Kom-Ombo region, the Menchian artifacts are manufactured predominantly on chert.

It is interesting to note that fragments of grinding stones were recovered with the Menchian material, as in the case of the Isnan material from Isna. The exact nature of the similarity between the Isnan and the Menchian cannot be ascertained, however, until the Menchian is reinvestigated.

Material from an occurrence at El Kilh (E71P5), some 400 years younger than the Isnan material from Dishna and Isna, shows overall typological similarities with the Isnan, but differs in its larger content of microlithic tool elements (about 15%). The Isnan material also bears some resemblance to the material referred to as the 'Menchian industry'. Unfortunately, the data available on the Menchian are not sufficient to permit a firm judgment on the nature of the affinity between the two.

The Gemaian (Shiner 1968) is a macrolithic flake industry known from six sites in the Second Cataract area. The sites of this industry are believed to be associated with the Sahaba formation as defined in Nubia (de Heinzelin 1968). The Gemaian contains Levallois flake cores. Denticulates are very frequent, followed by scrapers and pointed flakes struck from specially prepared cores. Burins, backed pieces, and truncations are rare, while geometrics, microburins, backed bladelets are absent. The artifacts are manufactured exclusively on Nile flint cobbles. The sites are oval and limited in size (ca. 350 m^2 in average). Animal remains consist of a fragment of bone of *Equus asinus africanus,* a bone fragment of hartebeest, and fragments of fish bone (Gautier 1968).

The Sebilian (Vignard 1923; Smith 1967; Marks 1968c; Hassan 1972a; Hassan & Wendorf 1974) is known along the Nile from the Second Cataract to Qena, dating approximately between 15 000 and 11 000 B.P. The Levallois flake and the discoidal core techniques are the most common core techniques in this industry. The industry is highly macrolithic with a low blade index and a high faceting index. Although tools are dominated by single and double tuncated pieces, all other tool types are present in negligible amounts. The raw material utilized consists of a variety of materials; ferruginous sandstone, quartz, dacite, quartzite and chert concretions. The Sebilian as envisaged by Vignard consists of three stages. Recent studies on Sebilian collections from Nubia and Upper Egypt (Marks 1968c; Wendorf 1968; Hassan 1972a) revealed that these collections strongly resemble Vignard's Sebilian I.

The differences within the macrolithic-flake category cannot be ascribed to seasonal variations since there are major differences in the basic manufacturing

techniques of cores and tools. Explanation of such differences in terms of seasonal variations (Lubell 1971) seems very unlikely unless one is ready to assume that a group changes its manufacturing technology seasonally. Most of the sites of these industries are also spatially contiguous. This would preclude the hypothesis that these settlements belong to different seasons, unless the seasonal variations were not associated with seasonal mobility. Moreover, the seasonality model cannot be accepted without explaining the observed differences in tool classes and manufacturing techniques in terms of seasonally specific activities.

Industries of the microlithic group which are for the most part older than 17 000 B.P. include the Halfan, the Idfuan, and the Fakhurian. The Halfan (Marks 1968d) – an industry subdivided into five stages, the first of which is hypothetical – dates between ca. 20 000 to 17 000 B.P. The industry is characterized by a variety of Levallois flake core called the Halfa core, and single platform and opposed double platform cores. Wedge cores are also characteristic. The industry is highly microlithic and becomes lamellar after Stage III. Halfa flakes are common, and decrease through time, whereas backed blades show a gradual increase. Scrapers, burins, denticulates, and notches are usually uncommon and likewise decrease with time. Truncations and scaled pieces are rare. The raw material utilized consists mainly of Nilotic flint. Halfan sites are known along the Nile from the Second Cataract to Kom Ombo and are described from the latter area by Smith (1967). The sites are generally oval and small (ca. 250 m^2). Fish remains are common in most of the sites.

The Idfuan (Wendorf & Schild 1976a) is known from el Kilh area, near Isna, dating between 17 800 and 17 000 B.P. The Idfuan industry is subdivided into two units, the first characterized by Levallois elements (IL slightly below 10%), microlithic blades and opposed platform cores. The tools show variations in the frequency of burins and Ouchtata retouched pieces. Notched and denticulated pieces are numerous. The other subdivision is characterized by the absence of Levallois flake cores and flakes, and the presence of prepared double platform cores. The tools show much variation in the proportions of Ouchtata bladelets and burins. The raw material utilized for the manufacture of the Idfuan artifacts is predominantly Nile flint. The Idfuan sites are varied in size, some are large and dense. Faunal remains include wild cattle, hartebeest, fish and mussels (*Unio* sp.).

The Fakhurian industry (Lubell 1974), also from the area in the neighbourhood of Isna, dates between 18 000 and 17 600 B.P. The Fakhurian industry is characterized by the absence of the Levallois technique, and an emphasis on double platform and single platform cores. Microlithic blades are the most frequent blanks. Tools are dominated by backed bladelets, retouched pieces, double backed perforators, and denticulates. Truncations, endscrapers and burins are rare. The material utilized for the Fakhurian artifacts is mainly Nilotic flint. The sites are generally small. Faunal remains consist of wild cattle, hartebeest, redfronted gazelle, hippopotamus and rabbit. Fish and bird remains are also present.

Other industries of the microlithic blade tradition in the younger time bracket include the Ballanan, the Affian, the Silsilian, and the Sebekian. These

sites are within a time range from ca. 16 000 to 14 000 B.P.

The Ballanan (Wendorf 1968) is known only near Ballana, Egyptian Nubia, dating between ca. 16 000 and 14 000 B.P. The Ballanan is a non-Levallois microlithic blade industry. The blades are detached from single and double platform cores. Tools are characterized by truncated and backed microlithic blades. Burins are common. Denticulates, notches, scaled pieces are rare. Ouchtata bladelets, geometrics, microburins are absent. Retouched cores, core scrapers, sidescrapers and points form a characteristic component. The material utilized is mostly Nile flint. Sites are small and faunal remains are very limited. They consist of wild cattle and hartebeest. Fish remains are also present.

The Affian industry (Wendorf & Schild 1976a) is known from six sites near Isna. The industry is dated on stratigraphic evidence at around 14 000 B.C. Two subdivisions are recognized. The first is characterized by prepared, flat, wide, opposed platform cores, whereas the second shows, in addition, a high frequency of columnar opposed platform cores. The Affian industry is a microlithic blade industry with a significant Levallois element. Diagnostic tool classes include truncated, microlithic blades, geometrics, backed bladelets, endscrapers and retouched pieces. The range of variation is high. Raw material utilized is mostly Nile flint. Sites are small. Faunal remains include wild cattle, hartebeest and fish.

The Silsilian and Sebekian (Smith 1967) are found in the Kom Ombo Plain at a large stratified site. The Silsilian (Phillips & Butzer 1973), at the base, is characterized by small opposed platform cores, high microlithic index, high blade index geometrics, microburins, and absence of Levallois technique. Raw material utilized consisted of a variety of agate, chalcedony and jasper. A date on organic material associated with a similar assemblage is 15 310 B.P. ± 200 (Y-1376; op cit.:148). The Sebekian overlying the Silsilian, is characterized by columnar, opposed double platform cores, high blade index, high microlithic index, and a high frequency of backed and retouched blades and bladelets. Endscrapers, sidescrapers and burins are present, but geometrics, microburins, and Levallois flakes are absent. The raw material favoured in the Sebekian is mainly Nilotic flint. Four dates on charcoal range from 16 000 to 13 611 B.P. (op cit.:148-149). Faunal remains associated with the Silsilian and Sebekian include hartebeest, hippopotamus and a large variety of avifauna. The Nile soft-shelled turtles and Nile catfish are represented. One Silsilian site, however, yielded neither avifauna, nor turtles, but it yielded hartebeest, wild cattle and Dorcas gazelle (Churcher & Smith 1972; Churcher 1972). Grinding stones are reported in both the Silsilian and the Sebekian. Unit D known from Site E71K12 (Phillips 1970, 1972, 1973) is characterized by columnar opposed platform bladelet cores, single platform cores and a high frequency of bladelets. Straight backed and pointed backed bladelets are the most common of all tools. Ouchtata retouched bladelets, denticulates, double-backed perforators, notches, burins and truncations are present but rare. The raw material utilized consists mainly of Nilotic flint. Another site (E71K13, 'Unit E'), in close spatial and stratigraphic proximity to the previous site, displays a heavy emphasis on Ouchtata retouched bladelets (more than 80% of all tools) and flat, broad double platform cores. The raw material utilized consists mainly of limestone chert

concretions. Denticulates, notches, backed bladelets, burins and truncations are rare.

One site (E71K20), situated on top of the Ballana dunes at Isna, shows some similarities with the Silsilian (Wendorf & Schild 1976). The most characteristic core type is the opposed double platform type. The dominant tool classes include truncated microlithic blades, backed microlithic blades, microburins, notches and denticulates. Burins and endscrapers are rare.

The Qadan industry (Shiner 1968), located from Tushka to Abka (Nubia), is a microlithic-flake industry. The span of time covered by the Qadan is very long, ca. 15 000-6 000 B.P. (Wendorf 1968:1051). According to Marks (personal communication), the younger date is uncertain due to contextual problems. The later stages show an increase in the content of blades. Microlithic elements, nonetheless, are dominant throughout. Diagnostic tools include scrapers, lunates, burins, truncated microflakes and blades, and leaf-shaped points. Scrapers and lunates show marked temporal variations. Levallois flakes are rare to absent. The material used is mostly Nile flint. Cores are mainly unfaceted, single platform cores. The sites are generally large. A graveyard with 58 individuals is associated with Qadan artifacts (Wendorf 1968). Grinding stones are present, suggesting the use of grain foods, and hunting was doubtless practised. Faunal remains include wild cattle, hartebeest, and fish.

Industries younger than the Isnan include the Arkinian, the Shamarakian, El Kabian and the Qarunian. All of these have affinities to the microlithic tradition. The Arkinian (Schild et al. 1968) is known from one site near Wadi Halfa dating around 9 500 B.P. Unfaceted single platform cores are common. Major tools include endscrapers, backed bladelets, Ouchtata bladelets and scaled pieces. The material utilized is mostly Nilotic flint. Sites are small and oval. Faunal remains include mostly hartebeest but the sample is very small. Fish remains of many species are present. The Arkinian contains several grinding stones.

The Shamarkian industry (Schild et al. 1968), dating around 7 700 B.P., is known from four sites near Wadi Halfa (two post-Shamarkian Neolithic sites, DIW-50 and DIW-4, are probably related technologically to the Shamarkian). The Shamarkian is an industry characterized by microlithic flakes and blades. Unfaceted single platform cores are common and similar to those of the Arkinian. Tools are characterized by backed bladelets and truncated flakes. Burins, notches, denticulates, and scaled pieces are present. Krukowski microburins are common. The material utilized is mostly Nile flint. Faunal remains are very rare to absent. Fish (*Lates*) are known from one site (DIW-51).

El-Kabian (Vermeersch 1970, 1976) is an industry similar to the Shamarkian. El-Kabian dates around 8 000 B.P., a similar date to that of the Shamarkian. Unfaceted, single platform cores are common. Tools are dominated by backed bladelets and microburins, including Krukowski microburins. Endscrapers, perforators, geometrics are rare. Burins are absent. The El-Kab assemblages differ mostly by their richness in microburins. The raw material utilized is mostly Nile flint. Another site, of about the same age as the Shamarkian, is the 'Cat Fish Cave' site near Korosko (Wendt 1966). The site consists of two occupation layers. The top layer is dated to 7 060 B.P. on stratigraphic evidence. The

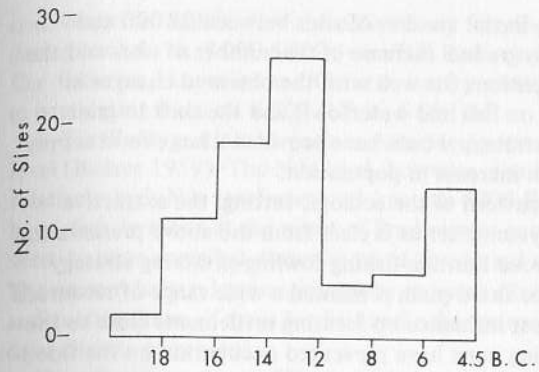


Figure 17.7 Number of sites from 20 000 to 4 500 B.C. in the Nile Valley.

lower layer is not older than about 8 450 B.P. The lower occupation contains microlithic debitage, one truncated blade, and bone points with a single row of barbs. The top layer has a microlithic industry. The industrial affiliation of this site can hardly be made on account of the incomplete nature of the remains. Large amounts of fish were recovered from the lower occupation.

The Qarunian industry (Wendorf & Schild 1976a) located in the Fayum Depression is dated between 8 100 and 7 180 B.P. Cores are predominantly unfaceted single platform variety. Tools are dominated by backed bladelets (some with retouched and truncated bases). Notches and denticulates are common. Microburins, geometrics (triangles and trapezes), and endscrapers are present. Grinding stones and bone tools are also present. Site concentrations are small. Fish remains are abundant. Hartebeest bone fragments are more numerous than those of wild cattle. At one site red-fronted gazelle remains are reported. The faunal remains also include hippopotamus.

An analysis of the number and size of sites during the Late/Terminal Palaeolithic shows that between 18 000 B.P. and 16 000 B.P. sites were mostly between 400 and 800 m^2, during the following 2 000 years (16 000-14 000 B.P.) sites were mostly between 800 and 3 500 m^2. During the next period, between 14 000 and 12 000 B.P., concomitant with the use of cereal-grain type grasses, sites of 3 500 to 10 000 m^2 and larger were present, and sites between 400 and 3 500 m^2 were numerous. During most of the periods, sites between 20 and 400 m^2 were common (30 to 60% of all sites). These sites, indicating an occupational unit of between 5 and 40 persons, would seem to be the basic nuclear settlement of a band. The larger settlements probably represent repetitive occupation of the site area by a group or a number of related groups for a considerable span of time. The Isnan occupation at Isna (E71K14) is about 15 000 m^2 with three dense concentrations. The Qadan site 8905, is in fact, a site complex extending over an area of about 280 000 m^2 with more than 100 hearth areas. The two Quarunian sites at Fayum measure about 65 000 and 3 000 m^2 each with many small concentrations. This increase in the number of site areas as a result of a greater density of archaeological occurrences, is associated with the economic shift to grain utilization. It is also interesting to note

that there is a gradual increase in the number of sites between 22 000 and 14 000 B.P. (Figure 17.7). This gradual increase in the number of sites and the change in the density of occupations fits well with the observed changes in faunal remains (more reliance on fish and waterfowl) and the shift to grain utilization. A broad adaptive strategy would have provided a large food supply which could have permitted an increase in population.

The interplay between the pattern of the ecologic setting, the extractive strategy, and settlements in dynamic terms is clear from the above presentation (see Hassan 1974). Under a broad hunting-fishing-fowling-gathering strategy during the late Palaeolithic, the flood-plain presented a wide range of resources which must have exerted a great influence on locating settlements close to the flood-plain. The annual flooding must have prevented occupation on the flood-plain for a significant part of the year. Seasonal settlement out on the flood-plain was possible only during the winter season. A seasonal congregation of populations during the fall-winter season was probably followed by breaking camp and dispersion of population in the form of small groups along the river. With utilization of grain, a more stable source of food seems to have been secured, allowing for denser occupation in one area. The collecting of grain would have coincided with the fall-winter season where food from other resources was also abundant. Thus, although storing may have been practised (there seems to be also some evidence that fish was smoked and stored), camps probably continued to be broken up seasonally. This pattern may have prevented the development of large social groupings of a much higher organizational level than that of simple hunter-gatherers, as evidenced by the persistence of small settlements and the presence of small occupational occurrences within the large site complexes characteristic of the period of grain utilization. The transition to an economy based on the use of grain was therefore followed by an increase both in the number and size of sites and site complexes.

17.5 THE NEOLITHIC/PREDYNASTIC PERIOD

The systematic study of the Predynastic of Egypt began with the work undertaken by Petrie (1895) in Nagada and was interrupted by World War I and World War II. Most of the excavations were done before World War II. Recent developments in the study of the Predynastic include radiocarbon and thermoluminescent age determinations and studies of the geology and ecology of the sites.

Traditionally, the Predynastic sites have been grouped into 'cultures' on the basis of their ceramic content. The cultures include the Badarian, the Merimda 'Neolithic', the Fayum 'Neolithic' A, the Amratian and the Gerzean (Baumgartel 1955-1960, 1965; Arkell & Ucko 1965; Arkell 1975; Krzyzaniak 1977).

The Predynastic archaeological units (cultures) were arranged according to Sequence Dating of ceramics (Petrie 1920) into, from older to younger, three stages: Badarian, Amratian (Nagada I), and Gerzean (Nagada II). This sequence is highly questionable. The chronology of the Fayum A and Merimda Neolithic is controversial, and examination of available chronometric determinations (Hassan, Hays & Shepard, n.d.) reveals that it is highly probable that the Fayum A

and Merimda Neolithic are the oldest early farming cultures in the Nile Valley dating back to ca. 7 000-5 500 years B.P. (tree-ring corrected radiocarbon years). The Badarian, Amratian and Gerzean were probably contemporaneous, at least in part dating from ca. 6 000 B.P. to 5 600 B.P.

The Predynastic occupations coincided with a period of declining Nile level (Butzer 1959). The Nile level, however, was higher than today and relatively high Nile level occurred towards 6000 B.C. Local climate was perhaps slightly moist at the onset of Predynastic occupations but drier conditions seem to have prevailed during most of the period of Predynastic development. The present barren landscape may be more a reflection of overgrazing by goats and cutting-down of trees for fuel and other purposes, than a result of a much drier climate at present.

The subsistence base of Predynastic peoples was varied, consisting of cultivating barley and emmer wheat, raising of goats, sheep, cattle and pigs, hunting, fishing and plant gathering. The catchment territory from sites located at the edge of the floodplain or on the desert pediments and abandoned Nile terraces provided access to several biotopes. Cultivation could have been undertaken at the outer edge of the floodplain; hunting was practised in the desert and along the Nile channel for hippopotamus and crocodile; plants were collected from the floodplain, the Nile channel and the wadi banks and fish were caught from the channel and flood swamps (Hays & Hassan 1976).

The Nile flooding governed subsistence activities, resulting in three economic seasons which coincide with the inundation, the drought, and the period in-between. The importance of agriculture is in producing a high yield of storable, nutritious food which can be consumed during the period of lowest overall economic productivity of wild resources (drought and periods of peak flooding).

The agricultural economy was associated with intensive internal trade in various raw materials for decoration and tool-making. It is very likely that grain and perhaps dried fish were exchanged. There is also abundant evidence for imports from distant lands, which are not only evidence of a complex economy, but also of vigorous cultural contacts.

The Predynastic Settlements seem to have been established in many places along the Nile Valley and the Nile Delta, on desert spurs and promontories of abandoned Nile terraces and dissected pediments overlooking the floodplain of the Nile. While it would appear that no settlements were established in the floodplain itself, it is very likely that many settlements were established on the outer margin of the floodplain which is rarely affected by the inundation. Butzer (1960) suggests also that older high levees in the floodplain might have been inhabited. These settlements were most probably destroyed by high floods during Old Kingdom times and might also have been destroyed through subsequent utilization of the floodplain for intensive cultivation and habitation. The ground on which the Predynastic settlements were established consists of old wadi deposits or Nile silt and sandy gravel. At the Fayum, sandy lake shores were inhabited.

The wadis during the time of Holocene occupation were not as active as they were during the Pleistocene. There were no streams of any significance except

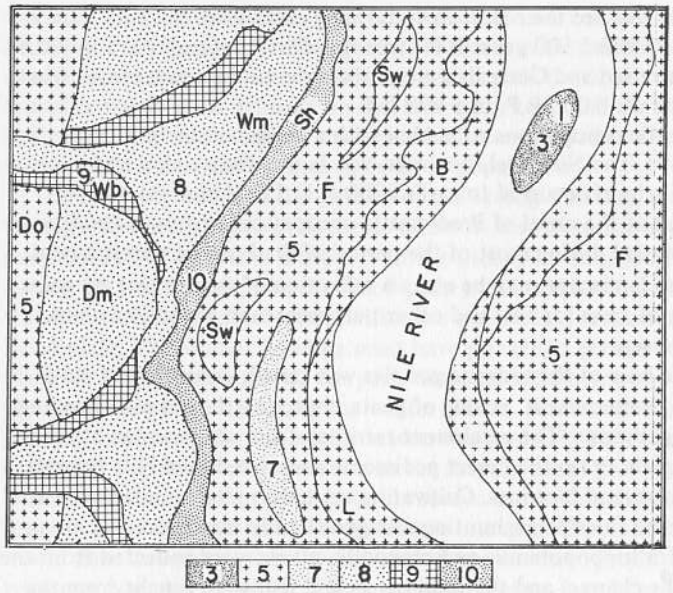


Figure 17.8 Geoekistic map of an area near Luxor showing suitability for settlement location on scale from 10 (most suitable) to 1 (least suitable). See text for explanation.

I, Channel Island; B, Point bar; L, Levee; F, floodplain; SW, backswamp; Wm, Wadi mouth; Wb, Wadi bank.

in major wadis such as Wadi Qena and Wadi Hammamat on the east bank, and even these were reduced to ephemeral streams dominated by erosion rather than alluviation.

Vegetation on the low desert margin was scant. A discontinuous grass cover and a few scattered Acacia trees which thrived in protected localities constituted the major vegetation elements of the low desert. Vegetational change, both seasonal and accidental, was doubtless as common then as it is today in the wadis in the northern parts of the Egyptian deserts (Kassas & Girgis 1965). *Panicum turgidum* and *Pennisetum dichotomum* are generally associated with wadi silt and Nile deposits and would have been locally available in the area of the Predynastic sites. Tamarisk might have also been present, especially in areas with deep wadi fill where water seeping from surface run-off accumulates.

The width of the Nile Valley is variable, ranging from 5.3 km near Qena to 17.2 km near Beni Suef, and 14.7 km near Assiut. Settlement location at the edge of the floodplain would thus imply a maximum radius of about 8 km or on the average about 5 km. Thus, settlements could be located at the edge of the floodplain without any logistic difficulty since the range of the radius of catchment territory usually varies from ca. 5 to 10 km among cultivators and hunter-gatherers, respectively. Settlement location at the edge of the floodplain would also be advantageous because it would provide ready access to the desert resources.

In order to determine the best places for settlement location, several variables in addition to access to various biotypes were included in a geoekistic model.

Various geomorphic units in the landscape were evaluated for suitability for shelter and protection from flood damage, access to water, transportation logistics, and productivity of resources in immediate areas.

Geomorphic units were then ranked on a scale from one to ten from the least suitable to the most suitable (Figure 17.8). The outer margin of the floodplain and the desert pediment overlooking the floodplain were ranked the highest. This is very interesting because many of the Predynastic settlements are located on the edge of the floodplain while cemeteries are placed in the desert area bordering the cultivation. Such villages were perhaps the victims of expanding population and intensive cultivation over the last 5 000 years.

The large area of Merimda, Maadi, Nagada and Hierakonpolis, and the large cemeteries (more than 100 graves at Badari and Mostagedda) seem to indicate large settlements of a permanent nature.

At Merimda (uppermost layer) settlement remains (Junker 1929, 1940) consist of *pise* dwellings of wadi silt and Nile mud, shelters, workshops and storage facilities. The dwellings are arranged in rows along winding alleys. The dwellings are oval, measuring from 1 x 1.5 to 2 x 3.2 m. Some of these dwellings undoubtedly housed only a single adult, whereas others were for small families. The floor of the dwellings is sunk in the ground to a depth of 45 cm. The dwelling had walled layers of rough blocks ('galoos', Arabic) of mud tempered with straw. The mud walls rise about 1 m above the surface of the ground and were probably covered by reed or rush roofs. Pairs of postholes at the end of some of the dwellings suggest that in those cases the roofs might have been double pitched. The tibia of a hippopotamus was used as a step from the floor of the dwelling to the outside. The floor was mud-plastered. A jar was often embedded in the floor, perhaps to hold drinking water. Semi-oval to oval shelters with a circular arrangement of posts were also occupied. They measure 3.4 m in diameter and open towards the east or the southeast. Storage bins, mud-lined and hemispherical in shape were dug in the ground. Basketry granaries (30-10 cm in diameter and 30-60 cm in depth) were also used. In addition, huge jars more than 1 m in height were embedded in the ground. Tombs were interspersed with the settlements and were similar to the oval dwellings. The graves were occasionally lined with coarse matting and were scattered either singularly or in groups. The burials were mainly those of females and children. The persons were laid on their right side facing the northeast with the head to the south. The knees were flexed to the chest.

The settlements of El-Omari at Helwan (Debono 1948, 1956) consist of more than 100 circular huts, in addition to numerous oval dwellings. The houses are about 1.6 m in diameter and are dug to 40-50 cm in the ground. Some of the house floors were lined with clay covered matting. Wood posts were used to support the superstructure. Baskets, as in the Fayum and Merimda, were used to store grain. Pits lined with matting were also used as silos. Small rounded depressions served as hearths in the centre of dwellings. There is evidence that some of the dwellings were abandoned and used as dumps before being reoccupied. The circular dwellings also sometimes cut into each other. Fenced shelters covering large areas were constructed. Tombs were found inside the settlement. They consisted of oval graves. The body was placed in a flexed

position with knees to the chest, the head to the south, lying on the left side facing east. Two cemeteries were also located in the area. One of the cemeteries has tumuli, 7 m in diameter with a mound of stones covering a depression 1 x 1.5 m in diameter. The tombs are in groups of twos or threes scattered over a large area. The dead were placed on either the right or the left side and parallel to NS or the EW directions. The other cemetery consists of shallower oval graves.

At Hamamiya (Brunton & Caton-Thompson 1928), Badarian settlements consisted of nine circular huts surrounded by a low footwall. Stakes were used to support a wattle and daub superstructure. At Badari, huts with a circular or sub-circular floor sunk in the ground were used. The dimensions of the huts are 3 x 2.25 m, 2.7 x 2.7 m, 1.6 x 2.1 m. The floor was mud-plastered and two wainscots of bricks were used. At Mahasna (Garstang 1902; Ayrton & Loat 1911), postholes seem to suggest the use of a shelter. At Bet Khalaf (Garstang 1902), mud walls were found. At El-Amrah (Randall-McIver et al. 1902), a clay model of a rectangular house was luckily found. It stands 10 cm in height which is used to assume that the house was 5.7 x 8.0 m. The door was made from wood.

Unfortunately, we have very little information on the size, number of houses, tombs, storage pits, spatial layout, etc., of the Predynastic sites in Egypt. The information available on some of the sites is given in Table 17.2.

Merimda, Nagada and Hierakonpolis are usually referred to as towns, which might indeed have been the case, but further studies of site layout are needed. Butzer (1959) provides approximate population size estimates based on one hut per 65 m² from observation at Hierakonpolis. He assigns six persons per house. The population size estimates, according to Butzer, are given in Table 17.3.

Hays & Hassan (1976), however, mapped in detail one of the Predynastic sites (Khattara, 75/3) and found 15 areas of cultural deposits covering roughly circular areas ranging in diameter from 10 to 27 m. The total area of the concentrations of archaeological remains is 4 081 m² compared with 33 000 m² for the area covered by the site as a whole (see Table 17.4).

The area of the concentrations of archaeological remains averages 272 m² and seems to represent the remains of a household cluster as defined by Winter (1976), i.e. houses, tombs, storage areas, trash disposal areas, and so on. A part of a house cluster illustrated by Winter provides an area of 121 m². Assuming that there were five persons per household, the settlement consisting of 15 households would have totalled 75 persons, a reasonable size for many villages in Egypt and other parts of the Near East and elsewhere. This would mean that the area of the site per person is 440 m² (also 9.2 persons/acre). If we use these figures to estimate the population size of Merimda, Nagada, and Hierakonpolis we come up with the figures as in Table 17.5.

The settlements of Hamamiya and Armant (2 000 and 700 m²) seem to represent small settlements. It is interesting that the data presented by Marcus (1976) on the number of households and the area of the sites per hectare can be shown to give approximately ten households per hectare. If we apply this to the Predynastic (using five persons per household), the Predynastic settlements

Table 17.2 Available information on the Predynastic sites in Egypt

Site	Available information	Area (m²)	Author
Merimda	Houses mixed with magazines, tombs, and storage pits	180 000	Junker (1928, 1940)
Maadi	Houses, magazines, silos, cellars, and storage pits	180 000	Amer (1947), Menghin (1934), Menghin & Amer (1932-36)
Mahasna	Evidence for a windbreak, circular oven 3 m in dia.	710	Garstang (1902), Ayrton & Loat (1911)
Hamamiya	Clay hut circles, 40 x 50 yards	2 000	Brunton & Caton-Thompson (1928)
Nagada	Houses, graves, silos	50 000	Petrie (1895)
Hierakonpolis	Town and village clusters	1×10^6 (with 50 800 m² of debris)	Butzer (1959)
Armant		716	Mond & Myers (1937)

Table 17.3 Population size estimates according to Butzer (1959)

Site	Population
Merimda	16 000 persons
Hamamiya	20 persons
Mahasna	1 000 persons
Nagada	1 500 persons
Armant	110 persons
Hierakonpolis	4 700-10 000 persons

Table 17.4 Total area of concentration of archaeological remains

Number of sites	Site area (m²)	Total area (m²)
2	79	158
1	113	113
1	154	158
3	177	531
5	314	1 570
1	452	452
1	530	530
1	573	573
15	Total	4 081
	Mean	272

Table 17.5 Estimated population sizes based on a density of 9.2 person/acre

Site	Population
Merimda	409 persons
Maadi	509 persons
Nagada	114 persons
Hierakonpolis (towns and villages)	2 272 persons

Table 17.6 Estimated population sizes based on the data presented by Marcus (1976)

Site	Population
Merimda	900 persons
Maadi	900 persons
Nagada	250 persons
Hierakonpolis	5 000 persons

of Egypt would have been inhabited by the numbers of people shown in Table 17.6.

These figures and mine seem reasonable in view of the size range of formative villages, and indeed modern villages, and towns in Egypt, the Near East, and Mesoamerica (Braidwood & Reed 1957; Marcus 1976). The figures, however, are based on a very inadequate data base and should be completely recalculated on the basis of properly collected field evidence.

17.6 CONCLUSIONS AND FINAL REMARKS

The Nile Valley has been the stage of many dramatic events in prehistory. Cultural and environmental events are recorded in the archaeological sites which are encountered along the whole length of the Main Nile and in the geological record of the Nile and the adjacent desert.

The oldest human occupations belong to the Lower Palaeolithic and indicate that early man had penetrated the Nile Valley as early as the early Acheulian, if not earlier. Some of the sites or site complexes are exceptionally large, reaching as in the case of site 400 and ARW-8, 550 000 and 314 000 m^2 respectively. The density of artifacts varies, but at one site the density is as high as 249 artifacts/m^2. These site complexes represent multiple re-occupations with lateral shifts through time, a pattern which is seen again during the Middle and Late/Terminal Palaeolithic sites. However, the maximum area for the Middle Palaeolithic sites is 31 415 m^2 and for the Late/Terminal Palaeolithic, 15 386 m^2. The Middle and Late/Terminal Palaeolithic sites, however, seem to be dominated by small sites (Figures 17.9, 17.10). The artifact density is high for many Middle and Late/Terminal Palaeolithic sites. A large number of Middle Palaeolithic sites show a small site area and a high artifact density indicating long periods of continued site occupancy. How representative is the archaeological sample of the original area and artifact density distribution of original settlements? This is a very difficult question to answer, but we must entertain the idea that the archaeological record may be biased towards the preservation of large and densely settled sites. Such sites also have a higher probability of being discovered. Nevertheless, the presence of such sites indicates repetitive use of the same site area or locality and long-term occupancy of a site, and suggests that local spatial mobility rather than long range mobility was the norm. This seems to be substantiated by a consideration of the ecologic setting of the Nile Valley (Hassan 1974). The site locations are at the edge of the floodplain or on top of residual hills or the desert plateau overlooking the floodplain. The geoekistic study dis-

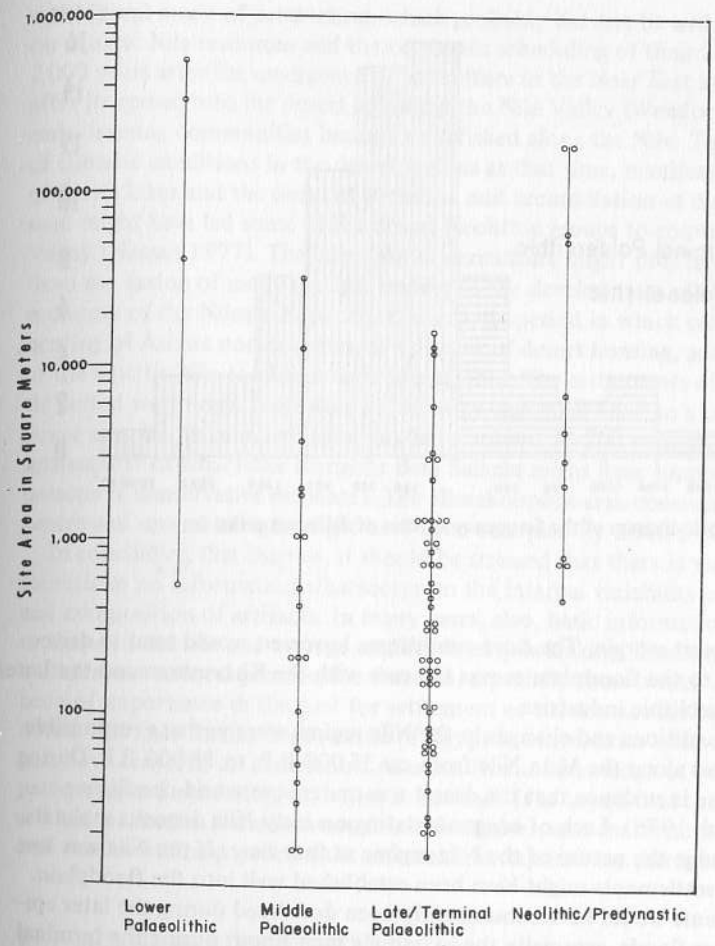


Figure 17.9 Site area in square metres of prehistoric sites in the Nile Valley.

cussed previously in dealing with the Predynastic sites does indicate that such a location is the most advantageous since it provides protection from high floods and ready access to both Nile and desert resources within a catchment area between 5 and 8 km. The linear pattern of the Nile Valley, the absence of geographical variation along the length of the Main Nile, and the concentration of resources along the Nile would indicate that there was no necessity for long range seasonal or daily mobility. Variations in the spatial location of settlements within that narrow zone bordering the Nile might have resulted from amelioration of climatic conditions leading to abundant plant and animal life in the desert margin and especially along the course of the wadis. This was the case during the Middle and Lower Palaeolithic. These conditions would lead to a deeper penetra-

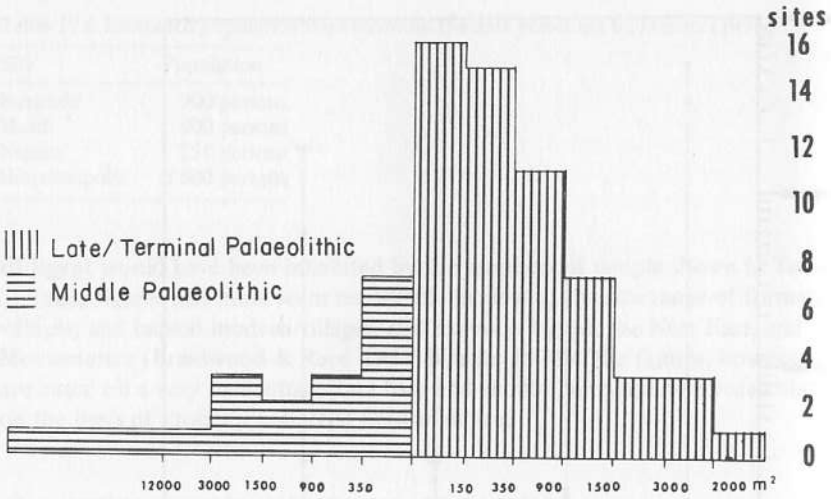


Figure 17.10 Block diagram of the frequency of sites of different areas.

tion of the desert margin. The drier conditions, however, would tend to drive people closer to the floodplain as was the case with the Khormusan and the Late/ Terminal Palaeolithic industries.

Climatic conditions and changes in the Nile regime were perhaps responsible for lack of sites along the Main Nile from ca. 35 000 B.P. to 18 000 B.P. During that time there is evidence that the desert was under severe arid conditions (Wendorf et al. 1976). Lack of adequate dating on early Nile deposits make it difficult to judge the nature of the Nile regime at that time. If the Nile was low at that time, settlements might have been established well into the floodplain. Such settlements would have subsequently been destroyed during the later episodes of higher floods, especially the extremely high floods during the terminal Sahab/Gebel Silsila stage. There exceptionally high floods might also have been responsible for the reduction in Nilotic population represented by a sudden change in the number of sites, changes in the subsistence regime toward greater dependence on aquatic Nile resources, and the elimination of many stylistic traditions (Hassan 1972b). Such events might have aborted the trend toward domestication which was begun in Egypt as early as 16 000 years ago. During the period from 16 000 B.P. to the time of that catastrophic event, ca. 12 000 B.P., there is evidence for an increase in the number of sites and changes in the subsistence suggesting an increase in the Nilotic population and an acceleration of the tempo of change, also manifest in the proliferation of stylistic traditions. The 12 000 B.P. floods, seem to have led to a drastic change in economy which put an end to the intensive exploitation and dependence on wild cereals, which could eventually have led, if they were not interrupted, to the domestication of cereals as in the Near East. The inhabitants of the Nile did not race to adopt the

agricultural mode of production, which probably did not fit with their emphasis on aquatic Nile resources and the economic scheduling of their activities. About 2 000 years after the emergence of agriculture in the Near East and 1 000 years after its spread into the desert adjoining the Nile Valley (Wendorf et al. 1976) early farming communities became established along the Nile. The deterioration of climatic conditions in the desert regions at that time, manifest in the drying of desert lakes and the onset of deflation and accumulation of dune and drift sand might have led some of the desert Neolithic groups to converge on the Nile Valley (Hassan 1977). The adoption of agriculture might thus have resulted from the fusion of many groups, leading to the development of the unique economy of the Nilotic Neolithic/Predynastic period in which cultivation and herding of Asiatic domesticates, the pursuit of desert hunting, and exploitation of the aquatic Nile resources were inseparable. The settlements of the Predynastic period were large, indicating a shift from the small band to a community of larger size. Hamlets and villages may have housed 50-200 persons, but large settlements (towns?) like Merimda Beni Salama might have supported 400-500 persons (a conservative estimate). The Hierakonpolis area consisting of a larger centre and several villages might have been occupied by 2 500-5 000 persons.

In concluding this chapter, it should be stressed that there is very little and sometimes no information whatsoever on the internal variability in the density and composition of artifacts. In many cases, also, basic information on the area or shape of the site and average artifact density is lacking. The location of sites with respect to local geomorphic features, especially those which might have been of importance in the past for settlement or subsistence activities, is rarely noted. The case for the Predynastic of Egypt is worse, since excavations in the past have centered on cemeteries. As a result, our knowledge of community patterning and residential activities is minimal. It is hoped that the potential of settlement studies is demonstrated in this chapter, and that future excavations and studies will help procure the information required for this kind of analysis.

17.7 ACKNOWLEDGEMENTS

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18

The Neolithic tradition in the Sahara

La tradition néolithique au Sahara

En Europe et au Moyen Orient le Néolithique est caractérisé à la fois par l'élevage et l'agriculture, mais aussi par les premières céramiques et les premiers outils en pierre polie. Une telle définition ne peut s'appliquer strictement au Néolithique du Sahara, car les premières céramiques sahariennes apparaissent plusieurs milliers d'années avant les premiers essais de culture et d'élevage connus jusqu'ici. Les premières céramiques sahariennes sont associées à une économie lacustre fondée sur l'exploitation des mammifères aquatiques et des poissons des lacs du Sahara central et meridional d'âge Holocène inférieur (9 000 à 7 500 B.P.). Les témoignages culturels comprennent la céramique de style décoratif 'dotted wavy line', les pointes en os barbelées, et les microlites géométriques. Ces cultures lacustres ou 'aqualithiques' s'étendaient du Nil jusqu'en Mauritanie. Le complexe lithique est assez uniforme à travers cette vaste région, mais ceci n'implique pas nécessairement des migrations de population. Il y a eu vraisemblablement la même adaptation aux conditions de milieux très comparables, aidée sans doute par des contacts culturels entre les divers bandes de chasseurs/pêcheurs.

Peu après 7 500 B.P. la plupart des lacs sahariens se sont asséchés, et ils sont restés secs jusqu'à environ 6 000 B.P., date à laquelle réapparaissent les gisements préhistoriques. Ces nouveaux habitants du Sahara central et méridional pratiquaient l'élevage des bovins et des moutons/chèvres. On ne sait pas s'ils étaient de même origine ethnique que les chasseurs/pêcheurs de l'Holocène inférieur, mais ils ont occupé des sites presque identiques, et les contacts culturels entre la vallée du Nil et le Sahara central se sont maintenus. L'assemblage lithique à Adrar Bous semble indiquer que quelques outils caractéristiques des économies lacustres de l'Holocène inférieur ont persisté dans le Néolithique du Ténéré.

Des peuples pastoraux sont encore restés au Sahara central jusqu'à environ 4 500 B.P., quand l'assèchement du milieu les a forcés à converger sur des cours d'eau pérennes ou temporaires tels que l'Azaouak ou le Tilemsi. Le résultat éventuel était un mouvement vers le sud le long des grandes vallées, aboutissant à la colonisation de localités nouvelles, et à la répartition de l'élevage dans la zone soudanienne de l'Afrique de l'Ouest.

Le grand problème de l'influence de l'Homme sur le milieu saharien est encore à résoudre. On peut noter que l'adaptation des hommes à la sécheresse sahélienne contemporaine (1968-1973) est très semblable à celle des peuples préhistoriques, avant entraîné aussi une migration vers le sud le long des cours d'eau comme le Niger, où se trouvaient eau et pâturage. La situation actuelle au Sahel n'est donc pas unique, car les pasteurs nomades ont dû s'adapter à des problèmes de milieu assez variables. Certes, la pratique de l'élevage a dû participer à la dégradation du milieu saharien, mais il faut souligner que les oscillations climatiques existaient déjà bien avant les premiers vestiges d'animaux domestiqués au Sahara.

18.1 INTRODUCTION

In European and Near Eastern prehistoric studies the term 'Neolithic' is used to encapsulate not only the beginnings of food production, but also the appearance of a number of concomitant aspects of material culture, namely ceramics and ground stone tools. In the Sahara such a definition of the 'Neolithic' has no meaning since ceramics appear long before the first indication of domestic plants or animals. Thus the 'Neolithization process' in the Sahara using the European criteria must be seen as a dynamic process that covered at least three millennia.

18.2 THE LACUSTRINE TRADITION IN THE EARLY HOLOCENE

Environmental conditions in the Central and Southern Sahara in the 7th and 8th millennia B.C. were such that a great deal of surface water was evident in the form of perennial lakes. These former lakes have left behind thick beds of diatomite in areas that today are incapable of supporting any animal or plant life. Human exploitation of these lakes is evident from the material culture that has been found around these lakes and in situ in the diatomites, along with remains of the aquatic animals hunted and fished. From Adrar Bous, the faunal list includes: fish (*Lates, Clarias*), crocodile, turtle, hippopotamus (Smith 1976:192). This list is consistent with the fauna from other early post-Palaeolithic sites such as Asselar in the northern Tilemsi Valley of Mali (Joleaud 1935); Outeidat in the Azouad (Gallay 1966; Joleaud 1935); and Tamaya Mellet in Niger (Kelley 1934; Lhote 1936). The cultural material associated with these faunal remains is primarily hunting equipment, such as bone harpoons and microliths (Figures 18.1 and 18.2) but it also includes pottery.

A number of sites throughout the Sahara have produced early dates for ceramics. Barich (1977) indicates four levels containing pottery at East Torha in the Acacus Mts, Libya, each with ages ranging from 9 080 ± 70 B.P., to 7 990 ± 70 B.P. Similarly from Tamaya Mellet a date of 9 350 ± 170 B.P. has been obtained for a harpoon bearing industry, although the stratigraphic association with the artifacts is unclear (Delibrias et al. 1974). From Adrar Bous the harpoon industry with pottery was not directly dated, but a minimum date of 7 310 ± 120 B.P. was obtained from $CaCo_3$ concretions that were formed when the lake dried up suggesting the occupation was some time before that date. Camps' (1969) work at Amekni produced early pottery dated to c. 8 700 B.P.

The interesting aspect of much of this pottery is that in decorative motif that from Amekni, the Fezzan and the Acacus Mts, and that from the Ténéré at Adrar Madet (Photo 18.1) has strong similarities with that found by Arkell (1949) at Khartoum. This 'dotted wavy-line' ware suggests some cultural link between the Nile Valley at the confluence of the Blue and White Niles and the Central Sahara. Gallay (1966:206) also found wavy-line ware at Outeidat in the Azaouad north of Timbuktoo. He stresses, however, that it was not found directly associated with bone harpoons. To support this suggestion, bone harpoons and microlithic tools are also recognised as being part of the tool kit of the Early Khartoum Neolithic. From Tagra on the White Nile a date of 8 370 ± 350 B.P. on shell was associated with a bone harpoon and fragments of mammal and fishbones (Adamson et al. 1974). Barich (1977) suggests that the cultural tradition of this hunting/fishing/gathering society comes out of the Ibero-Maurusien of the Maghreb, based on stone tool typology and frequencies. However, as has been noted elsewhere (Smith, in press) bone harpoons are almost non-existent in the Maghreb, in spite of the large range of other bone tools (cf. Camps-Fabrer 1966). Since pottery is a much more plastic medium it renders itself more towards defining a cultural identity than does stone tool technology. This fact and the basic subsistence strategy of lacustrine exploitation suggest that the cultural association should rather be with the upper Nile Valley.

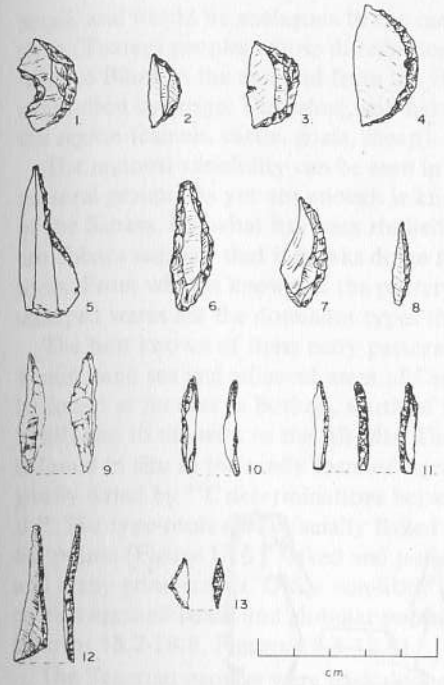


Figure 18.1 Early post-Palaeolithic microliths, Adrar Bous.

After 7 500 B.P. deteriorating environmental conditions in the Central Sahara resulted in the drying up of many of the lakes. Whether this meant abandonment of large parts of the Sahara by human populations at this time has yet to be determined, but at sites such as Adrar Bous and possible Tamaya Mellet there appears to be a break in the cultural tradition (Clark et al. 1973; Smith 1976). By 5 800 B.P., living conditions were again capable of supporting human populations whose material culture included a new element, domestic animals.

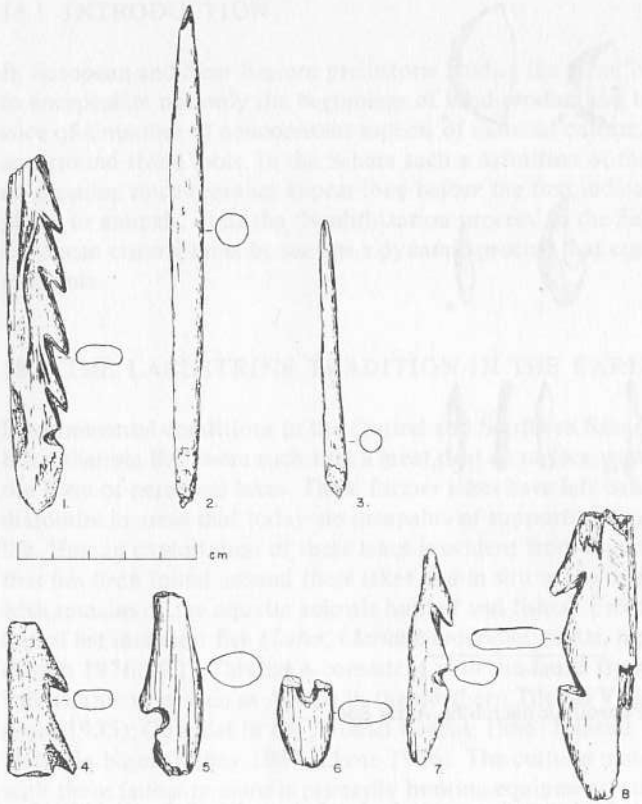


Figure 18.2 Early post-Palaeolithic bone-points and harpoons, Adrar Bous.

18.3 PASTORALISM IN THE SAHARA

Domestic animals first appear in the Saharan zone shortly after 7 000 B.P. The animals involved are cattle, goats and/or sheep. One of the earliest sites recording cattle is Uan Muhuggiag in the Acacus Mts, whence has come a ^{14}C date of 5 952 ± 100 B.P. in direct association with the skull of a shorthorn Bos. However, a date of 6 754 ± 175 B.P. has come from the neighbouring site of Uan Telocat from a level containing cultural material similar to the pastoral level at Uan Muhuggiag (Mori 1965).

Pastoralism appears to be the common denominator of Saharan sites from this time on. A number of sites have yielded *Bos* and Caprine remains (Chapter 20, this volume) and cultural material which, although it shows some regional variability, still has strong similarities, especially in the over-all 'genre de vie' of herding combined with hunting and, from the large numbers of grindstones, the gathering and processing of wild grains. The range of regional variability is quite

small, and would be analagous to the range found today among the Kel Tamasheq (Tuareg) peoples whose distribution extends from Timbuktoo to the west to Bilma in the east and from the Hoggar to Tahaoua. These people speak a common language, Tamasheq, and have a similar pastoral life-style throughout the region (camels, cattle, goats, sheep).

The regional variability can be seen in the typology of the tool-kits of these pastoral groups. As yet not enough is known of the pottery in the southern part of the Sahara, but what has been studied by Camps-Fabrer (1966) in the northern Sahara suggests that it breaks down roughly along the same lines as the stone tools. From what is known of the pottery it appears that the roulette and rocker stamped wares are the dominant types throughout the area (Photos 18.2-18.8).

The best known of these early pastoral industries is the 'Tenerian' from the Ténéré sand sea and adjacent areas of Central Niger. The Tenerian industry is to be found as far east as Borkou, south of the Tibesti highlands (Courtin 1966, 1969) and to the west in the Aïr Mts. The Tenerian, as defined in Smith (1976), is found in situ in the sandy loam of Agorass-in-tast, Adrar Bous. It is chronologically dated by ^{14}C determinations between 5 700 ± 500 B.P. and 4 440 ± 120 B.P. The type-tools are: bifacially flaked disc knives (Figure 18.4) and projectile points (Figure 18.3), flaked and polished stone axes and adzes (Figure 18.5) and many grind-stones. Other non-lithic elements include ivory bracelets, ostrich eggshell beads and globular pots and bowls with impressed decoration (Photos 18.2-18.8, Figures 18.6-18.8).

The Tenerian peoples were basically herdsmen, but wild animals were also hunted. These included: antelopes, hippo, rhino and warthog. The plants that have been identified from impressions in pottery are predominantly hydrophiles that grew around the marshes of Agorass-in-tast. The list includes: *Rhytachne* cf. *triarista* or *rottboelliodes, Brachiaria brizantha* and *Echinochloa stagnina.* A single identification from an impression on one of the surface sherds of *Sorghum* cf. *durra* or *cernum* is an intriguing hint that some domesticated plants were known to these peoples, but this needs more confirmation.

A number of the tool types of the Tenerian have strong similarities with places even further east than Borkou. From Es Shaheinab and Kadero, near Khartoum, have come similar adze types to those found at Adrar Bous (see Arkell 1953). The pottery decorations are also similar. The distinctive comb rocker stamped motif is common (Photos 18.7-18.8) and the recent work by Krzyzaniak (1976) has shown that the Kadero peoples were also herdsmen with cattle and small stock.

The collections at IFAN, Dakar, from the intervening areas between Adrar Bous at Borkou, strangely, show less affinities with the Tenerian. The Kaouar region around Bilma has yielded very limited quantities of the green vitric tuff, most of the stone tools being made in quartzite, but point types are similar to those from Adrar Bous (Hugot 1957: Figure 61). In some collections, such as those from the Madama area, roughly 170 km northeast of Djado, there are very few hollow-based points (most are foliates), while from Seguedine on the track between Djado and Bilma no hollow-based points were collected, in spite of the large number of foliates found. No green vitric tuff was to be found in this collection either.

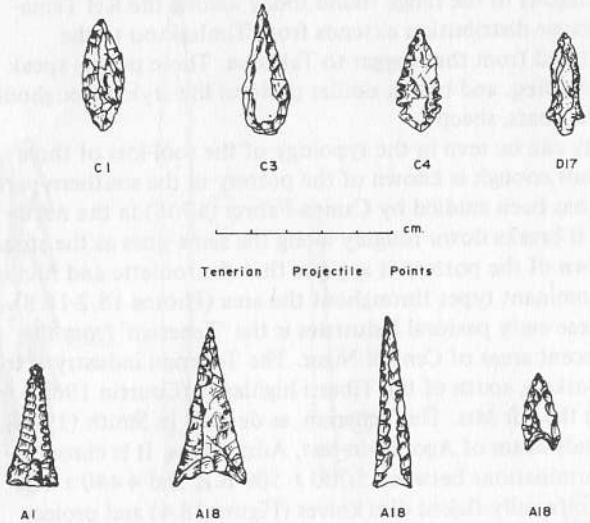


Figure 18.3 Tenerian projectile points.

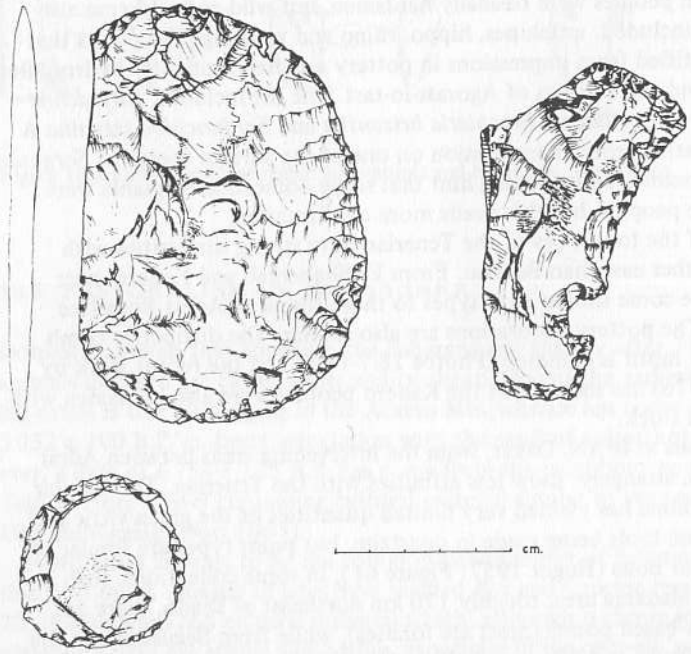


Figure 18.4 Tenerian tools: top left, disc knife; top right, 'Egyptian' knife; bottom, circular scraper.

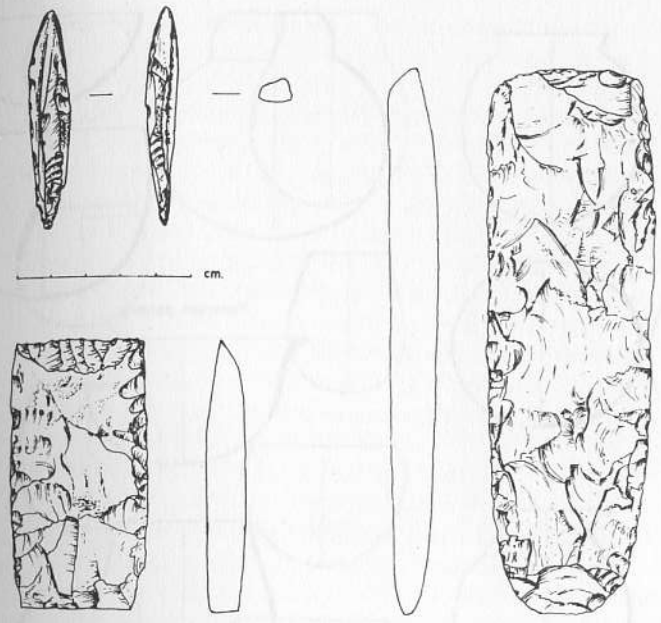


Figure 18.5 Tenerian tools: top left, polished/facetted drill; bottom, two examples of 'Shaheinab'-type adzes.

From the western side of the Aïr Mts, Henri Lhote excavated cultural material from Arlit very similar in many respects, and contemporaneous with, the Tenerian at Adrar Bous. The fauna included domesticated *Bos*, caprines and possibly dog, plus fish, birds and wild mammals (warthog, hippo, gazelle and a large antelope the size of a kob). The cultural material comprised pottery and stone tools, both of which have affinities with the Tenerian, although with some differences. Similar tool-types include 'Shaheinab'-type adzes, projectile points, but the stone material seen by the writer appears to lack the disc knives and 'couteau égyptien' found at Adrar Bous. A tool-type that distinguishes the Arlit industry from that at Adrar Bous is a 'lozenge' scraper. This elliptically-shaped tool is unifacially retouched around its entire edge and has its analogues in the cultural material from further south at In Waggeur. This industry can be seen as a marginal one on the edge of the Tenerian cultural area, sharing some features with its nearest neighbour to the west from the Azaouak Valley.

The Aïr Mts themselves appear not to have been occupied as much as the surrounding lower country. Although rock engravings attest to the exploitation of the mountains by hunters, and later pastoralists, few remnants of their cultural equipment were left behind, suggesting that hunting forays were made into the highland zone, but the main exploitation was around the lakes on the edges of the mountains.

As has been previously noted similar exploitation patterns were to be found

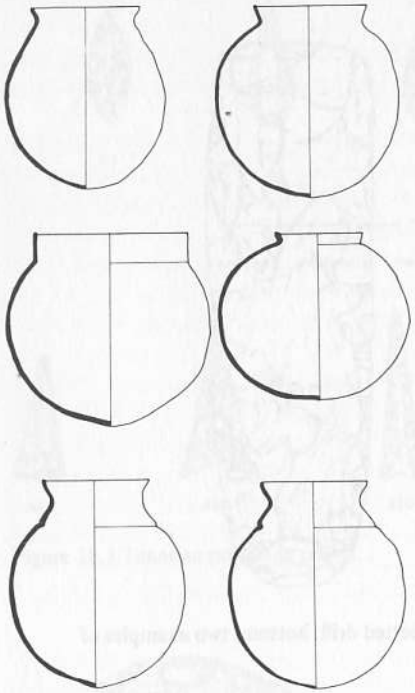


Figure 18.6 Tenerian pottery.

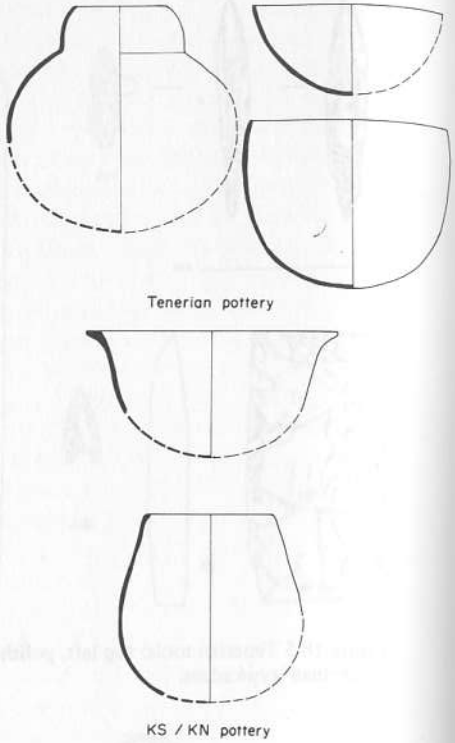


Figure 18.7 Tenerian pottery. KN is from Karkarichinkat Nord, KS is from K. Sud.

in the north at this time. From the Tassili n'Ajjer, Acacus Mts and Hoggar come the splendid rock paintings depicting pastoralism. These have been dated to between c. 7 000 and 4 500 B.P. (Mori 1965). *Bos* remains have also been excavated at Erg d'Admer and at Adrar Tiouiyne on the western edge of the Hoggar and dated at 5 150 and 5 320 B.P. (Camps 1974:237).

The cultural material from this area, particularly the stone tools, differs somewhat from the Tenerian, but there was obviously cultural contact between the two areas. This can be seen in the movement of the green vitric tuff found in the eastern Aïr at places such as Amakon which was used by the Tenerian occupants of Adrar Bous as their major raw material.

It is also to be found in the collections from Erg d'Admer, at In Relidjem, about 75 km southwest of Djanet in the Tassili n'Ajjer. The stone tools from this area are similar to those from Adrar Bous, except that the polished stone celt is lacking. The pottery also has some similar features including spatula rocker-stamped wares and chevron designs. From approximately 40 km to the north at Anou Aoua Lelioua (Aumassip & Roubet 1966) comes more of the green vitric tuff, this time in the shape of a disc knife identical to its Adrar

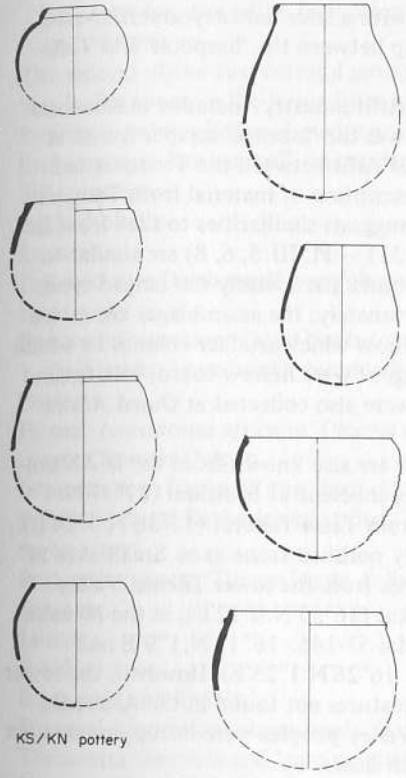


Figure 18.8 Tenerian pottery from Karkarichinkat Nord and Sud.

Bous counterparts but, again, no polished celts or adzes. The pottery includes one fragment of dotted wavy-line ware. Two ^{14}C dates run on ostrich eggshell in association with these industries (7 220 ± 110 B.C. and 4 890 ± 80 B.P.) certainly place them chronologically within the range of occupation of Adrar Bous. The points include hollow-based, foliates, stemmed/tanged and a different and distinctive tool-type, the tranchet (form F2, Hugot's 1957 classification). This is found not only at Erg d'Admer, but also at Meniet in the Hoggar (Hugot 1963), Timidoin (Maître 1971) and further north around Zouia el Kahla (formerly Ft Flatters) and at Aoulef (Hugot 1957). This projectile point is missing from collections made west of the Hoggar in the Tanezrouft, and apparently disappears north of the 28° parallel.

A tantalizing find from the east of Erg d'Admer in the Fezzan, 21 km ESE of Kourini-Aski-Nosan (23°12'N:15°20'E) (IFAN Collections Lib-49-295) was a 'Shaheinab'-type adze.

From the Azaouak area information is as yet very sparse. Post-palaeolithic material has been known from this area for many years (Le Rumeur 1933; Lhote 1955) but there are two conflicting dates from the two sites (Tamaya Mellet: 9 350 ± 170 B.P.; Taferjit: 4 080 ± 110 B.P.). However, the difference may well

be a result of mixture of cultural material with a later industry superimposed on an earlier one, similar to the relationship between the 'harpoon' and Tenerian industries from Adrar Bous.

As mentioned above with regard to the Arlit industry, included in these collections from In Waggeur (16°8′N:6°42′E) was the 'lozenge' scraper found at Arlit confirming the transitional position of Arlit between the Tenerian and the industries of the Azaouak area. The description of material from Tamaya Mellet and Taferjit by Le Rumeur (1933) suggests similiarities to that from In Waggeur. His 'grattoirs ovals ou ronds' (p. 311 – Pl. III:5, 6, 8) are similar to our 'lozenge' scrapers, and the projectile points, particularly the tanged type (Pl. IV:3) also have their analogues. Unfortunately, the assemblages are mixed in Le Rumeur's article so that we do not know which artefact belongs to which site. The projectile points found at In Waggeur were hollow-based, foliates and tanged denticulate types. Similar foliates were also collected at Ouled Ataba (16°16′N:6°21′E).

Some of the tool types from In Waggeur are also known from the IFAN collections in Dakar (No. So-49-77), from Iredenbelene at In Aridal (17°47′N:4°23′E) and Tirikin (17°10′N:4°43′E), and from Tassa-Takorat (17°30′N:5°24′E). These collections include small, completely polished stone axes. Small axes of this type are a common feature of industries from the lower Tilemsi Valley north of Gao, at sites such as Karkarichinkat (16°53′N:0°12′E), in the Menaka region at Tecoufit (IFAN collection No. Mal-51-145: 16°12′N:1°9′E and Telataye (Collections of Dr Jean Gaussen: 16°28′N:1°25′E). However, the lower Tilemsi Valley industry has several other features not found in the Azaouak, suggesting that the Azaouak and Tilemsi Valley peoples were occupying distinct territories, but came into contact with each other.

18.4 THE CULTURAL DIVERSITY OF THE TILEMSI VALLEY

The lower Tilemsi Valley industries have been studied in some detail (see Gaussen & Gaussen 1962; Mauny 1952; Smith 1974a, 1975). From this work three facies of late prehistoric occupation from the full length of the valley have been described. The first, 'facies A' used Asselar in the northern Tilemsi as the type-site. This facies is found west of the Adrar des Iforas but does not appear to have penetrated south of Anefis (Gaussen & Gaussen, n.d.). It has produced the following collection of cultural material and faunal remains:

Projectile points: triangular with concave bases, foliates (straight or denticulate edges), tranchets. Points with tangs and stems constitute less than 1% of the total number of points.
Geometrics: triangles, lunates.
Polished axes, adzes, stone rings, 'haches à gorge'.
Bone harpoons (unilateral barbs).
Personal decoration though rare includes: beads, pendants.
Quartz labrets (no ostrich eggshell beads so far been found).
Pottery.
Fauna: *Bos* sp., *Gazella dorcas; Hyaena* sp., *Giraffe camelopardalis; Panthera leo;* tortoise; crocodile; fish: *Silures, Lates;* mollusca: *Limicolaria chudeaui* sp., *Melania* sp.

The second of the two cultural groups was 'facies B'. The type-site in this case was In Begaouen in the lower Tilemsi Valley. This site yielded:

Projectile points: hollow-based, triangular, denticulate edges.
End scrapers: 'en éventail', triangular, 'à museau', 'carénés'.
Side scrapers.
Backed blades.
Lunates.
Polished azes (both small hornfels and siltstone).
Bone awls.
Personal decoration: stone beads (carnelian, amazonite, granite), ostrich eggshell beads, bone beads, ceramic beads, quartz labrets.
Pottery.
Fauna: *Loxodonta africana; Diceros bicornis; Phacochoerus aethiopicus; Bos* sp., *Capra* or *Ovis* sp.

In contrast to 'facies B' the third cultural grouping was named 'facies K' from the type-site of Karkarichinkat Sud. The distinctive characteristics of this facies were:

Projectile points: 'Tilemsi' type, foliates.
Scrapers.
Lunates.
Polished axes.
Bone awls and 'lissoirs'.
Personal decoration: stone beads, bone beads, ostrich eggshell beads.
Terracotta figurines and 'gaming pieces'.
Pottery (Figures 18.6-18.8).
Fauna: *Diceros bicornis; Loxodonta africana; Hippopotamus amphibius; Bos taurus, Ovis* or *Capra; Gazella dorcas; G.* of *rufifrons; ?Taurotragus; Redunca redunca; Tragelaphus scriptus; Hippotragus equinus; Oryx* sp.; *Ourebia ourebi;* Alcelaphini; ?Cephalophini; *Phacochoerus aethiopicus; Giraffa camelopardalis; Orycteropus afer; Canis* sp.; *Hyaena* sp.; ?*Genetta* sp.; *Jacalus jacalus; Lepus* sp.; tortoise; crocodile; fish: *Clarias, Auchenoglanis, Synodontis,* ?*Clarotes.*

As can be seen from the lists above, the distinctions are quite real, especially when one bears in mind that the Asselar region was populated some time earlier than the lower Tilemsi Valley. Unfortunately this region is very poorly studied archaeologically, in spite of having been known for decades when Boule & Vallois (1932) published their work on the 'Homme d'Asselar'. However a date of c. 4 500 B.P. was obtained from the skeleton (Camps 1974:241). The single radiocarbon date from the cemetery on the Algeria-Mali border of 4 750 ± 80 B.P. (Mauny et al. 1968:1319) probably dates the later occupation of the area.

Elements that are thus far known to be in common with the lower Tilemsi are the hollow-based projectile points which appear in the 'facies B', and the fauna which includes probably domesticated Bos, as well as both terrestrial and acquatic fauna.

'Facies B' and 'facies K' differ in their projectile points. In 'facies B' these

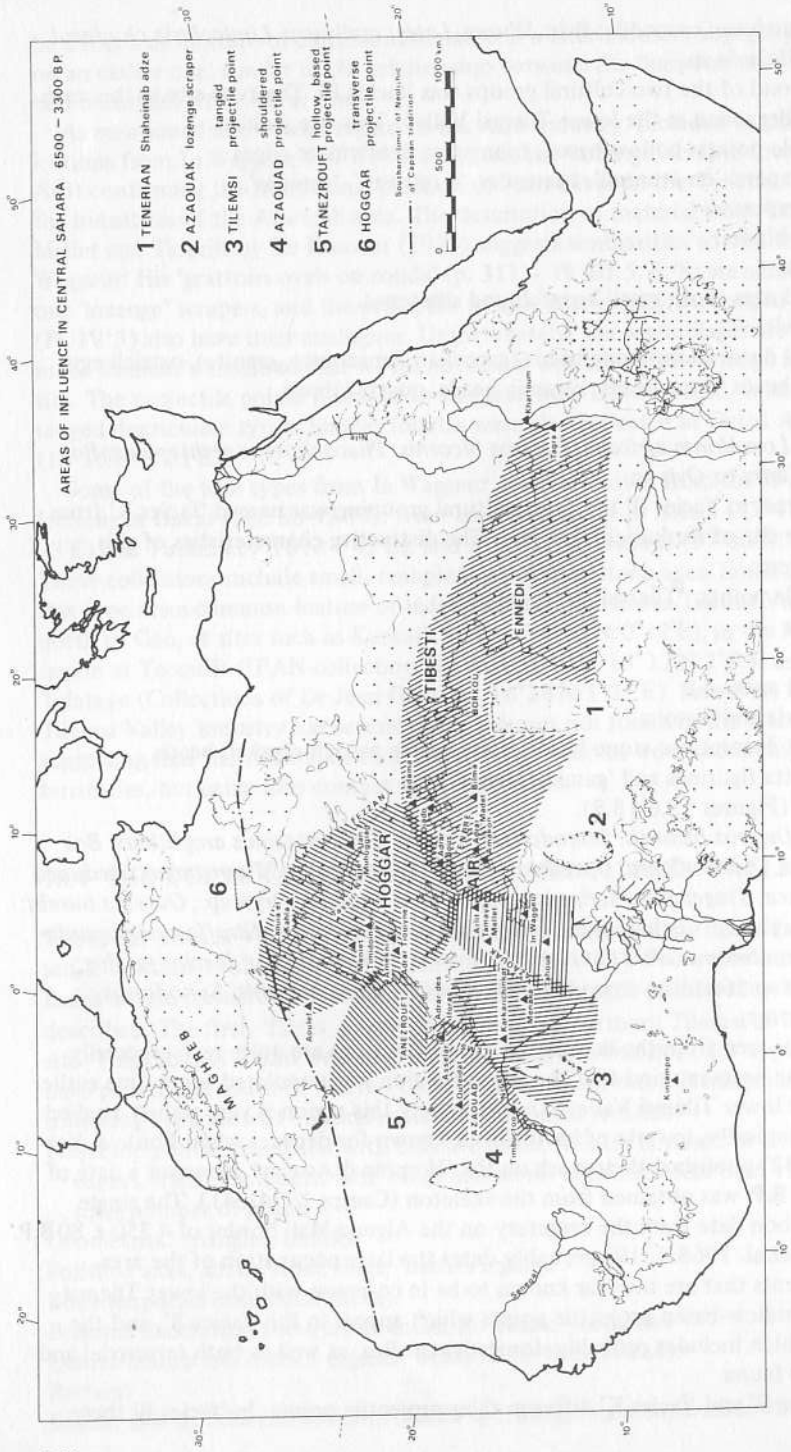


Figure 18.9 Areas of influence in the central Sahara 6 500-3 300 B.P.

are hollow-based and bifacial with denticulate sides and tangs extending as low as the base of the stem ('Tilemsi' points). The unifacial types with bifacial and often denticulate bases common with 'facies K' are also found in the 'facies B' collections but are very low in number. Sites having these include In Begaouen, Kassembar, In Aoukert and Ti Geroui.

Elements in common between the two facies are greater than their differences. Other than projectile points these include pottery with very similar rim forms and decorations, higher percentages of scrapers with tapered planform ('en éventail') in 'facies B' sites, small hornfels axes, and the fauna, again including *Bos*. Quartz labrets, however, are totally absent from 'facies K. sites.

The similarities between the three facies suggest a continuum in both time and space. The 'facies A' is a 'Saharan'-type industry which was transferred to the southern Tilemsi over several centuries resulting in the 'facies B', which, in turn, was the slightly earlier forerunner of 'facies K'. The 'facies K' has been dated from excavations at Karkarichinkat to between 3 960 ± 160 B.P. and 3 310 ± 110 B.P. There is no indication of prior occupation of the area before the 'facies B' industry which has not been dated, but is assumed to be only slightly earlier than the 'facies K'. Since the dates are somewhat later than those from the industries further north, and coincide with the aridity that caused abandonment of such sites as Adrar Bous after 4 500 B.P., it is probable that the Neolithic pastoralists were eventually forced to move south along permanent water courses, such as the Azaouak and Tilemsi Valleys, resulting in colonization of the lower Tilemsi Valley. That this was the beginning of the spread of the cattle complex into West Africa is further suggested by the early dates for *Bos* from the Kintampo Neolithic in Ghana between 3 560 and 3 220 B.P. (Carter & Flight 1972).

18.5 CONCLUSION

It can be seen from the information available on the 'Neolithic' of the Sahara (Figure 18.9) that the criteria used to define the Neolithic in the Near East and Europe, while very similar, have a completely different chronological arrangement. Pottery appears in the 8th millennium B.C. in the Sahara in association with a lacustrine-based economy based upon aquatic mammals and fish. These lacustrine-based cultures have been found from the Nile Valley to Mauritania. This industrial complex does not necessarily mean migrations of people, but probably rather similar environmental conditions sparking very similar responses over a large area with the possibility of some cultural contact. It is interesting to note that after 7 500 B.P. geomorphic indications suggest desiccation resulting in the abandonment of a number of central and southern Saharan sites with reoccupation perhaps a thousand years later. The new occupants of the area were pastoralists with herds of cattle and goats/sheep. It is difficult to be certain that these pastoral peoples were of the same ethnic origin as the previous hunting/fishing peoples. However, the geographical area occupied by the herdsmen is almost identical to that of the fisher/hunters – lakes are attractive to pastoralists too – and the cultural contact between the central

Sahara and the Nile Valley also appears to have been maintained. There is another hint in the stone-tool assemblages from Adrar Bous, that some of the tool-types of the lacustrine-based economy were to continue into the later Tenerian (Smith 1976:191). The problem in this case is that the samples were from surface collections, so a degree of mixture of earlier with later materials is possible.

The central Sahara continued to be occupied by pastoral peoples until c. 4 500 B.P. when another drying trend forced the pastoralists to confine themselves to permanent or seasonal rivers, such as the Tilemsi and Azaouak Valleys. This meant a southerly focus that led to colonization of new areas and the spread of the herding complex into the Sudanic zone of West Africa.

The question of man's effect on the Saharan environment still remains unanswered. It is thought by some writers that present climatic conditions are no different than they were 5 000 years ago and man has been the major agent of change. This is still an open question. There is no doubt that the present human response to drought conditions, such as those experienced in 1970-73, is very similar to that of the prehistoric pastoralists. This was to go south along the present water courses, such as the River Niger, where water and forage could be found.

It is obvious that the present situation in the Sahel is by no means a unique one and that pastoralists have had to survive under a range of environmental pressures since herding was introduced into West Africa. It is probable that the herding complex was a contributing factor to the desiccation of the Saharan zone, but fluctuating conditions were experienced prior to domestic animals appearing on the Saharan scene. They probably helped to exacerbate a deteriorating situation.

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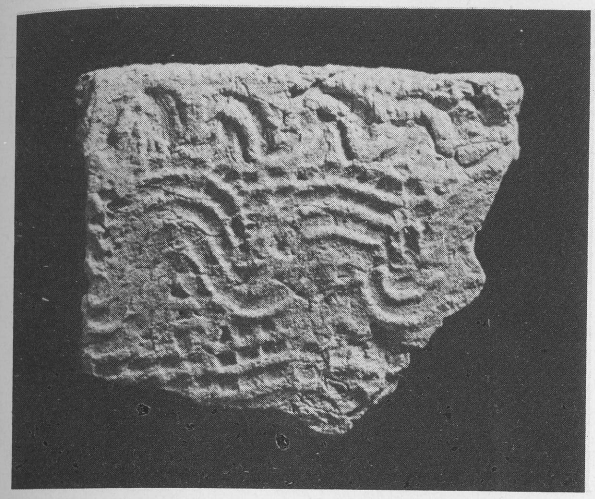
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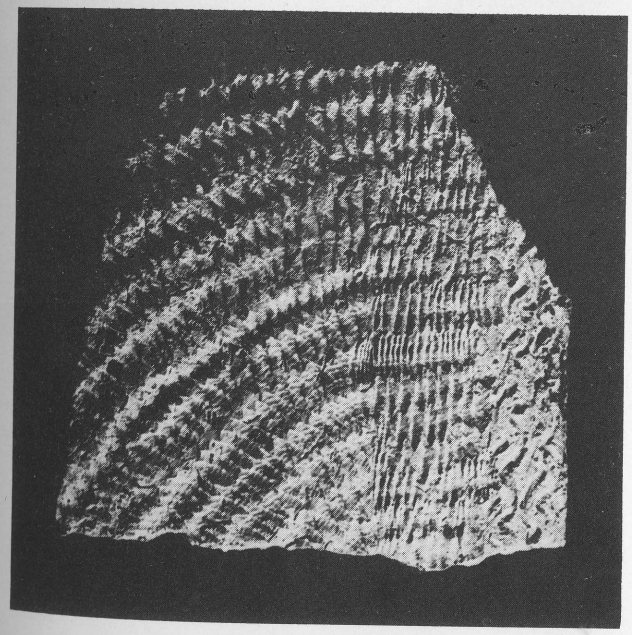


Photo 18.1 Rim sherds from Adrar Madet, Niger.
Top: Dotted wavy-line decoration.
Bottom: Wavy-line with roulette decorations.

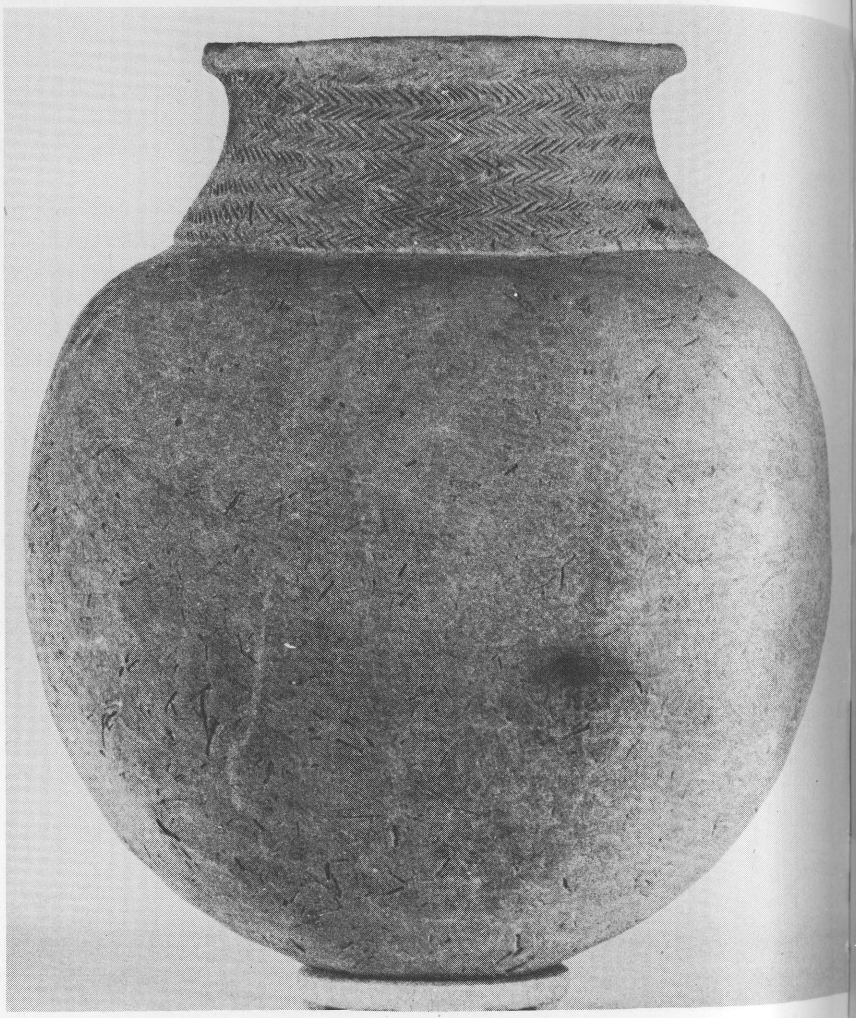


Photo 18.2 Pottery: Ténéré desert, Niger.



Photo 18.3 Pottery: Adrar Bous, Niger.

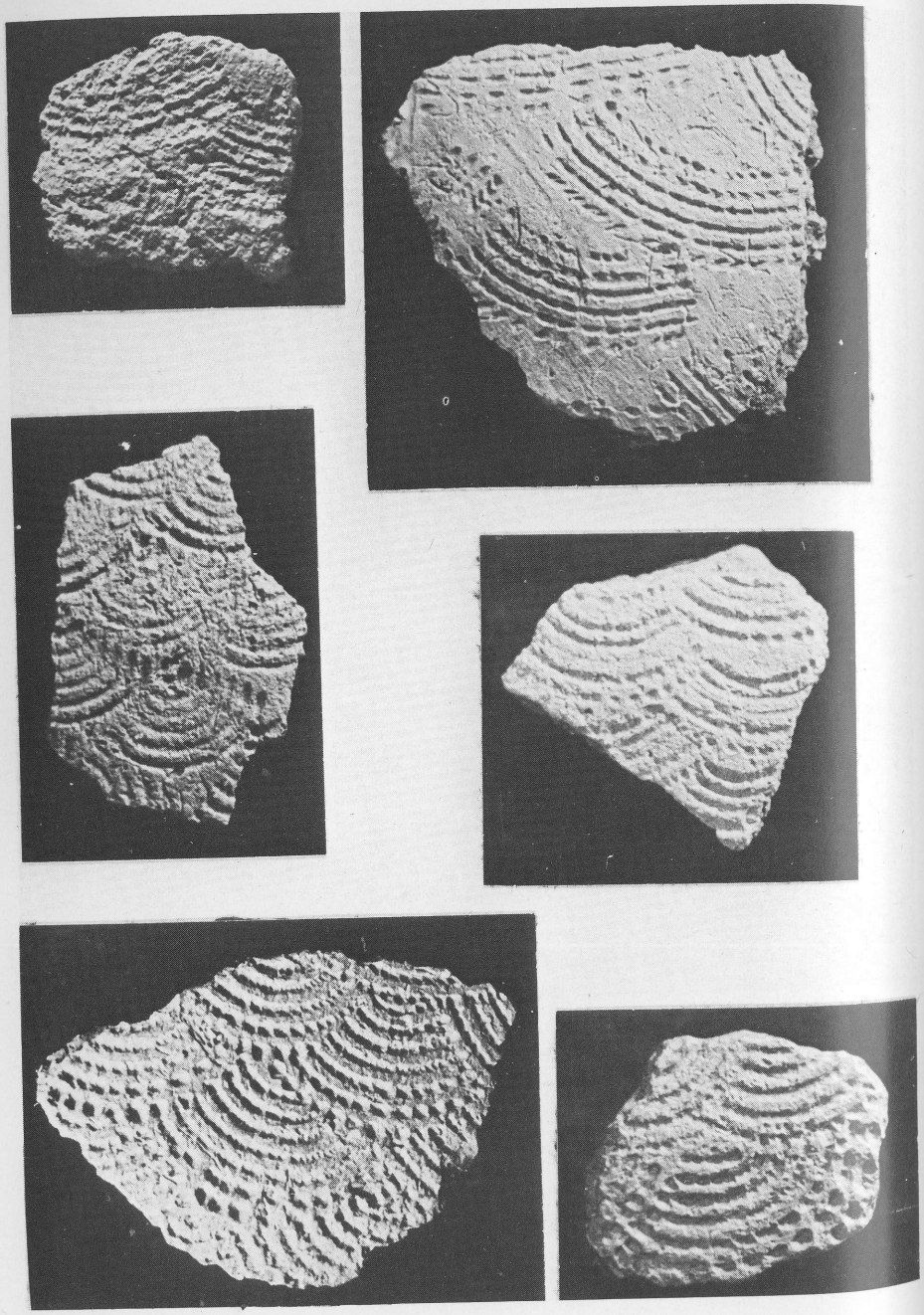


Photo 18.4 Pottery: Adrar Bous, Niger.

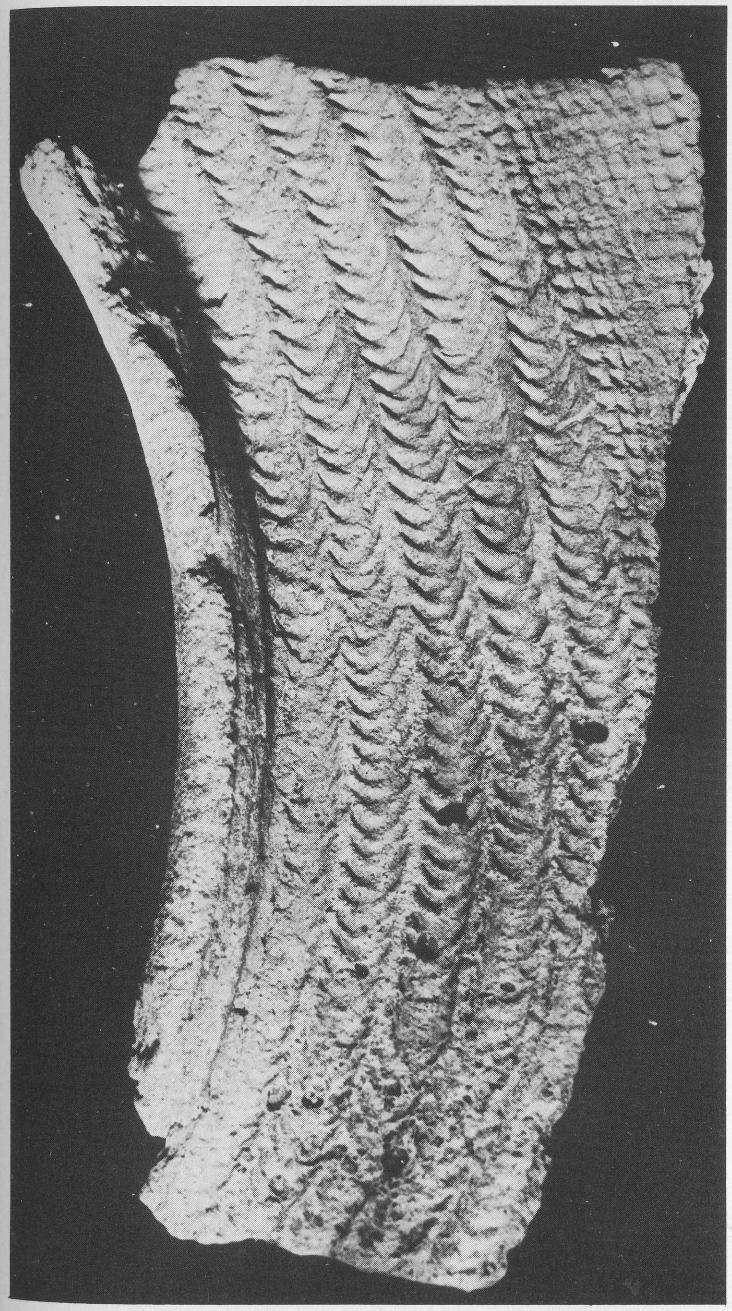


Photo 18.5 Pottery: Adrar Bous, Niger.

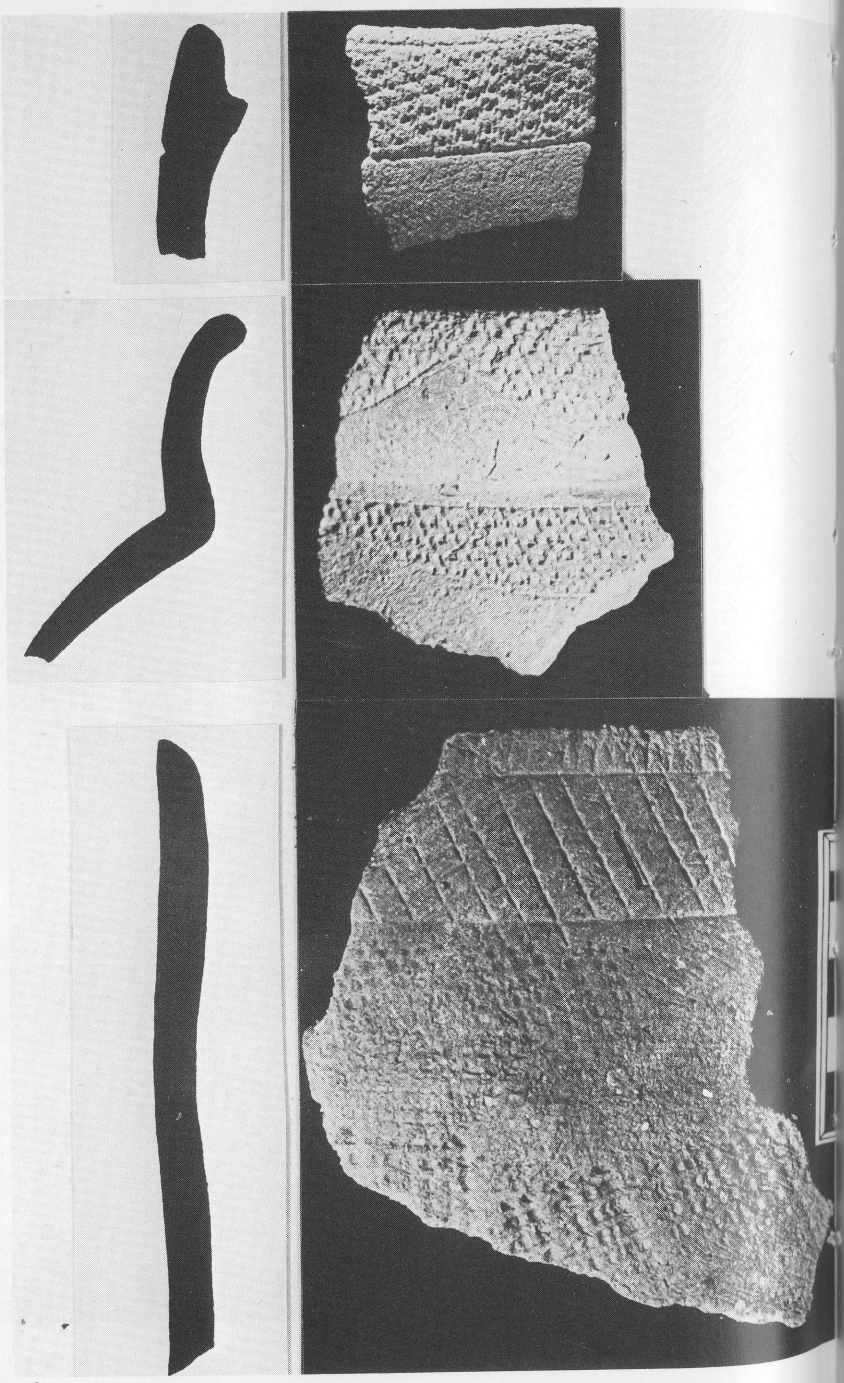


Photo 18.6 Pottery: Adrar Bous, Niger.

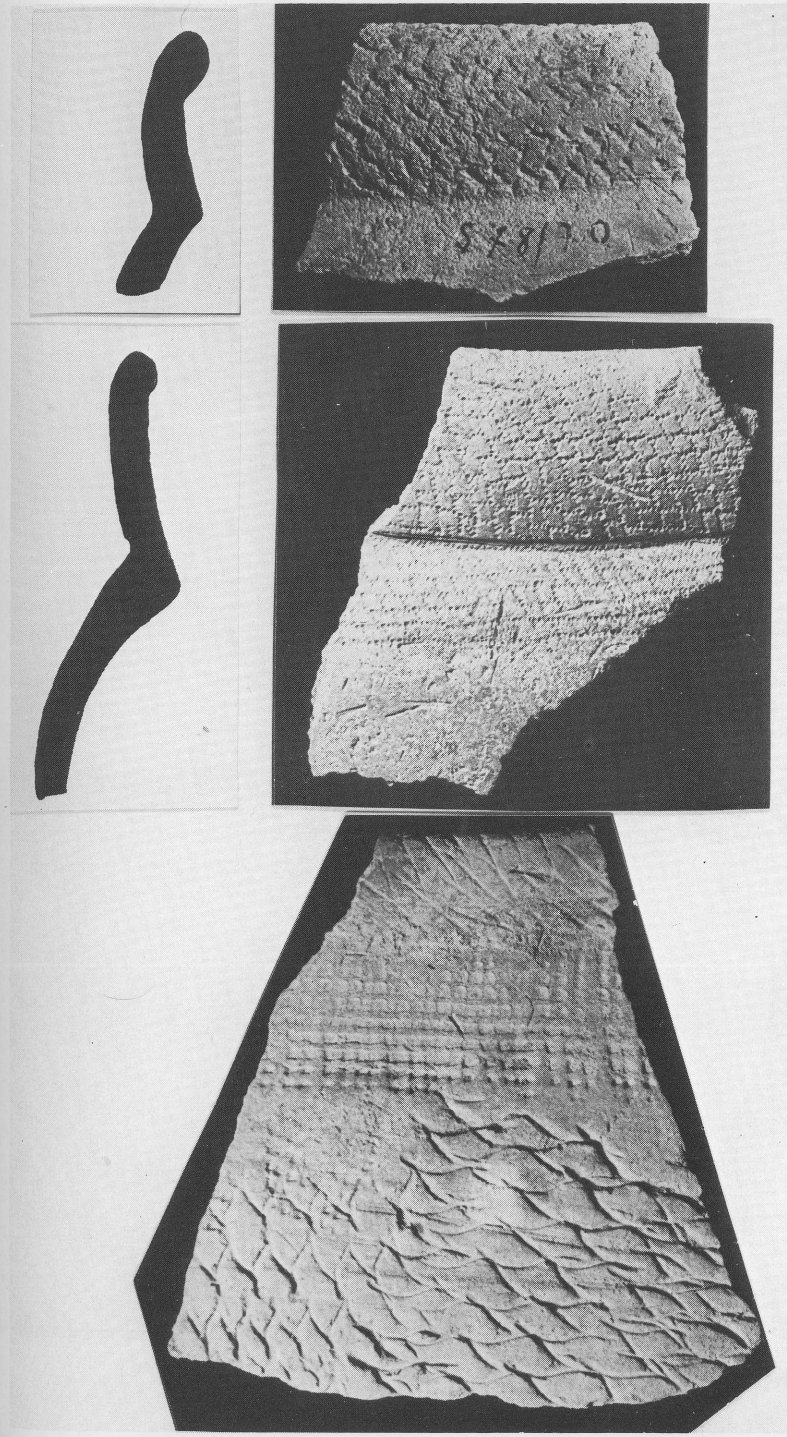


Photo 18.7 Pottery: Adrar Bous, Niger.

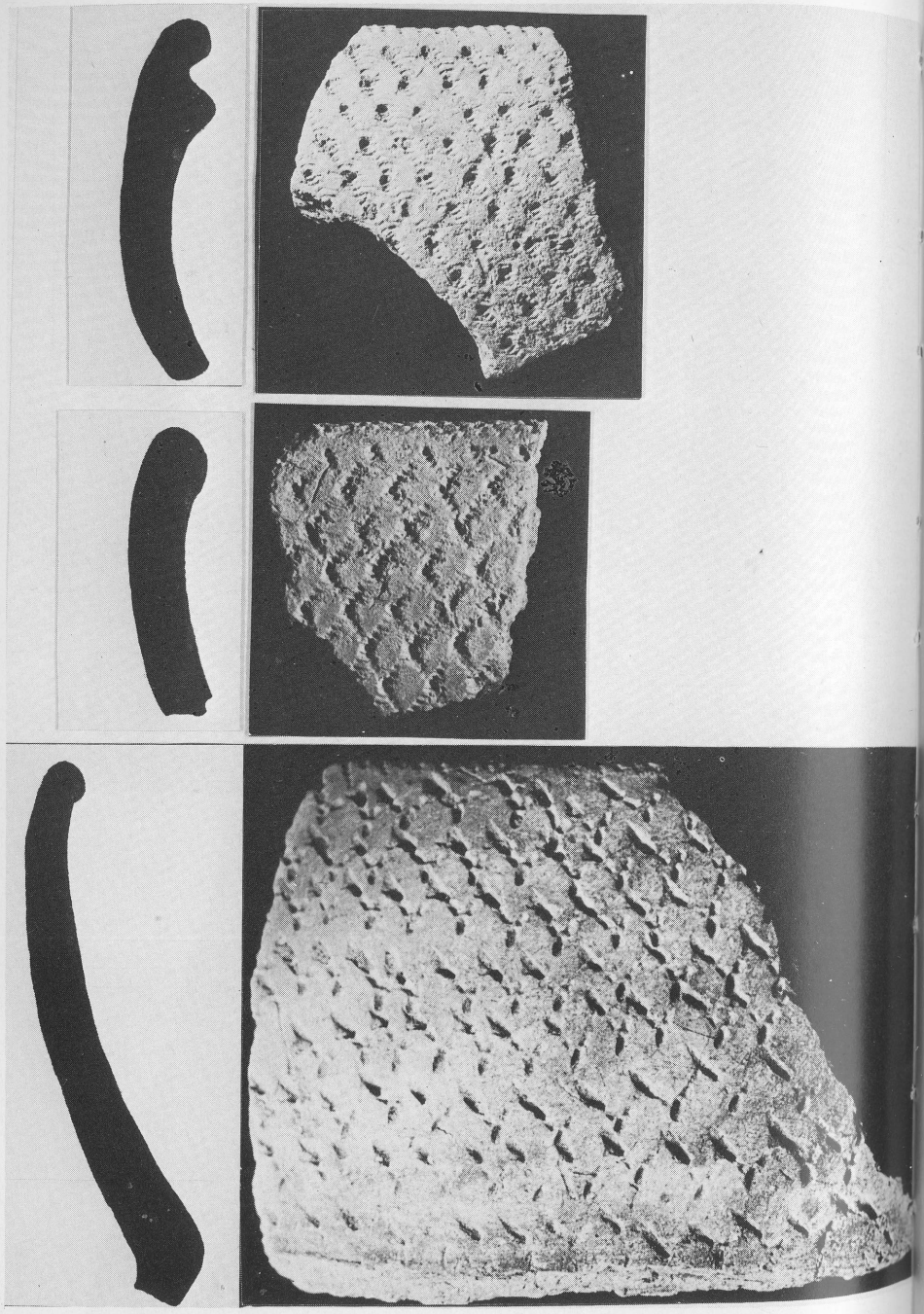


Photo 18.8 Pottery: Adrar Bous, Niger.

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19

The environmental adaptation of nomads in the West African Sahel: A key to understanding prehistoric pastoralists

L'adaptation des nomades au milieu naturel du Sahel de l'Afrique de l'Ouest: jalons pour une compréhension des pasteurs préhistoriques

Il faut toujours employer beaucoup de soins en utilisant des arguments fondés sur les analogies ethnographiques quand on parle des relations entre les hommes et les milieux préhistoriques. Cependant, ces arguments peuvent fournir des aperçus très utiles sur le comportement de divers peuples dans le passé, et peuvent ainsi nous aider dans l'interprétation des gisements archéologiques. La façon de vivre actuelle des Kel Tamasheq du Mali méridional est probablement assez semblable à celle des autres pasteurs nomades qui habitaient cette région du Sahel depuis le Paléolithique.

Le cours des migrations saisonnières est gouverné surtout par la localisation des ressources en eau et en pâturage pendant les longues saisons sans pluie, ainsi que par les besoins d'accès aux terres salées et de contact social pendant la très courte saison des pluies (mi-juin à septembre). Après les pluies, les campements nomades sont situés d'abord auprès de puits peu profonds creusés à la main dans les lits d'oueds au milieu des pâturages. Dès que ces puits commencent à se dessécher, les groupes nomades partent pour les points d'eau plus permanents, et en particulier pour les puits creusés dans les fonds de lacs qui ne fonctionnent plus à l'heure actuelle. Au fur et à mesure que le pâturage s'appauvrit, les campements s'éloignent progressivement des puits, et vers la fin de la saison sèche ils sont immobilisés entre l'eau d'un côté et le pâturage de l'autre. La distance à l'abreuvoir est contrôlée surtout par les veaux, mais ce sont les besoins des animaux adultes qui déterminent le temps de déplacement vers de nouveaux pâturages.

Les groupes nomades vivant dans les alentours du Niger se déplacent vers la fleuve à la fin de la saison sèche afin que leurs troupeaux puissent brouter les plantes aquatiques qui poussent au bord de la rivière. D'autres groupes nomades se déplacent vers le nord à la recherche des terres salées à la lisière du désert pour que les troupeaux puissent brouter les herbes salées et s'abreuver dans les eaux minéralisées de ces lieux. Pour les nomades la saison des pluies est aussi la saison des fêtes, des concours sportifs, et des fiançailles.

La nourriture et les besognes domestiques des nomades sont telles qu'ils laissent très peu de traces lorsqu'ils se déplacent: quelques os brisés, des foyers, et des morceaux de cuir et de bois. Les nomades Kel Tamasheq ne se servant pas de pilons et de mortiers en pierre, et n'emploient que rarement les pots en terre cuite, qui sont lourds, fragiles et peu faciles à transporter. Ils récoltent beaucoups de graines sauvages, surtout les *Panicum* et les *Eragrostis*, et quelques fruits et végétaux non cultivés, mais ce sont les troupeaux domestiqués qui sont les sources principales de nourriture et de boisson, et qui constituent leurs richesses et leurs moyens d'échange et de transport.

19.1 INTRODUCTION

Archaeologists obtain a reasonable picture of the physical setting of the prehistoric populations they are investigating through analyses of the floral/faunal remains and the geomorphology. However, they are then faced with the question: given this type of environment what adaptations enabled the people to extract from it their basic requirements of food, water and perhaps, shelter? Ethnographic analogy cannot describe the man/land relationship that existed in a particular case but it can suggest a range of alternatives that may provide clues for further archaeological investigation.

The following discussion is intended as an example of one of these alternatives. It is based on nine months' fieldwork undertaken by the writer in southern Mali among the nomadic Kel Tamasheq who exploit an environment and illustrate a life style similar in many important respects to the post-Palaeolithic inhabitants of the area. The majority of this time was spent with the Oulliminden tribe who inhabit the area between Gao on the Niger River and the Niger border. These people are one of the most isolated of Tamasheq groups and the lack of outside influence is reflected both in the material culture and diet.

The physical setting to which they are adapted borders the southern Sahara and is known as the West African Sahel. This region is characterized by an annual rainfall of 50-150 mm which allows the survival of a vegetation pattern dominated by such grasses as *Cenchrus biflorus* and *Tribulus terrester* and trees such as *Balanites aegyptiaca* and *Acacia* spp. The fauna include *Gazella dorcas* and *G. dama,* as well as ostrich, warthog and giraffe, although these wild populations have been drastically reduced in recent years due to the use of firearms and motorized vehicles (Nicholas 1950: Pl. 1; Richer 1924:9). Three seasonal extremes can be distinguished: a cold period from December through February, a hot dry period during April and May, and a wet season beginning in mid-June and lasting to September during which violent storms and the only measurable precipitation during the year occur. Temperatures during the day reach highs of 115°F (46°C) in May and at night may dip as low as 40°F (4.5°C) in December. The Sahel dwellers have adapted to this environment by utlizing almost all natural resources, either directly or through the medium of animals, and have obtained them in amounts sufficient to sustain life by moving from area to area.

The nomads do not form a homogeneous society although they have a common designation as Kel Tamasheq (Tamasheq speakers) or Kel Esuf (people of the bush). Many authors have used the Arab term 'Tuareg' in reference to this group but since it is sometimes used to refer only to noble classes and because the nomads never use it, their own designation for themselves, Kel Tamasheq, will be followed. Recently non-Tamasheq speakers have been moving into this area, mainly Peul (Fulani) and Arabs. The adaptation pattern of the Arabs is very similar to that of the Tamasheq but the Peul lifestyle differs considerably. They comprise five distinct social categories: nobles (known as Imajaren), their vassals (e.g. Imrad, Debakar, Chamenamas), marabout tribes (Kel Essouk), slaves (Iklan or Bella), and artisans (Inadan). Slaves and artisans may reside either independently or, as is traditional, in the camps of the wealthier nobles, vassals and marabouts; the latter three groups may visit each other for long

Table 19.1 Average number of lactating animals per household, according to social class and animal type (example drawn from one camp, 6/72)

Animal	Nobles (Imajaren) (5 households)	Iklan of Cows (7 households)	Iklan of Camels (5 households)	Artisans (4 households)
Camels	3.0	0	3.5	1.3
Cows	2.4	3.2	0	4.0
Goats	0	9.0	5.0	6.0
Sheep	0	+	0	0

* Ratio changes as new animals are born.
\+ Only 1 household has lactating sheep (10)

Table 19.2 Approximate yields of milk according to animal type at evening milking (in litres)

Animal	Cold season	Hot season	Wet season	# times milked per 24 hours
Camels	5-7	2-4	7-9	3
Cows	3-4	2-3	4-7	2
Goats	0-½	1	2	2
Sheep	2	0	3	1

Table 19.3 Lactation patterns according to animal type

Animal	Months gestation	Months between gestations	Births per 2 yrs	Months lactation
Camel	12	10-12	1	18-24
Cow	10	2-4*, 12‡	2	10-15
Goat	5	2	8 (twins)	7-8
Sheep	6	2*	6 (twins)	7

* If pasture is extraordinarily good
‡ If pasture is extraordinarily bad

periods but do not live together permanently. Details of occupation, ritual, physical type and kinship patterns vary among these groups but on the whole their adaptation to their environment is quite similar. All are pastoralists with herds including camels, cattle, sheep and goats (household animals include donkeys and dogs); are traditionally 'pure' nomads, i.e. never sedentary; are Muslim; and speak a common language, Tamasheq.

19.2 DIET

Although diet varies according to the season, wealth, age and social position of the individual, milk is the basic for all. It is drunk either fresh or soured. For the latter a culture is placed in fresh milk (preferably cow's) and it is allowed to stand for 14 hours. It then may be drunk plain, or with the addition of water, the dried and pulverised fruit of *Zizphus* sp., flour of millet or wild grains, cheese or dates. The preparations, translated as 'crème', are considered very fortifying. Butter is made from cow's milk and is churned in a goat skin each

Table 19.4 Commonly used wild grains and other wild foods

Name of grain	Collection	Preparation	Importance or use
Asaral*	Aug.-June in watered plateaux and valleys by Iklan or Imrad	Cooked, always needs sauce (milk or butter)	First grain to ripen, very light, no diseases, 'good for diarrhoea'
Akasof*	Drier plateaux, is smaller than Asaral		
Tegebart	Found in same places as Asaral, often mixed	Cooked or raw as 'crème', does not need sauce	Is considered to be the best variety of ishiban
Wajag	Needs heavy rain before growth starts, must wait till straw is dry before gathering – by all Iklan on dunes and plains	Cooked or raw as 'crème'	Considered more nutritious than ishiban, was main feed for horses with milk. If eaten excessively, can give diarrhoea
Agarof	During wet season when still slightly green on dunes	Pounded to break off spines (vicious!), cooked or raw	Flavourful, especially 'good for old people as tonic, and blood diseases'
Afaso	On dunes in same areas as ishaban during October	Harder to pound than ishiban, raw or cooked	Can be found in great quantities but only harvested if ishiban lacks – famine food low status
Tajite	A red grain found in clear spaces after a rain, collected by ants, can be scraped up with hands	Difficult to pound, cooked or raw	One of the few grains available at this time 'keeps stomach full till next day, good for men'

* Asaral and akasof are both called ishiban

morning. Cheese is only made during the rainy season when there is a surplus of milk; after drying it can be kept for more than a year. Donkey's milk is used only for medicines.

In principle, the milk supply available to each family at any one time should vary according to the number of milk animals it owns, or, as in the case of Iklan, the number allotted to it; and the type of animals, since this determines when lactation begins, how long it continues and the amount produced (Tables 19.1-19.3). (An individual family is likely to have only one or two types.) However, these social and economic variations are minimized through a system of redistribution operating both between the households and between the social categories within camp. The common mechanisms are trading (e.g. tobacco for milk, camel's milk for cow's milk), sharing and 'stealing'. Imajaren households are an exception in that they cannot share the milk itself with others of the same rank but may instead either borrow a lactating animal or send their children to drink with a family which has a surplus.

Except during the wet season milk is insufficient to nourish adults and therefore is supplemented with wild and domesticated grains. The former, gathered by the slaves and poorer vassals, consists primarily of *Panicum* sp. (ishiban, which can be further separated into akasof and asral) and *Cenchrus biflorus* (wajag) (see Table 19.4 for additional species), *Panicum* is the most important wild grain because it is more abundant, is the first to ripen after the rains, requires very little preparation (pounding), and does not cause digestive upsets. It is harvested at three different stages in the ripening process: the first, beginning in August or September lasts only 10-15 days and involves cutting the heads from the standing grain. This harvest is especially important if the milk supply is low. The second follows in mid-September when the grain is ready to fall and is harvested by bending the stalks over a basket and beating the grains into it. This ishiban is considered the cleanest and is most preferred. The final harvest begins in October and lasts until the next rains in June or July and consists merely of sweeping up seeds which have fallen naturally after the straw has been cut, eaten by animals, or burned off. Grain gathered in the latter manner is considered of lowest quality since it requires considerable preparation before eating to remove the sand. After harvesting the grain is dried and stored in leather sacks, mud-brick granaries rented in towns, or in holes in the sand (diameter 0.5 m, depth 1.5 m) lined with matting. Grain which is stored in this lat-

Table 19.4 (continued)

Grains:		
Asaral	=	*Panicum laetum* Kunth
Akasof	=	*Panicum laetum* Kunth
Tegebart	=	*Echinochloa colona* Link
Wajag	=	*Cenchrus biflorus*
Agarof	=	*Tribulus terrester*
Afaso	=	*Panicum turgidum*
Tajite	=	*Eragrostis* sp.
Vegetables:		
Eshako	=	*Glossonema Bovennum*
Agar	=	*Maerua crassifolia*
Tagoya	=	*Citrullus colocynthis* Schrad
Alikid	=	*Citrullus colocynthis* Schrad
Ibellawent	=	*Rumumex?*
Abedebit	=	*Boerhavia agglutinans*
Tamasalt	=	*Limeum indicum* Stacks
Fruits:		
Amalaja	=	*Acacia raddiana* Savi
Tadant	=	*Boscia senegalensis* Lamk.
Abora	=	*Balanites aegyptiaca*
Terakot	=	*Grewia populifolia* Vahl.
Tabakot	=	*Ziziphus saharae*
Gums:		
Tamat	=	*Acacia Seyal* Dil
Afaja	=	*Acacia raddiana* Savi

Table 19.5 Harvest periods of major domestic and wild grains

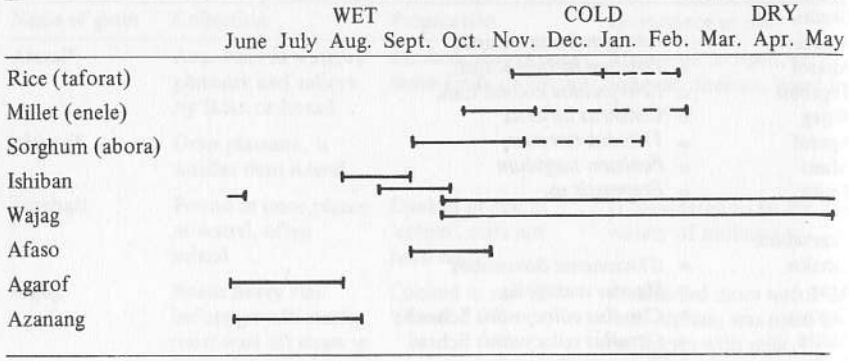
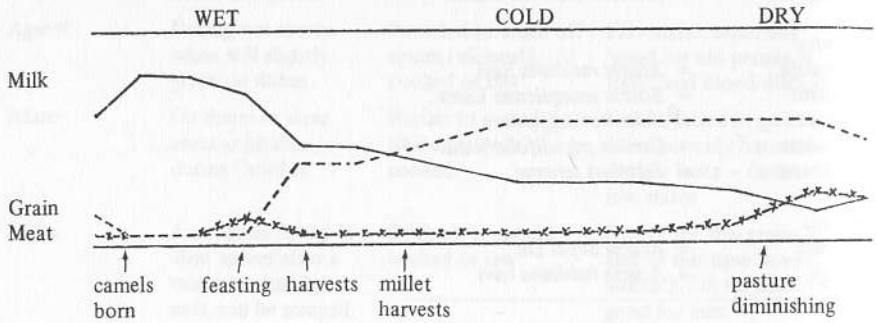


Table 19.6 Proportion of milk, meat and grain in diet according to season



ter fashion is usually conserved for times of scarcity. When the first harvests come in, in September, these reserves are immediately replenished, whatever old grain remaining is either eaten or sold. The grain is said to suffer little loss in quality for at least two or three years. The location of the holes is secret but often are placed near the wells frequented by the group, besides the stands of grain, or on the edge of a village. (Table 19.5 lists the harvest periods of the primary grains.)

Domestic grains (wet rice, millet and occasionally sorghum) which are grown by sedentary agriculturists along the Niger River, were traditionally supplied to the nomads as tribute but now are purchased by them when the wild grains are unavailable, or for special occasions. Domestic forms constitute roughly half of the grain eaten by nobles, but only a quarter for the Iklan, although this depends on the size of the harvests. During the months from September to January ishiban and wajag are eaten by everyone but as the supplies diminish the wealthy nomads and Imajaren eat an increasingly greater proportion of domesticated grains whereas the poorer people resort to the less common wild grains, e.g. *Tribulus terrester* (agarof) (Table 19.6).

Both domestic and wild grains are pounded in a wooden mortar to remove

Table 19.7 Commonly used vegetables, fruit and gums

Name	Collection	Preparation	Importance or use
Vegetables:			
Eshako	At end of wet season, in stony ground.	Pull off leaves and boil in water.	Important food plant in barren areas.
Agasse	Short plant found after rains beside lakes.	Remove thick stems, boil leaves in water.	Eaten in great quantities by children.
Akowat	Parasite growing usually on afagag or tazite.	Eaten raw (leaves) never cooked, slightly bitter.	
Agar	Leaves of tree are picked.	Must be cooked twice, first water discarded.	Not very tasty, only for emergencies.
Tatola	Thick woody vine that grows up trees, eaten after rain.	Root eaten raw, leaves cooked in three waters or roasted.	A sweet famine food.
Tagaya	Melon seeds taken from excreta of cow.	Wash, pound, add tabakaten.	Sweet 'like dates'.
Alikid	Fruit of melon after wet season, found 'everywhere'.	1. Put fire in hole in sand, remove, add melon. 2. Boil in water.	Food source, water source (juice), medicine.
Ibellawent	At end of hot season, on dunes.	Eat raw.	A sweet.
Abadebit	–	Fruit: raw; Grain: pounded, boiled; Leaves: boiled	–
Tamasalt	Grain found in ant hills or beaten out of husk with stick.	Grain: pound, boil, mix with ichiban. Leaves: cook in water.	Food source.
Fruit:			
Amalaja	Shake from trees at end of dry season.	Pound, sieve, add sour milk and Ibakaten.	'Very good for getting fat', enjoyed by sheep.
Tamint	Fruit of Tadant.	Dry near fire, pound, put in cloth in water 10 days, cook with meat, also can be eaten raw.	Food source, a sweet.
Ebelekunt	Fruit of Agar, when ripe are black.	Eaten fresh; dry, then add water.	Sweet, good for journeys.
Aboragen	Fruit of Abora gathered from ground during dry season.	Eat fresh or cook green fruit.	A favourite sweet of children, nut is important medicine.
Tamont	Picked from bush in wet season.	Eaten raw, skin is discarded, nut is sucked.	Only eaten by children.
Terakot		Ground, seeds discarded or eaten as is.	For sweetening sour milk.
Tabakot	Picked by Iklan.	Eaten as is or ground, mixed with water, baked.	The most important fruit for sweetening.
Gums:			
Awarwar		Eaten raw.	Anti-sorcery.
Tamat		Eaten raw.	Tonic.
Afaja		Eaten raw.	Sweet.
Ibalugalug		Sucked.	Medicine for mouth sores.

the bran which is then separated from the grain by shaking from one flat basket to another, the process also used for removing sand. No stone querns, pestles or grinding stones were observed among the Tamasheq Sahel dwellers although Nicolaisen (1963) and Gast (1968) note their use in the northern Sahara. The bran is frequently given to slaves and is eaten either raw or cooked. The cleaned grain is boiled in open metal pots, then eaten with butter, pounded meat or sour milk and salt.

Vegetables are consumed mainly when other foods are lacking or by children of lower status group. This is largely due to prohibitions against eating them held by higher class Tamasheq as well as the slaves and artisans who live with them, and perhaps also to their relative scarcity in the Sahel. Vegetables are usually cooked in water although the melons (tilagarien) may be roasted in hot ashes. Some (e.g. tatola) are eaten raw but this is rare.

Fruits are generally tabooed although small dried berries of *Ziziphus* sp. (Tabakat) and *Grewia populifolia* (Terakat), which are gathered by Iklan during August and September, are sometimes used as a sweetening for sour milk. Iklan and artisan children also collect and enjoy 'date sauvage' (aborak) and the gums of several trees. Aborak is the fruit of *Balanites aegyptiaca* and not that of wild date palm *Phoenix reclinata.* Dates are used for sweetening also but are scarce since they are not found in the Sahel, being acquired through trade with northern oases. Some leaves which are used as medicines, e.g. *Cassia obovata* (agargar), may impart some nutrition; they are usually chewed or brewed as tea. (Species of vegetables, fruits and gums and mode of preparation are listed in Table 19.7).

The Imajaren are prohibited from eating fish and insects as well, but other groups, especially those whose nomadic patterns bring them close to the Niger River, eat fish. Use of locusts has been noted among the Tamasheq tribes of the Sahara by Foley (1930:209) and Gast (1968:251).

Meat of domesticated animals is used mainly only on special occasions, such as religious festivals, arrival of visitors, major camp movements, and for medicinal purposes, although Kel Tamasheq believe that meat should be eaten at least every one or two weeks in order to maintain health and have been known to stage a 'special occasion' to justify butchering an animal. Goats are most frequently used because they are least valuable and are generally kept near the camp. A larger animal may be butchered when meat is scarce, if there are many visitors, or it is too weak – from thirst, hunger or travel – old, or sick to continue. However, the latter depends on the type of infirmity, for example, victims of pleuro-pneumonia are not eaten.

Wild animals are seldom eaten; this may be partly due to their present scarcity, food taboos, or possibly the lack of means of expertise. (Weapons consist only of knives and throwing spears; no bows are used except as toys.)

Animals are killed by slitting the throat. Blood and stomach contents are the only parts not used and the meat is divided according to strict social rules: chest to marabouts, if present, ribs to man of highest rank, head to shepherd or owner of herd, neck to elders in shepherd's family (if he is young), stomach and intestine to Iklan, lower legs to children, the rest to the owner of the animal. This pattern differs slightly according to type of animal. Large animals

such as camels or cows must be partitioned among the whole camp; sheep and goats are primarily for the family that butchered them although almost anyone may come to eat with that family or ask for some of the meat. Organ meats (liver, heart) are roasted on hot coals immediately after butchering and are eaten with salt by the family head and respected guests. Later, the haunch and meaty portions are prepared in any of these three ways: (a) roasted by burying in sand and fire built on top; (b) boiled in water, meat removed from bones and pounded in a mortar to break up the fibres, then served with grain or very rarely with butter only; (c) cut from the bones, divided into thin pieces and hung inside the tent to dry. Bones are discarded.

Fresh milk is the first meal of the day for children and is taken at dawn; the adults drink only sweet tea and chew tobacco. At mid-morning 'crème' is eaten by men and children, and less frequently by women. In early afternoon a major meal of grain with either meat, butter or milk is prepared if grain is available. In the evening, fresh milk is drunk by all, occasionally supplemented by a small dish of grain if milk is scarce. Visitors are usually given a meal of meat and grain, preferably millet or rice, in the evening.

Food is served in wooden bowls with 4-5 people partaking from each, using either the hand or a wooden spoon. Bones are broken open with knives or Neolithic stone implements to obtain the marrow and when finished are thrown outside the tent. If the camp remains in one place for more than a few days, such debris will be swept further away from the tent (8-10 m). Occasionally dogs (one or two of which are present in most camps), will scatter bones further. However, scavenging is not their main means of getting food since they are fed on milk and grain when it is available. Bones seem to accumulate on the west side of the tent during the cold season and on the east side during the hot months. (At other times, camps are not stationary long enough for debris to concentrate.) This difference may be due to the fact that in winter meat is eaten to celebrate the arrival of visitors and is served at the evening meal when people sit on the west side (perhaps for protection against easterly winds). During the hot season, however, meat is most frequently eaten at the main afternoon meal when tent occupants gather on the shady east side. Meat has less of a ceremonial function at this time since visitors are not common; it is more important as a food source because milk and grain are insufficieint and also many animals which are dying of starvation or thirst are having to be slaughtered.

19.3 DETERMINANTS OF MOVEMENT

Nomads' most common response to pressures from the physical and social environment (hunger, thirst, political hostility) is to move. It is one of the most effective means of exploiting widely scattered and scarce resources. The precise nature of the movement (its time, frequency, direction and distance) is the result of a complex interplay between the needs of people and animals and the availability of food and water, the latter being the most critical commodity.

Kel Tamasheq do not wander randomly but circulate in general 'home' regions, and within these, follow a habitual route, e.g. south to north to south

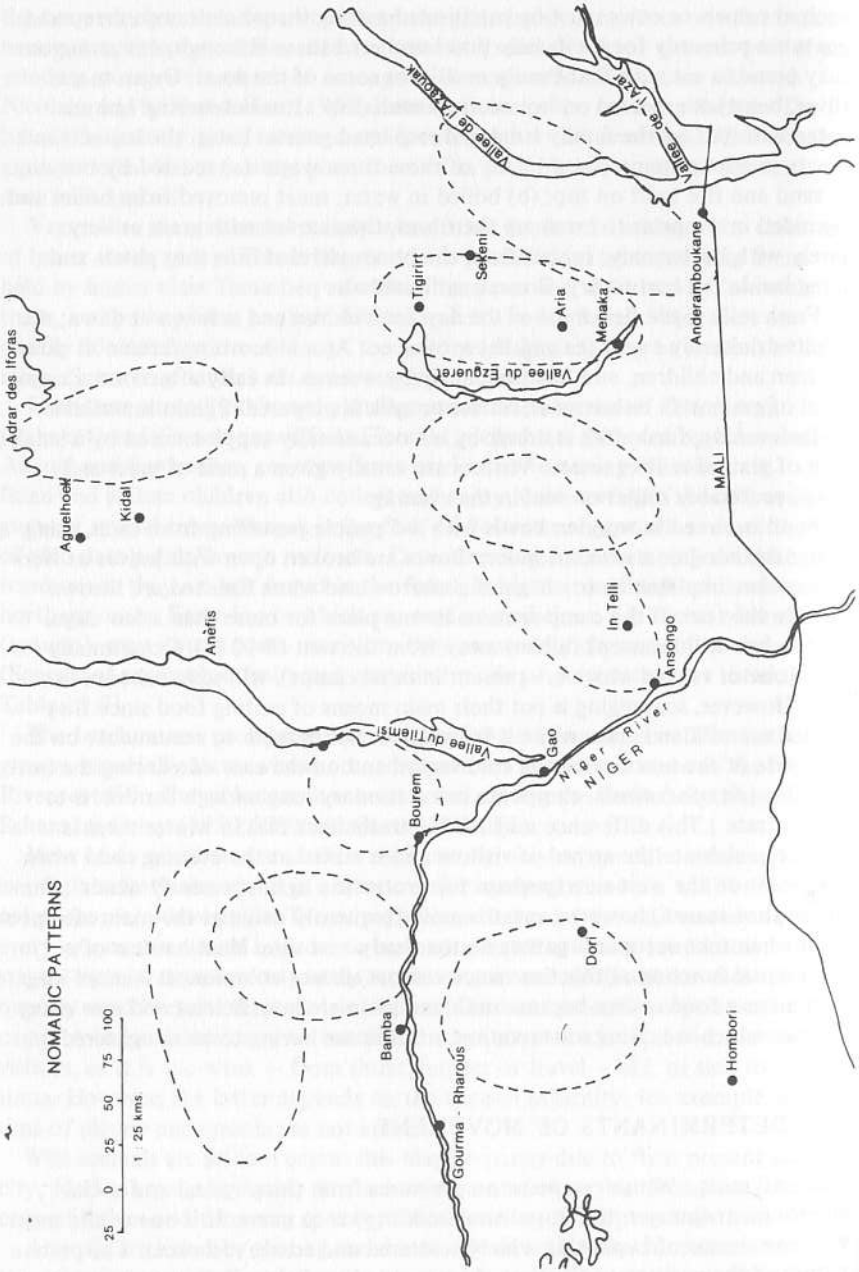


Figure 19.1 Approximate extent of areas occupied by nomadic pastoral groups in the vicinity of the lower Tilemsi valley, Mali.

again, although both the region and the route can change in response to unusual political or seasonal situations. The nomadic pattern is oriented to seasonal water points and key pasture areas (Figure 19.1).

In the first months after the rains, September-December, water is obtained from shallow hand-dug wells which are usually surrounded by adequate pasture. Camps are located near the water and this enables them to remain in place for as much as a month at a time. As this water dries up, usually between January and February, groups move toward more permanent sources such as bored or pump wells, or the traditional hand-dug wells in beds of now-dry lakes. As pasture is consumed in all directions around these wells the camps move gradually outward, spending no more than a week in one spot, until the distance between water and pasture is the limit that mature cows and caprines can travel (Table 19.8). At this point, occurring at the height of the dry season when it is tied to one water source, the camp is positioned between the well and the pasture and again remains immobile for several weeks. The exact placement of the camp itself at this and all other times is determined by the water requirements of the young animals which remain inside the camps, as well as those of the people themselves. Lambs, kids and humans do not require great quantities of water (sufficient amounts can be carried in leather water bags for two days' supply) but since calves drink more they must be taken directly to the water source every day. The extent of their daily travel depends on age and physical condition but is unlikely to exceed 10 km one-way. It can be postulated, then, that it is calves which determine the exact distance of the camp from water.

On the other hand, the crucial decision of when to move appears to depend on the food needs of mature animals, specifically those which are lactating. They must return to the camp each evening to be milked and feed their young and therefore cannot travel more than 20 km (for cows) in search of pasture. To ensure their return herders send the mothers in one direction and their young in another on the principle that in the evening both will converge on the camp – the young being hungry and the females seeking relief; if however, the two somehow meet in grazing (a not uncommon occurrence) neither comes back to camp. When the pasture is consumed beyond this limit the camp and herds must move to another permanent water source or possibly, if it is near the usual end of the dry season or if the source is beyond the capabilities of the

Table 19.8 Resistance of animals to thirst, hunger and fatigue

Animal	Max. no. of days without water*		Max. no of days without food	Max. km/day
	Cool season	Hot season	Hot season	
Camel	90	5-7	5-7	80
Cow	3	2	2	20
(calves)	1	1		10
Goat	15	2	2	20?
Sheep	30	1-2	2	30?

* Depends on quality of pasture

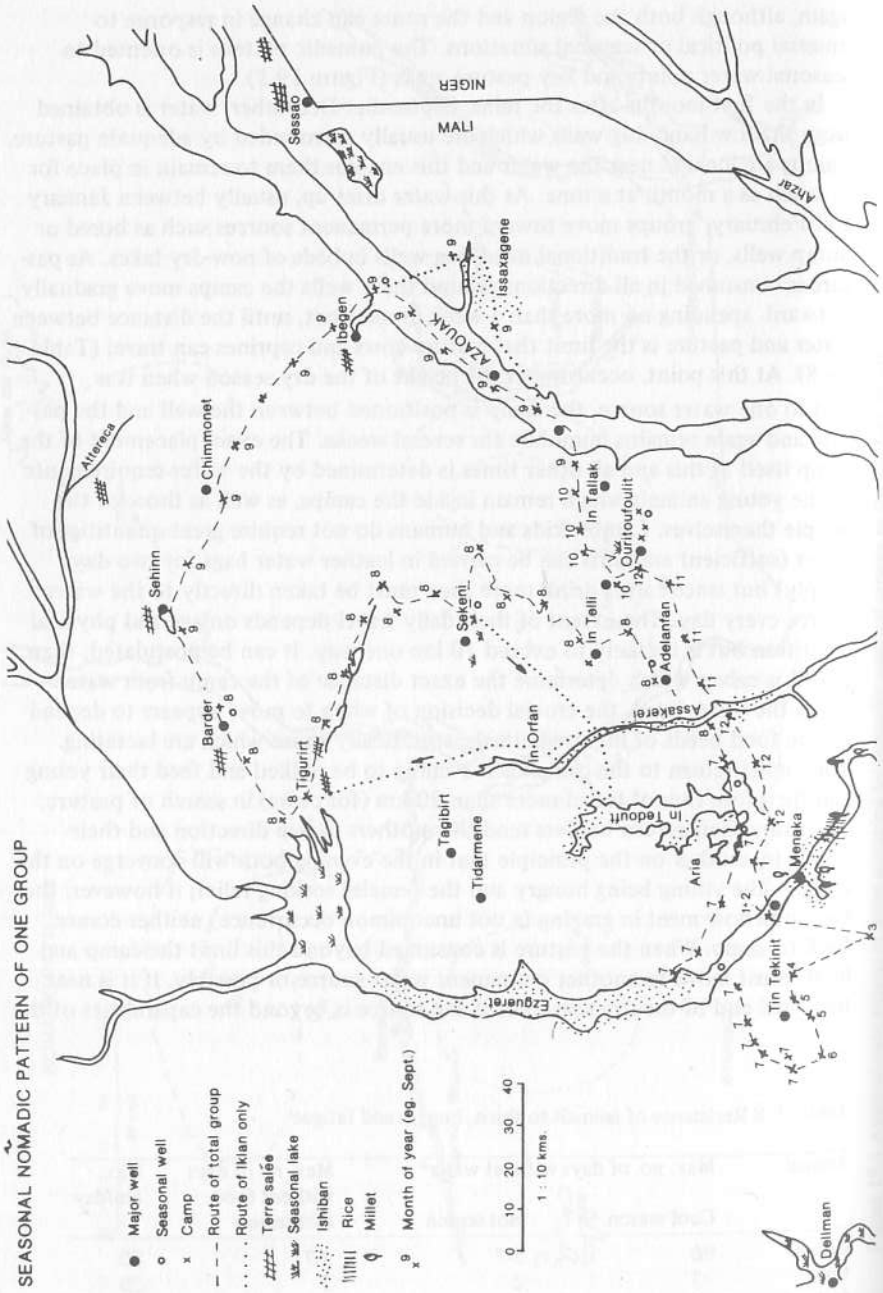


Figure 19.2 Seasonal pattern of movement by one nomadic group in southern Mali.

animals to walk, they may remain and try to eke out a living until the rains come. In either case, and especially when the rains are delayed, a considerable toll is taken in animals.

Such extreme conditions do not occur every year but they serve to illustrate the critical balance which exists between man and land at all times in a marginal environment. Nomadic life requires a sensitive evaluation of the needs of animals and an awareness of where the optimum supply of water and pasture can be found. Increase in population or change in environmental conditions may bring nomads into competition for these limited resources. It seems likely that these mechanisms were at work 4 000 years ago when the prehistoric pastoralists were being forced out of the Sahara to find new and more permanent water sources.

During the wet season an entirely different set of considerations dictates the location of camps and the time of movement. The needs of animals are no longer critical since new grass is growing and water is available everywhere in streams and shallow lakes. At this time, the mature non-lactating animals which until now have been totally independent of the camps and wandering freely in search of food and water are rounded up, a process that may take several weeks. When all the animals have eaten enough new grass to regain strength lost during the hot season the camp and its consolidated herds embark on a month-long journey to areas of salt earth ('terre salée') which are generally located to the north on the edge of the Sahara (the precise area differs for each region). This trek has both a health and a social function. Regarding the first, it allows the animals to graze on salt grasses and drink water of high mineral content which the nomads believe is necessary for health of both their animals and themselves. Secondly, since related tribes usually frequent the same 'terre salée' this is a time of feasting, competition sports (camelracing, wrestling), and above all, courtship.

During the wet season, the camps usually move each day or every other day, although the exact speed and frequency of movement is dependent on the strength of the young animals which are usually being born at this time; for example, young camels must rest at least a day after birth before they can travel, even then they may not be able to keep up with the herd and a herder will often drop back to walk with the mother and infant. Progress is often slowed also by the need to retrieve each morning the animals that have wandered during the previous night (during seasons when movement is infrequent the day before the trek animals are collected and hobbled but when camp is being moved each day the animals must be left free to graze at night). A minor factor affecting the speed with which the salt areas are attained is the search for appropriate routes. Large lakes must be skirted, and in the Saharan region good water and pasture again become a problem. The northward journey, then, is not direct but carried out in a zigzag fashion (Figure 19.2).

During all seasons, the distance that a camp moves at any one time is strictly dependent on the availability of water and pasture but normally it ranges between 2 and 30 km. Movement begins at dawn, taking approximately half an hour to break camp and continues only until noon. If still more territory needs to be covered the journey will resume after the day's heat diminishes.

During August and September, the movement pattern of Iklan, both those

who are a component of other camps and those who are independent, is slightly different from that of the nobles and marabouts, since it is influenced by their search for wild grains. At the time of the first harvest Iklan groups will converge on the areas which have been favoured by rain or soil conditions. If the yield is abundant the second and third harvests will be limited to collection of grains encountered while herding and will affect their movements to a lesser degree.

A local variation of the general pattern of movement is found among groups living near the Niger River, especially those between Timbuctoo and Gao. At the end of the hot season and especially if it is prolonged or severe the groups will reverse their pattern of following the diminishing pasture away from the river and make a forced march back toward it through now barren country in order to feed their animals on the river plants (bourgou) exposed by the lowered water levels.

Movement of all groups is influenced by death and disease. Nomads are aware of the danger of contagion and will isolate the tent of one who has an infectious illness. When travelling they will try to pass on the upwind side of a stricken camp. When a person dies he is buried several hundred metres from the camp, oriented to the east in the Muslim fashion, and the grave is covered with straw, after which, ideally, the camp will be moved. Tamasheq do not condone amputation, surgery, or mutilation of the body even in order to save life.

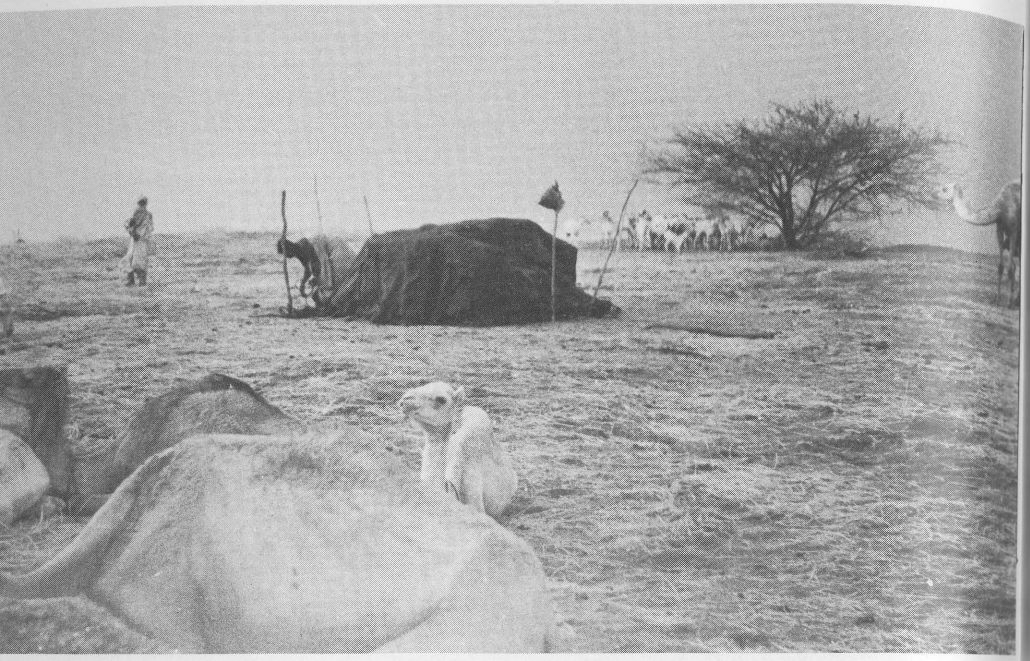
19.4 CAMP ORGANIZATION

The necessity for more or less constant movement has greatly influenced both the material culture and the living pattern of the Kel Tamasheq. The former is restricted to household necessities which are light and not easily broken; for this reason little pottery is used, most vessels being made of wood. The only item of pottery noted in one of the camps was a large broken pot (1 m diameter) in which hides were soaked to remove the hair prior to tanning. With superfluous items cut to a minimum, aesthetics are expressed in such functional items as carved tent poles, beds, bowls, and intricately woven mats, and through personal decoration: hair styles, necklaces, swords, charms, and leather wallets.

Tents are the logical response to needs for a shelter that can be quickly and easily dismantled and rebuilt during seasons of rapid movement, Photo 19.1. Tents are placed over a framework of wooden poles which are lashed together with ropes made from the bark of *Acacia raddiana* (afagag). They are fashioned from goat or cow hides, the number depending on the wealth or social status of the occupant – from as few as four to as many as 60 – sewn together with thongs. They constitute the heaviest and bulkiest item of gear but this weight is necessary in order to withstand the high winds and torrential rains of the wet season. During these storms tents are secured by tying their edges to the bases of the auxiliary tent supports (Photo 19.2a, b) and by throwing across the tent ropes whose ends are knotted around straw and buried in holes 1 m deep. Tents have an average life of ten years and are easily repaired by stitching circular patches of leather over rips or holes. During the hot season when the camps are stationary for weeks at a time, straw huts are constructed which are cooler than the dark tents;



Photo 19.1: Tent layout looking northeast. Note: small tent of household Iklan beside noble's tent.



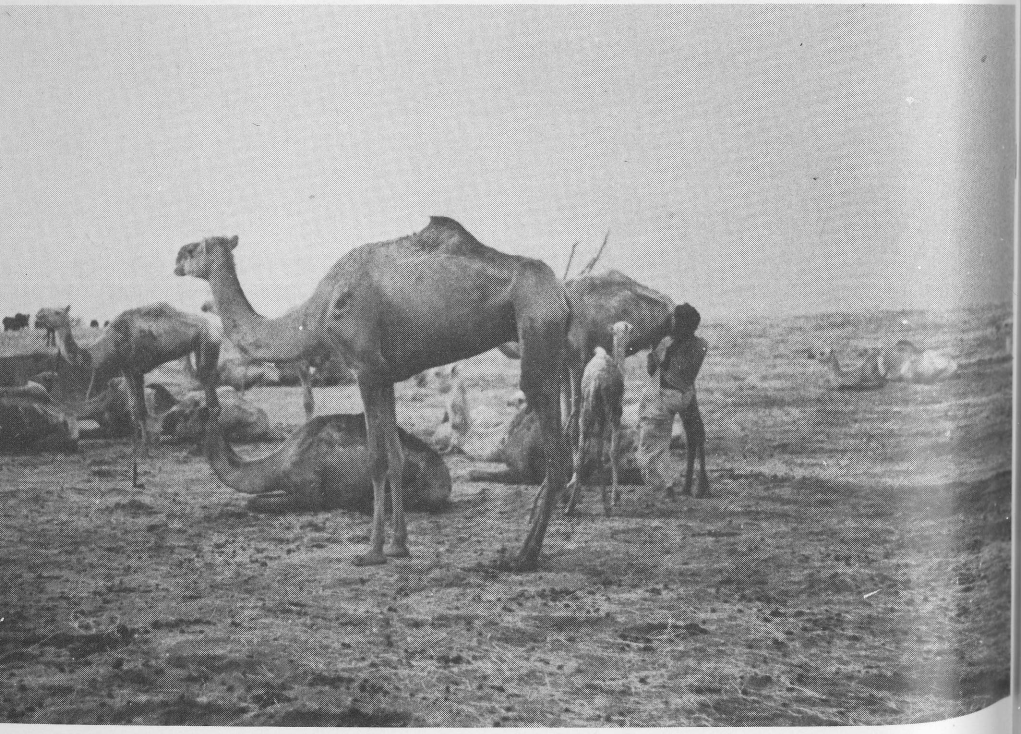
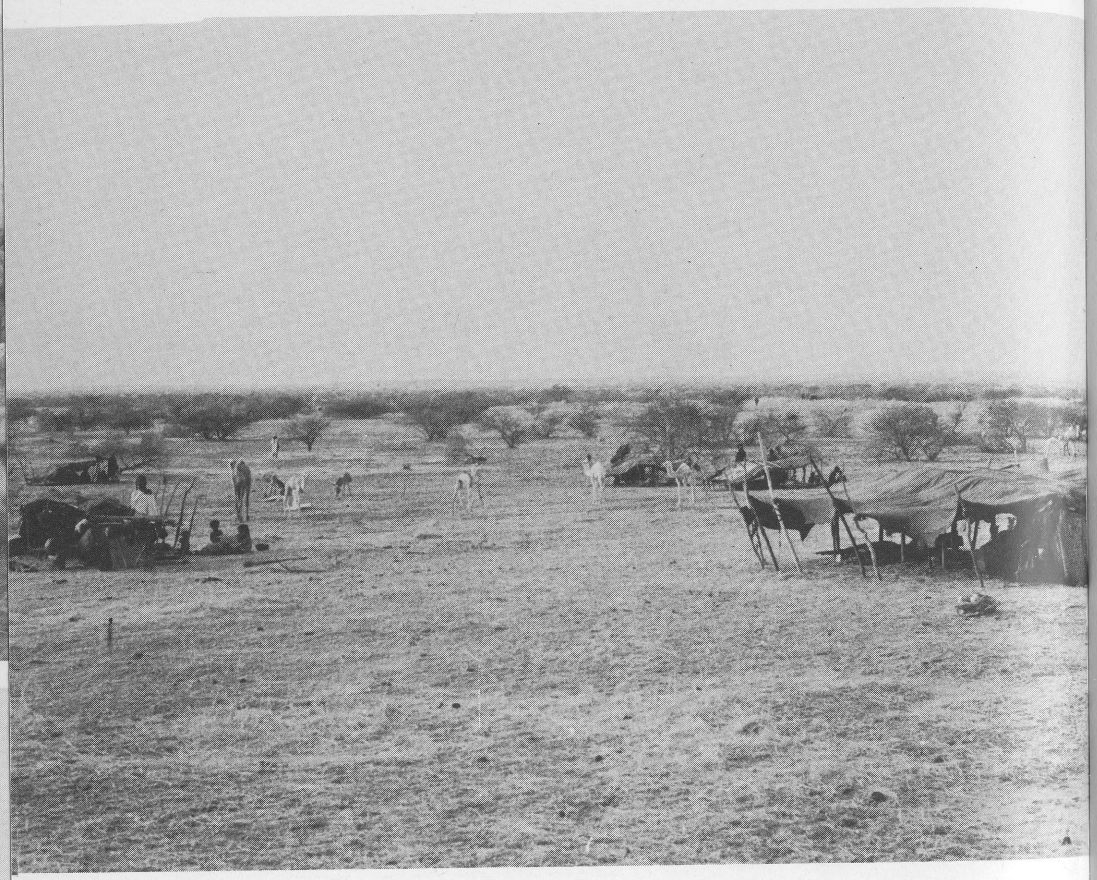


Photo 19.2:
a) Camp prepared for storm (1 600 hrs).
b) Iklan milking camel. Bowl is balanced on his right knee (05.30 hrs).



Photo 19.3:
a) Typical scene of camp looking southwest (1600 hrs).



b) Camp scene looking northeast (1600 hrs).

the latter are stretched out on the ground where they are mended and butter is melted into the leather by the hot sun in order to soften and preserve it. Red ochre (temesgeit) is then rubbed in as an additional preservative.

Camps are located in relation to natural features according to the season. In the cooler months (September-November and February-March) the camp is placed near areas of small trees or bushes that can provide fodder for young goats. In the cold months of December and January, the camp is moved into the shadow of an acacia 'forest', or, if that is unavailable, a large dune to gain protection from the cold winds. During the hot and rainy seasons, the camps are made on top of high dunes to take advantage of cooling breezes during the former and to avoid the mosquitoes and water runoff associated with the latter.

The nomads explain that at no time are camps placed within 100 m of a water source since it is prohibited to eat in such places.

Within the camps there appears to be no pattern regarding the placement of tents other than personal preference (e.g. some family heads prefer higher ground, others like to camp beside a tree, and some families habitually camp near each other because they get along well or have herds in common). The exceptions are that tents of slaves who care primarily for camels (Iklan n iminas) will be placed to the east of the master's tent and the tents of those who are 'slaves of the cows' (Iklan n tess) are always to the west. Also tents of the artisans are generally situated in a cluster to the west of the camp. The chief or most respected person chooses his place first and the others follow, apparently in order of seniority. Tents appear to be always situated east, which is contrary to the observations of some other writers (Briggs 1960) in the northern Sahara, and Nicolaisen among the Kel Ayr (1963). Baggage is piled on the north and south sides allowing the east and west sides to be opened when sun, and sometimes wind, is not coming from these directions (at noon tents are opened on both sides to give maximum shade and ventilation).

The distance between tents varies according to the terrain. On small dune tops the major family tents of nobles, for example, may be as close as 10 m to each other with the household slave tents clustered within 2 m (Figure 19.3) whereas on open plains they may be separated by 40 m (Figure 19.4) obliging the women to ride donkeys when visiting friends on the opposite side of the camp.

Camps as a whole are vaguely crescent- or U-shaped. At night when the animals return to the camp for milking the camels are placed on the inside and goats, sheep and cattle lie outside. There is no rigid rule concerning this and it is largely a matter of what is most convenient for those who care for them. Newborn sheep and goats are kept inside the tents. Older ones are allowed to run free in the camp during the day but are tied by their necks to a rope stretched between two stakes at night. Bush enclosures are sometimes made to protect goats and sheep from jackals. Newborn camels are tied by one foreleg to individual stakes in the middle of the camel yard (Photo 19.3b); when older ones come back from pasture they are tethered in a group to one stake (Photo 19.3a). Calves are tied individually by the neck at night and are sent to pasture during the day. Donkeys' front feet are hobbled when they are likely to be needed but otherwise are allowed to roam freely. It must be emphasized that

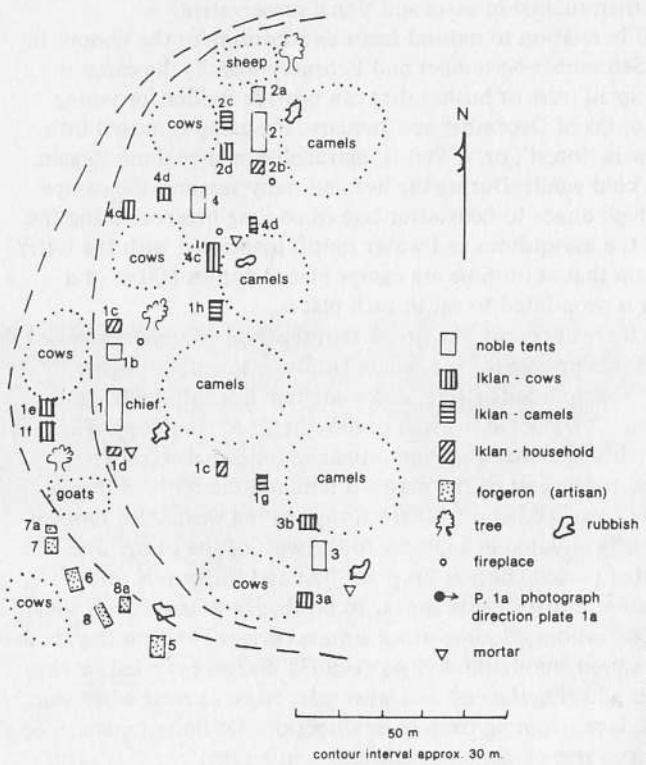


Figure 19.3 Disposition of a typical pastoral nomads' camp on a sand dune during the wet season (see text).

it is only young animals and mature lactating females which are usually found in the camps, the others are brought in only when camp is about to be moved and even then not all are found.

Since material culture is limited among the nomads, abandoned cool-season campsites are indicated only by trampled earth, dung, lack of grass in surrounding area and a few wooden branches used as auxiliary tent supports. Hot weather sites may show traces of straw huts and rainy season camps often have remains of 'nests' that children build in trees to escape the mosquitoes, or occasionally bed supports that lift sleeping mats 1-1.5 m off the ground for the same purpose. Sometimes there are remnants of charred branches left from the huge bonfires which are built during wet season storms to keep goats from stampeding. In the section of the camp inhabited by artisans, small pieces of brass and iron staples used in mending chips and cracks in wooden bowls may be found. Also, there are discarded pods of *Acacia scorpioides* (tagart) which have been used for tanning hides as well as numerous strips of leather and pieces of matting. Nearby trees may have scars where strips of bark have been removed for use in medicines, tanning, and rope making, depending on the type

Table 19.9 Demographic composition of a Tamasheq camp (June 1972)

Tent	Social category	Total persons per tent	Adults M	Adults F	Children Living	Children Dead	Elsewhere	Others Iklan	Others Artisan
1	Imajaren	7	1	1	3	2	3	1	1
1-a	Imajaren	3	1	1	0	0	0	1	0
1-b	Imajaren	3	2	0	0	0	0	1	0
1-c	Iklan-tent	3	0	1	2	1	1	0	0
1-d	Iklan-tent	4	1	1	2	0	0	0	0
1-e	Iklan-cows	7	1	1	5	3	1	0	0
1-f	Iklan-cows	8	1	1	6	1	0		
1-g	Iklan-camel	4	1	1	2	0	1		
1-h	Iklan-camel	8	1	1	6	0	0		
2	Imajaren	5	1	1	3	1	0		
2-a	Imajaren	2	1	1	0	0	0		
2-b	Iklan-tent	2	0	1	1	0	0		
2-c	Iklan-camel	4	1	1	2	2	3		
2-d	Iklan-cow	2	1	1	0	0	0		
2-e	Iklan-cow	5	0	1	4	1	2		
3	Imajaren	5	4	1	0	0	0		
3-a	Iklan-cows	6	1	1	4	2	0		
3-b	Iklan-cows	4	1	1	2	0	1		
4	Imajaren	6	1	1	4	2	0		
4-a	Imajaren	4	1	1	2	1	0		
4-b	Iklan-cow	5	1	1	3	3	0		
4-c	Iklan-cow	6	1	1	4	3	0		
4-d	Iklan-camel	5	1	1	3	3	0		
5	Artisans	9	1	1	7	0	0		
6	Artisans	4	1	1	2	2	2		
7	Artisans	5	1	1	3	3	0		
7-a	Artisans	1	0	1	0	0	1		
8	Artisans	5	1	1	3	2	0		
8-a	Artisans	2	0	2	0	0	0		

of tree. In noble camps the pounding and winnowing of grains is done by Iklan beside their tents, therefore seeds and chaff may remain in these areas. Cooking fires are usually near the tents of the household Iklan whereas fires for warmth, used only during the cold months, are located directly in front of the Imajaren tents. No stones are placed around campfires and such places are indicated only by darkened sand, charcoal and ashes (however, this could be due to the scarcity of rocks in the areas observed). The precise location of tents is indicated by areas swept free of dung and straw. The debris from the tents such as cooked grains, seeds of tarakot, excreta of babies, camel dung and wood fragments used for games, and pieces of charcoal used for heating tea, are accumulated about 10 m to the east or west of the tent site, where the bones have also been thrown (Figure 19.4).

The population of camps vary from over 100 people to less than ten, with an average of five or six people per tent. The population per km² is approximately 0.3. Size of camps depends primarily on the social class of the members since a camp of noble Tamasheq would include their slaves and artisans as well as their own families. Secondly, size depends on availability of pasture; a large camp

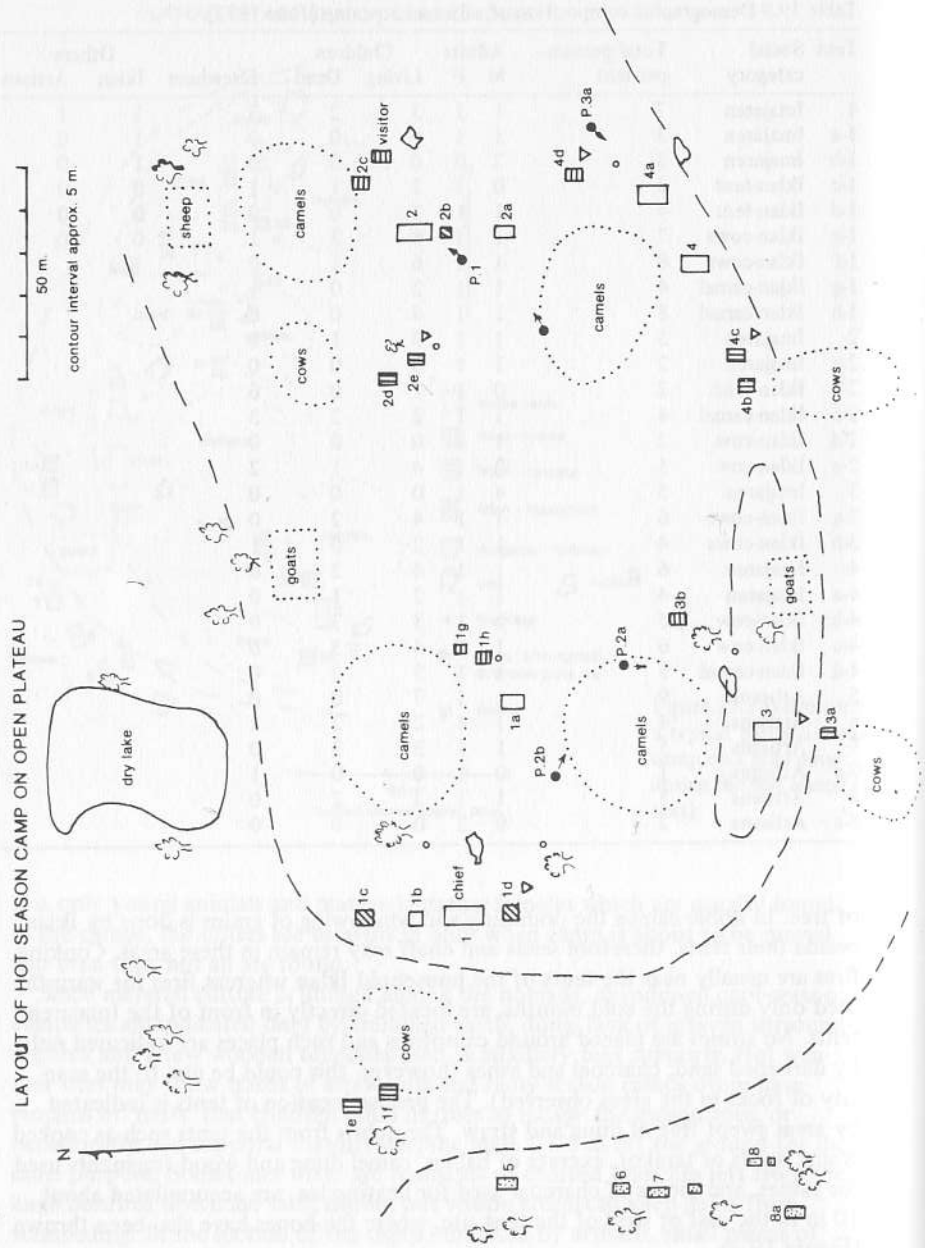


Figure 19.4 Disposition of a typical pastoral nomads' camp on the open plateau during the hot season (see text).

may split if there is insufficient food for the animals. Some nomads maintain that in the past, camps were considerably larger, perhaps several hundred people, because pasture was more plentiful. Others insist that this only appears to be the case because either the individual camps of 100 were more common, as slaves who now travel independently formerly lived with their masters, or these small camps would migrate as a group for protection against enemies rather than in dispersed units as they now are.

An example of the layout and demographic composition of a large Tamasheq camp (Oulliminden) is presented in Figures 19.3 and 19.4 and Table 19.9 respectively. The sexual distribution varies with the season, since during the months of February to May and September to November the males often make journeys to sell animals and buy necessities, collect taxes and tribute, conduct raids on enemies, or just visit. Recently major epidemics of smallpox, measles, pneumonia and meningitis have been decimating the youngest and oldest age groups. (In the past, war appears to have been a more significant factor in mortality than disease.) A few small groups differ significantly from this model in that their social codes have inhibited marriage and consequently they are suffering major population declines.

Herd size reflects the wealth of the owner but not his social status since, at present, there are slaves and vassals who have more animals than the nobles. Traditionally, however, the noble was considered to own the animals of his slaves and have access to those of his vassals. The number of Iklan tents associated with an Imajaren, vassal or marabout tent is, on the other hand, an indicator of status. For example, the largest herds among the Tamasheq are owned by the vassal tribe, Deousahak, but they do not have Iklan and care for the animals themselves.

19.5 CONCLUSION

This description of the habitation and exploitation pattern of a nomadic pastoralist group in a marginal environment with relatively harsh climate and scarce resources is suggested as a possible analogy with post-Palaeolithic herding peoples who inhabited the Saharan and Sahel zones c. 4 000-1 300 B.C. This pattern utilizes almost all the resources of the environment, either directly or through the medium of animals, and obtains them in sufficient quantities to sustain life by movement from area to area.

In terms of non-food resources, wood is the major element drawn directly from the environment. It provides heat for cooking and from it are made tent supports, beds, vessels and eating utensils.

The food resources directly available are vegetables, fruits, birds, fish and wild grains. Food taboos restrict the use of a number of these items, especially among the noble classes, but wild grains are an important source of seasonal food for all. The primary subsistence source, however, is the domesticated animals. They supply food, are the means for acquisition, through trade, of other goods, such as clothing, knives and domesticated grain, provide many of

Table 19.10 Comparison of uses of various domestic animals

Animal	Transport	Meat	Milk and products	Hides	Social function	Occasion when sold
Camel	a) Tent, large utensils b) Men, small boys, traditionally women also c) Grain in leather sacks d) Salt slabs e) War drum	Rarely – sick or weak animal	Fresh milk	Camel whips	a) Prestige (from number and form of animals) b) Bridewealth c) Camel dance for celebration and healing	Dire need: tax, fines
Cattle*		a) For large groups b) Weak animal	Sour milk Butter Cheese	Tents Sandals	Indication of wealth	Large purchases: tax, grain, clothes, saddles
Sheep		a) Religious sacrifice b) Visitors c) Celebration	Fresh and sour milk Butter	Pouches Wallets (hair not used)		Small purchases: grain, butter, leather work
Goats		a) For visitor b) Hunger	Fresh milk Cheese Medicine	Water bags Milk churns Cushions		Smaller purchases: tea, sugar, tobacco, salt
Donkeys	a) Women and children b) Pots, tent poles, and small camp gear c) Water		Medicine			
Horses	a) Respected elders				Chiefly status	
Dogs		?			Guarding camp and herds, for hunting, as pets	Usually given as gift

* Apparently bovids are used for transport in the northern Sahara but this was not observed in the Sahel.

the raw materials necessary for nomadic life – hides for tents, sandals and saddles, urine and excreta for medicines, and are the means of transporting both people and camp gear (Table 19.10). The animals, thus, are the primary link between the Kel Tamasheq and their environment, the West African Sahel, and their welfare largely determines the welfare of the people.

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20

Domesticated cattle in the Sahara and their introduction into West Africa

Les bovins domestiqués au Sahara et leur introduction en Afrique de l'Ouest

Ce chapitre est une synthèse des idées concernant la domestication du bétail en Afrique du Nord et au Sahara et l'introduction en Afrique de l'Ouest des bovins domestiques. La mensuration des restes fossiles montre que les bovins pléistocènes et holocènes de l'Afrique du nord ont pu être les progénitures des animaux domestiques dont les squelettes ont été retrouvées au Sahara dans des gisements préhistoriques datés de 6 000 à 4 500 B.P. Puisque le transfert de la notion de domestication des bovins aurait demandé de 700 à 1 000 ans pour atteindre les régions lointaines comme la plaine de Deh Luran (l'âge d'origine en Europe du SE étant de 8 200 B.P.), il est possible que la notion de domestication a commencé avec les ovins/caprins pour se diffuser ensuite par la Cyrenaïque à travers le Sahara et le Maghreb. L'application de cette notion aux bovins aurait pu être d'origine africaine.

Apparemment les bovins constituaient une partie importante de l'économie des peuples post-paléolithiques qui habitaient le sahel de l'Afrique de l'Ouest vers 4 000-3 300 B.P. – époque d'aridification du Sahara. On peut en déduire que les pratiqueurs d'élevage ont quitté le Sahara à cette époque afin de trouver des eaux plus permanentes pour leur bétail, situation qu'on retrouve auprès des pasteurs de l'époque actuelle. Il nous semble que le style de vie des pratiquants de l'élevage au Sahara et au sahel était assez comparable à celui des pasteurs sahéliens des temps actuels. D'une part les produits pastorales sont importants, de l'autre les ressources naturelles (plantes, animaux sauvages) servent de suppléments très utiles à l'alimentation quotidienne.

20.1 INTRODUCTION

Rock art in the Sahara and North Africa depicting *Bos* has been known for many years (Joleaud 1936; Winkler 1939). Scenes showing associated human herders (as in the Tassili n'Ajjer or Jebel Uweinat) left little doubt that at some time in the remote past these animals were domesticated. The questions of the age of these paintings and the source of the domesticated stock were asked, but it was not until the work of Mori (1965) that some reasonably certain answers started to appear.

In level VIII at Uan Muhuggiag, Mori excavated the skull of a shorthorn *Bos*. This level was dated to 5 952 ± 120 B.P. from charcoal. A child burial also found in this deposit was dated to 5 405 ± 180 B.P. At this same site a squarish

block with two oxen painted on it had fallen in and subsequently been buried by accumulating sediments. The deposits immediately above the block were dated to 4 730 ± 310 B.P. indicating that the paintings were older than this date. A similar situation existed at another site in the Acacus region, Uan Telocat. Level III of this site was dated to 6 754 ± 175 B.P. After the removal of this deposit it was found that it concealed some painted figures on the back wall of the shelter. An analysis of the cultural material from this level is suggested by Mori as being similar to the pastoral deposit at Uan Muhuggiag, thus inferring that the post-Palaeolithic herders were living in this region shortly after 7 000 B.P.

In 1970 the British Aïr Mountain Expedition archaeological group, under the direction of Professor J.D.Clark, was fortunate enough to excavate an almost complete *Bos* skeleton at Adrar Bous, Niger. This animal also was a shorthorn beast and fragments of the bone from the skeleton were dated to 5 780 ± 500 B.P. (Carter & Clark 1976:488).

In Churcher's (1972:74) discussion on the problems of *Bos* in Pleistocene Egypt he suggests that Gaillard's (1934) identification of *B. brachyceros* should not have been specifically separated from *B. primigenius,* but should have been considered a female form. A second *Bos* from Kom Ombo, described by Churcher, confirms the existence of a smaller animal in the Nile Valley. Although the small specimen from Kom Ombo (no. 8827) has only the base of the left horn core extant, Churcher says: 'the horns were decurved, as in the majority of recovered *B. primigenius*'. The diameter of the horn core bases are 33% greater in the large form of *Bos* from Kom Ombo while the skulls themselves only exhibit a 20% difference, i.e. the greater horn core diameters of the larger form are 104.5 mm and 107.7 mm, with the small animal giving a measurement of 70.0 mm. The distance between the dorsal bases of the horn cores measures 190 mm in the large *Bos*, and 170 mm in the smaller one. This latter dimension is considerably larger than the measurements of the Adrar Bous animal described in Carter & Clark (1976) which is only 126 mm between the horn cores.

These measurements suggest that the Nile Valley forms were both long-horned types, with the smaller form being similar in many respects to its small cousin in the Maghreb.

Therefore, since shorthorn cattle probably did not exist in the wild state, the shorthorn animals found at Uan Muhuggiag and Adrar Bous were domesticated animals. The question therefore remains: where did these animals come from?

Four hypotheses have been put forward for the introduction of cattle into North Africa. The first looked to the Near East for the earliest progenitors suggesting that since domestic animals were known in the Nile Valley in pre-dynastic times then the obvious source must have been the Levant (Esperandieu 1952; Epstein 1971; Boston 1963). The early dates for domestic cattle from Greece (c. 1 150 B.P., Rodden 1962), Asia Minor (c. 7 750 B.P., Perkins 1969) and Iran (c. 7 500-7 000 B.P., Hole et al. 1969) only helped to reinforce this idea.

The second idea proposed was that since two wild forms of *Bos, B. primigenius* and *B. ibericus,* were thought to have been indigenous to North Africa during the Pleistocene, these animals were the source of the earliest domesticated cattle in North Africa (Dechambre 1950; Mori 1965; Carter & Clark 1976).

Mauny (1967:590) offered a third possibility. He suggested that the concept of domestication was diffused from the east, but that local stock was involved, i.e. *B. ibericus,* sheep and goats.

A fourth idea found in McBurney (1967:327) is that there may have been some connection between Italy and the Maghreb via Sicily during Libyco-Capsian times (c. 10 000-7 000 B.P.). Therefore there is a vague possibility that this may have been the route of diffusion of the concept of domestication into the Maghreb in the following Neolithic period. An additional idea in this argument lies in the obsidian from the island of Pantellaria which was collected by pre-Bronze Age mariners and taken back to Sicily and Malta as early as the 4th millennium B.C. (Trump 1963). It appears also to have been transported to the Tunisian coast, but not before Neolithic times (Camps 1960).

A major problem with the acceptance of the first hypothesis to include the Sahara lies in the fact that shorthorn cattle are not known to have existed in the Nile Valley until the Vth Dynasty, c. 4 550 B.P. (Epstein 1971:288). This gives some credence to the second proposed scheme, and since shorthorn animals may have existed in the Central Sahara for at least 1 500 years prior to their appearance on the Nile, this suggests that the domestication, and therefore selection process, had been going on in the Sahara for some time prior to 6 000 B.P.

Unfortunately the fauna from many predynastic sites has been very cursorily described, or the horn cores of the *Bos* specimens have not survived, as in the cemeteries of Armant (Jackson 1937). At those sites where the skulls are intact, such as Badari (Brunton 1927), there is no indication of any shorthorn cattle mentioned. The writer was able to see the collections from Qau presently housed in the Department of Archaeology, Cambridge. This collection contains a number of bones of both large and small *Bos*. All the bones are somewhat water-rolled, but the horn cores which have survived suggest that most of the animals were shorthorned, e.g. one complete core measures 138 mm in length and 52.3 mm in basal diameter. The age of these bones is questionable.

From the predynastic settlement at Abydos the Bos remains have all been identified as *Bos africanus* or large oxen (Peet 1914).

The earliest indications of shorthorned animals, other than the engravings on monuments mentioned above by Epstein (1971), comes from a list of offerings from the Saqqara mastabas, where two lists, one from the third and one from the fifth Dynasties, have offerings of both long and shorthorned cattle (Murray 1905:34-35). However, since polled animals are fairly commonly depicted on tomb walls, it is possible that these could have been the 'short-horned' animals.

McBurney (1967:328) suggests that the strongest connection with the Haua Fteah in the Cyrenaican littoral during the Libyco-Capsian and Neolithic periods (c. 10 000-4 650 B.P.) was with the Maghreb and not the Nile Valley. It is unfortunate that the condition and size of the samples of the *Bos* remains from this site did not permit any stronger statement than '. . . there are further traces of a smaller animal suggesting the presence of *Bos ibericus*' (Higgs 1967: 169). However, it must be noted, there is still no easily substantiated evidence to refute the hypothesis that the wild cattle found in the Maghreb and the

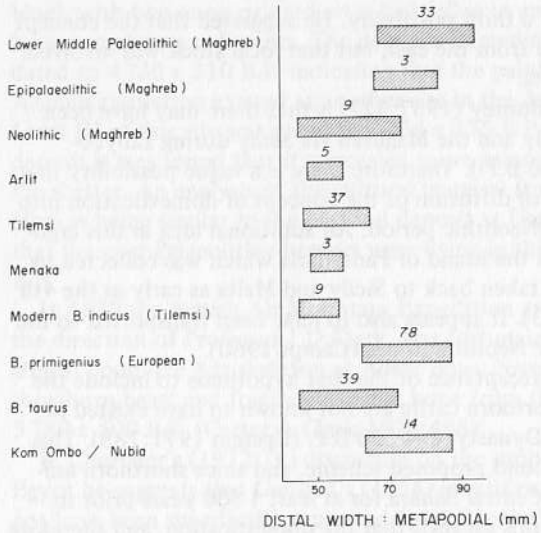


Figure 20.1 Distal width of *Bos* metapodials.

Sahara from Palaeolithic times onward were the stock from which the Saharan domesticated animals were derived.

The list of sites from which both *Bos primigenius* and *B. ibericus* have been identified is very long (see Romer 1928; Vaufrey 1955: Tables VIII-X), but the association with the stratigraphy is generally poorly described. The recent work by Dr Colette Roubet at Grotte de Capeletti is the best controlled and dated site from which *Bos* remains have been reported in the Maghreb.

20.2 *BOS PRIMIGENIUS*

The first person to acknowledge the existence of *Bos primigenius* in North Africa was Thomas (1881) but it was not described in detail until Pomel published his series of monographs in 1894. Pomel used the name *Bos opisthonomous* instead of *B. primigenius* for the North African species as this was the name given to it by Herodotus in his work on the land of the Garamantes. Later writers have preferred to use *B. primigenius* in faunal lists from Palaeolithic/Neolithic sites in the Maghreb and the Sahara (Durst 1900; Romer 1928; Arambourg et al. 1934; Vaufrey 1955). The animal was a large longhorned beast with horns often curving so far forward that Herodotus claimed that the animal had to graze backwards otherwise its horns would get stuck in the ground. The North African species was claimed to be smaller than its European counterpart and Churcher (1972:81) states that this is the case with the Nilotic animals that he studied, but Higgs (1967:170) notes that some of the *Bos* in his sample from Haua Fteah were occasionally larger than those of the European animal, e.g. the distal width of the metapodials ranges from 67 to 92 mm (Higgs

1967: Figure II.2). The possibility that the larger bones may be from *Bubalus antiquus (Homioceros/Pelorovis)* cannot be ruled out (Higgs 1967:169). Similarly, as illustrated in Figure 20.1, the Lower/Middle Palaeolithic distal transverse diameter of metapodials from the Maghreb ranges from 68 to 91 mm while that of the European animals given by Degerbol & Fredskild (1970) is 62-88 mm.

20.3 *BOS IBERICUS*

A second species of wild cattle from North Africa, *Bos ibericus,* also described by Pomel (1894), was suggested as being identical to Sanson's (1878) *B. taurus ibericus* from Algeria. This species was also longhorned, but, due to its smaller size, was considered specifically different. Pomel further distinguished another small *Bos* which he called *B. curvidens,* but Arambourg et al. (1934) considered this to fall into the range of *B. ibericus.* Since species capable of interbreeding and yielding viable offspring will not, in all probability, maintain their specificity when occupying the same ecological niche, more recent workers have considered *B. ibericus* to be a result of sexual dimorphism and suggest it to be the female of *B. primigenius* (Churcher, personal communication). Romer (1935) had difficulty in separating *B. primigenius* from *B. ibericus,* and he suggested that size should not be a distinguishing criterion.

In 1972 and 1973 the writer visited Paris to study some of the *Bos* remains from North Africa. Collections were located in the Département de Paléontologie, Musée d'Histoire Naturelle. Unfortunately, although a site location was given, information on the stratigraphic provenance of the specimens was not available, nor was their association with any human cultural material. This means that the ages of the specimens are, at best, only accurate within broad limits. However, for the purposes of the evolutionary schema proposed here this degree of accuracy will suffice.

Using the large amount of data available in the work of Degerbol & Fredskild (1970) on European *B. primigenius* and domesticated *Bos* as a standard we may be able to offer some metrical answers to the problems of *Bos* in North Africa.

All data available to the writer from North Africa were divided into three categories: (a) Lower/Middle Palaeolithic; (b) Epipalaeolithic and (c) Neolithic on the basis of the known ages of the sites represented. The material of Lower/Middle Palaeolithic came from a number of sites: Filfila (Ginsberg et al. 1968), Les Allobroges (mentioned in Tixier 1967:777), Aboukir (Pomel 1894) and El Guettar (Gruet 1950). The Epipalaeolithic samples came from Redeyef (Gobert 1912), Relelai, Beni-Segoual, Tamar Hat and Afalou (Arambourg et al. 1934). The Neolithic remains were from Capeletti (Roubet 1971), Gueldaman Akbou and Grand Rocher (Pomel 1894).

By using the chronological breakdown it can be seen from Figures 20.1 and 20.2 that there appears to be a diminution in size of the distal metapodials through time, the Pleistocene animals being considerably larger than those from the Holocene. This conforms rather well with the data available in Degerbol & Fredskild (1970), shown graphically in Figure 20.1, where Danish *Bos* speci-

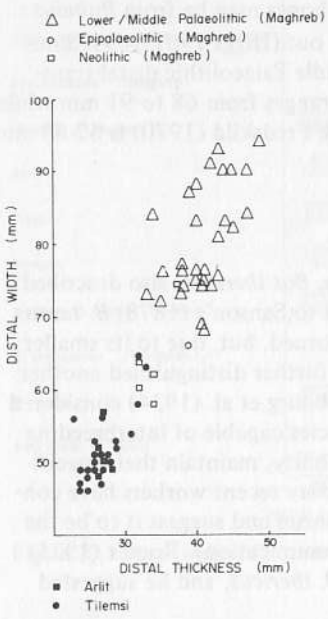


Figure 20.2 Distal thickness of *Bos* metapodials.

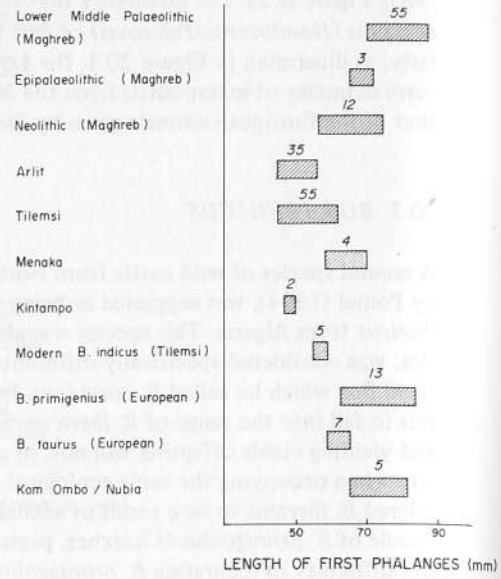


Figure 20.3 Length of *Bos* first phalanges.

mens also demonstrated a decrease in size in the Holocene period. Similarly, in Figures 20.3-20.5 the first phalanges and humeri also suggest that the same thing happened.

To see if the date represented single populations, coefficients of variation (CV) were run on the large samples (Table 20.1). Assuming that a single population would exhibit CV's of between 5 and 9, the results tend to show that each sample is a homogeneous unit, but in combination with each other they suggest more than a single population. It is unfortunate that some of the samples are so small as to be perhaps non-representative of the total population. Therefore the data illustrated here can only be used as a working guide until complete samples are available.

From the figures it can be seen that the measurements from the Saharan shorthorn cattle found in the archaeological sites of Arlit and Adrar Bous from 6 000-5 000 B.P. generally overlap the North African Neolithic measurements. Therefore the logical choice for the progenitors of the Saharan animals would be from the Maghreb. The question of indigenous versus introduced ideas on domestication would still remain. Given the previously suggested limited contact between the Nile Valley and Haua Fteah a reasonable argument could be expressed for the development of indigenous domestication, but this would be too coincidental with the earlier known dates for cattle domestication in SW Asia. Another point to bear in mind is that there is no clear evidence for bovine husbandry from the Haua Fteah associated with what have been considered

Table 20.1 Coefficients of variation on the large samples

Sample	N	CV
First phalanges (length):		
Lower/Middle Palaeolithic	55	5.37
Total Maghreb	70	9.51
Danish *Bos primigenius*	13	7.68
Total Danish *Bos*	20	9.81
Metapodials (distal width):		
Lower/Middle Palaeolithic	33	9.00
Total Maghreb	45	15.40
Danish *Bos primigenius*	78	9.82
Total Danish *Bos*	117	11.00
Humeri (distal condylar width):		
Total Maghreb	14	13.40
Danish *Bos primigenius*	26	6.99
Total Danish *Bos*	32	10.56

Table 20.2 C^{14} Dates for *Bos* in the Saharan and Sahel Zones of West Africa (B.P.)

Site	C^{14} dates (B.P.)
Uan Muhuggiag	5 952; 5 405
Adrar Bous	5 780; 5 740; 5 130; 4 910
Meniet	5 400
Adrar Tiouyine	5 150; 4 320
Erg d'Admer	5 420
Arlit	5 150
Karkarichinkat Sud	3 960; 3 640; 3 310*
Karkarichinkat Nord	3 950; 3 710; 3 620
Dhar Tichitt	3 465; 3 350; 3 620
Kintampo (suggested dates)	3 560-3 220
Daima	2 400

* These dates from KS/KN are based on the C^{14} half-life of 5 568 years.

possible domesticated caprines (Higgs 1967:166). Since the present dates for the earliest suggested domesticated cattle from the Zagros are 7 500-7 000 B.P. (Hole et al. 1969) it is therefore possible that the concept of *Bos* domestication lagged behind that of the domestication of caprines entering North Africa, sometime after 8 400 B.P. (Higgs 1967:169), and that the extension of this concept to include cattle was an idea indigenous to prehistoric peoples in North Africa and the Sahara who would have used the available wild cattle.

From an interpretation of Dr Roubet's material at Capeletti (1977) it would appear that there is some possible confirmation of this idea of *Bos* domestication lagging behind that of caprines. At her lowest level, dated to 6 530 ± 250 B.P., caprines constitute 98.7% of the fauna, while bovines only 7.3%. At her next level, dated between 5 900 ± 150 and 5 750 ± 140 B.P., the ratio is 84.7:14. The level-3 ratio is 90.4:6.8 (dates: 5 400 ± 140-5 380 ± 140 B.P.), while the upper level (dated between 4 670 ± 130 and 4 340 ± 200 B.P.) has a ratio

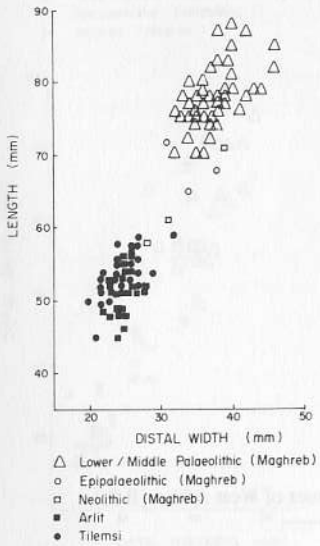


Figure 20.4 Distal width of *Bos* first phalanges.

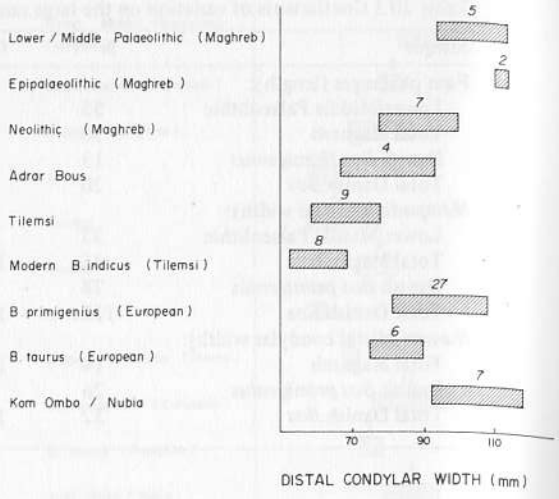


Figure 20.5 Distal condylar width of *Bos* humeri.

of 70:24.7. The increase in the percentage of bovines suggests a concomitant reliance on cattle, possibly even demonstrating the transition from the wild to domesticated stock.

Although the measurements of the bone sizes of the North African Neolithic animals considerably overlap the Saharan ones, except in the limited first phalange sample from the Maghreb, a difficulty for continuing the argument exists in the metrical use of limb-bones and podials. If one is going to argue for the selection of shorthorn animals from the longhorned wild form a great deal of cranial material would be needed. This, at present, is not available. Similarly, collections of *Bos* from other Saharan sites are extremely limited. The reports of faunal assemblages often are only limited to a list of species identified without any measurements, or parts of the skeleton represented. This has been particularly true of material from the Maghreb.

20.4 DOMESTICATED CATTLE IN THE SAHARAN AND SAHEL ZONES OF WEST AFRICA

From the work done at Adrar Bous in 1970 it is suggested that the pastoral groups (called Ténérian) who inhabited the area from c. 6 000 to 4 500 B.P. were possibly derived from the earlier inhabitants who exploited the fish and other aquatic resources found in the earlier lakes (see Smith 1976 and Chapters 18 and 22 in this volume). This implies that it was the concept of domestication

that was diffused, rather than a new, culturally distinct, group of migrants entering the area.

Using a chronology based on radiocarbon dates from sites reporting domesticated *Bos* (Table 20.2), the expansion of the cattle complex into the southern Saharan and Sahel zones of West Africa appears to have been a direct result of the desiccation of the Saharan region. It was partly for this reason that excavations were carried out in the Tilemsi Valley by the writer, since it was assumed that post-Palaeolithic pastoralists would have been attracted to regions with the greatest amounts of water, and there is every reason to believe that permanent surface waters existed in the Tilemsi until at least 3 300 B.P. (Smith 1975). In actual fact the highest percentage of bones at the two sites excavated, Karkarichinkat Nord and Karkarichinkat Sud, were those of *Bos* (41.4% of the mammal remains), with caprines comprising the second largest category (21.8% of mammal remains).

This geographic link between the Saharan and Sahel zones was probably one of the main routes whereby domestic cattle were introduced into West Africa, as originally suggested by Munson (no date). Other regions in the southern Sahara reporting *Bos* include Araouane (north of Timbuctou) in the area of the former lakes (Roman 1935) and Dhar Tichitt, Mauritania (Munson, no date). No dates are offered for the Araouane region, though it is quite possible, using the work of Gallay (1966) as an indication of the cultural material of the area, i.e. harpoons, microliths, etc., that the identification of *B. cf. ibericus* refers to an element in the early post-Palaeolithic hunting diet of this area. At Dhar Tichitt on the other hand, domestic animals appear later than in the Tilemsi Valley, i.e. c. 3 500 B.P. There is also a suggestion of a similar evolutionary pattern to Adrar Bous, with an earlier hunting-fishing economy (Akreijit Phase) being replaced by a pastoral one (Khimiya Phase).

Once the domestic cattle entered West Africa there are indications that the concept expanded very rapidly. Work done at Kintampo, Ghana (Carter & Flight 1972) recovered *Bos* remains from site K6. Unfortunately this site was not dated, but the writers suggest that K1, a nearby site is probably contemporary, and dates to 3 560-3 220 B.P.

The problem of the selection of the shorthorned animals found in the Central Sahara at an early date still remains unclear. If the animals were derived from the indigenous wild stock, as suggested above, then presumably a number of generations would have to pass after the first attempts at domestication before the shorthorned animal developed. At present the mechanisms for reduction in size of the horns are unknown. 'Unstable' characteristics such as horn shape, may vary with little or no selective pressure, but reduction in size is probably only achieved through conscious selection.

Herre (1969) suggests that with domestication the range of variation of characteristics must be greater, and Jarman & Wilkinson (1972) although questioning the 'necessity' of this happening suggest that this appears to be true only with regard to 'unstable' characteristics, e.g. horn shape and coat colour, and that well defined changes in phenotype appear to be a direct result of conscious selection by the breeders.

What would be the advantages of selection for this shorthorn type? Aesthe-

tics? In spite of Epstein's statement to the contrary (1971:293) the rock art of the Sahara depicts examples of both longhorned and shorthorned cattle (Lajoux 1963:120-121; Mori 1965: Plate 105) which would tend to suggest that one type was not considered to be more aesthetically pleasing than the other.

It is possible that smaller horns might inflict less damage, and this may be the reason that so many 'polled' cattle are depicted on ancient Egyptian monuments (e.g. Naville 1910: Plate XIII). However, this does not seem to be a consideration among present-day pastoralists of Niger (Peul), of the Sudan (Nuer) or East Africa (Masai) where long horns are highly esteemed.

20.5 MOVEMENT OF THE CONCEPT OF DOMESTICATION INTO WEST AFRICA

Since no earlier habitation by post-Palaeolithic peoples of the lower Tilemsi than the Gaussens' 'facies B' industry (1962, and A.B.Smith, Chapter 18 in this volume) has been found, it is highly possible that not only did the idea of domestication move south with the desiccation of the Sahara, but that there was also a migration of people at this time.

The cultural groups who lived in the northern Tilemsi, around Asselar, had an industry much closer in style to the Saharan post-Palaeolithic groups, such as those living in the Ténéré (Tixier 1962; Smith 1976), and are probably somewhat older than the lower Tilemsi groups. However, the cultural differences between the upper and lower Tilemsi mostly manifest themselves in such elements as projectile points (Gaussen & Gaussen 1962) and pottery (Mauny 1972: Plates X-XII). Both groups have grinding equipment (grindstones and polished axes), geometrics (although these are somewhat rarer in the lower Tilemsi), and scrapers and pottery. The fauna from the Asselar area comprises cattle and various wild mammals, reptiles and fish. Similarly, from Karkarichinkat the indications are that besides herding cattle the people were also hunters of wild game, fishermen and gatherers of both mollusca and wild plants (Smith 1975 and Chapter 18 in this volume). The ecology of the plants collected, from present distribution, suggests a rainfall of c. 200 mm, which is double the present precipitation in the lower Tilemsi Valley.

The desiccation of the Sahara must have been particularly harsh for cattle herders since the water needs of cattle are very high. A cow will consume four times as much water as a camel under similar temperatures, although cattle which are watered infrequently, i.e. for one hour every two to three days will drink 12-30% less than if water is always available (Schmidt-Neilsen 1964:79). Cattle respond differently from man to higher temperatures; it seems that: '. . . man does not readily drink enough to make up for water loss, and that the volume of his urine therefore decreases and its concentration increases. Cows behave differently. As their water intake goes up at high temperatures there is a parallel increase in urine output with increased frequency of urination and decreased concentrations. Thus the water intake goes up more than could be required to cover the increased evaporation. In one cow the urine output went

from 25 to 125 litres per day. It seems as if these cows drink, not to avoid dehydration, but to cool the body with huge volumes of water' (Scmidt-Neilsen 1964:79-80). For the present-day Kel Tamasheq of the Sahel zone in Mali the cattle, particularly calves, restrict the movements of the camps. The adult animals should be watered every other day, and every three days at the most, while calves must be watered twice a day except in winter (see S.E.Smith, Chapter 19 in this volume).

There seems to be considerable similarity between the life-styles and exploitation patterns of the post-Palaeolithic pastoralists from Karkarichinkat and the present-day pastoralists of the Sahel region such as the Kel Tamasheq and the Peul. Both these peoples are cattle herders, although the Kel Tamasheq are less traditionally so, being more involved with camel herding than cattle. The Peul, however, have more similarities to the Karkarichinkat pattern. Their shelters are very basic, often with no roof. They collect wild plants in season (Dupire 1962:62), and although hunting is not a common practice they will augment their diet with a gazelle or guinea fowl when the chance occurs (ibid.:54).

The Peul who live near the River Niger do not fish, but fish plays a large part in their diet. These are obtained from the Bozo fishermen who live on the river (Sundström 1972:93).

Milk is an extremely important element in the diet of all present-day Saharan pastoralists, and is sometimes virtually all that is consumed among some Kel Tamasheq groups, such as the Oulliminden, during the wet season (see S.E. Smith, Chapter 19 in this volume).

An interesting piece of ethnography commonly found with herding groups are clay figurines of animals made by children playing games imitating their elders. These are generally well made showing the parts of the animals that are most distinctive, e.g. the horns and humps of zebu cattle. These elements are also found in situ with the cultural material from Karkarichinkat. These archaeological specimens are quite delicate and the horns found have all been broken off the bodies. The cattle portrayed are of the humpless type.

Although one must be wary of drawing spurious analogies between cultures of different time periods the exploitation patterns of the present inhabitants of the Sahel appear to be so similar to those of the prehistoric pastoralists that data concerning diet, relationships between men and their animals, etc., can be of value for comparison.

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Origins of plant domestification in the Sahara and the Nile Valley

Les origines de l'agriculture au Sahara et dans la vallée du Nil

Malgré la mise en évidence d'une culture complexe et de l'emploi des céréales par les habitants épipaléolithiques de la vallée du Nil, et malgré la possibilité que le Sahara a pu supporter des orges sauvages, il est néanmoins fort probable que l'orge et le froment (qui sont les céréales les plus importantes au Sahara septentrional et dans la basse vallée du Nil) étaient d'abord cultivés en dehors de l'Afrique et ensuite introduits en Afrique par des fermiers ou pasteurs du Moyen Orient. La combinaison d'éléments allochthones et autochthones découverts en Egypte dans les assemblages préhistoriques liés aux origines de l'agriculture suggère que c'était bien les habitants de la région qui pratiquaient la culture, ayant déjà assimilés les plantes et les animaux domestiqués de provenance étrangère. La façon rapide avec laquelle ces cultigènes ont été adoptés semble montrer que les habitants du bas Nil pratiquaient déjà une vie sédentaire, voire même agricole, fondée sur les plantes locales qui furent abondonnées ensuite en faveur de l'orge et du blé froment.

Il est impossible de juger le rôle de la culture du froment et de l'orge quant aux origines des plantes cultivés en Afrique. Le grand problème est la manque de preuves directes de culture sous forme de grains carbonisés ou d'impressions de grains céréales. Une des meilleures coupes préhistoriques fournissant des indices sur la transition cueillette – culture d'une céréale africaine est celle découverte par P.J.Munson à Dhar Tichitt en Mauritanie, mais nous ne savons pas si le *Pennisetum* était cultivé dès l'origine à Dhar Tichitt, ou si ce grain avait déjà été cultivé ailleurs. Si cette culture est bien originelle à cette localité, l'âge d'environ 1 000 B.C. semble assez récente. D'autres céréales cultivés en Afrique, par exemple le *Sorghum* daté de A.D. 300 au Soudan central, sont encore plus récentes.

Faute de données archéologiques directes, il est impossible d'affirmer ou de nier les hypothèses à l'égard des 'centres de culture' (boucle du Niger, massifs sahariens). Les données écologiques et biogéographiques dont on dispose nous permettent de dire, à titre d'hypothèse, que la culture des plantes africaines a eu lieu sur une zone assez large traversant toute l'Afrique, y comprenant le sahel, la savane et l'écotone forêt-savane au sud du Sahara. La répartition biogéographique des plantes africaines cultivées est en accord avec une hypothèse de J.D.Clark qui suggère que la culture des plantes provenait d'une déséquilibre démographique qui a dû aboutir quand les pasteurs-cueilleurs étaient obligés de quitter le désert à cause de l'aridification croissante, surtout vers 4 500 B.P. On pense que lorsque les populations sahéliennes sont devenues trop nombreuses pour permettre aux pâturages de supporter leurs troupeaux, les chasseurs-cueilleurs sédentaires commencèrent à semer et à récolter les espèces qu'ils cueillaient depuis des milliers d'années. Pendant qu'ils ensemencaient la terre en céréales, et presque sans en avoir conscience, les cultivateurs choisissaient des populations de céréales qui ne répandissaient pas leurs graines – la critère primaire pour les céréales cultivées.

Etant donné l'absence de preuves directes de la culture préhistorique, nous ne pouvons que lancer l'idée encore mal établie de la jeunesse relative de la culture en Afrique. Ce retard provient sans doute du fait que la culture intensive n'est devenue necessaire que lorsque l'assèchement du désert a entraîné une déséquilibre démographique dans les alentours du Sahara.

A discussion of plant domestication and agricultural origins is more complicated for the Sahara and the Nile than for many other parts of the world because agriculture in northern Africa is based on plant domesticates developed both in Africa and in southwestern Asia. The situation is not surprising considering the land connection between the two continents and similarities in growing conditions in southwestern Asia and northern Africa. But it is unfortunate for those of us who would like to find simple answers to simple questions about plant domestication in Africa. The problem is compounded by the disparity in the amounts and kinds of evidence available for the course of plant domestication in Africa and in Asia.

The process of plant domestication of the most economically important crops grown in the Sahara and on the lower Nile probably began in neighbouring southwestern Asia. Considerable archaeological and palaeoethnobotanical evidence suggests that the process began by at least 7 000 B.C. in the region which includes parts of Israel, southern and eastern Anatolia, Iraqi Kurdistan, Jordan, Lebanon, Syria, and western Iran (Zohary 1969:53). But it is possible that the area of barley domestication may have also included parts of Africa. Pollen of barley that could have come from either wild or domesticated plants has been found at a Neolithic site in the western desert of Egypt (Wendorf et al. 1976). Furthermore, Camps (1968) and Wright (1976) find evidence that other parts of the Sahara may also have had populations of barley at this time. If so, people of the Sahara could have also been participating in the process of cereal domestication. However, there is not now sufficient conclusive evidence of climatic conditions, vegetation, and human economies in the Sahara to include the Sahara with certainty in the generally acknowledged area of domestication of barley. The evidence of domestication is much clearer in southwestern Asia. Studies of carbonized barley, emmer wheat, and other crops from sites such as Beidha in the southern Jordan highlands, Jarmo in Iraq, Ali Kosh in Iran, and Çayönü, Çatal Hüyük, and Hacilar in Anatolia have given us a relatively firm data base for studying the process of plant domestication in southwestern Asia as it occurred from, at least, the 7th millennium B.C. onward (Renfrew 1969; Zohary 1969; Harlan & Zohary 1966).

Unfortunately, the same cannot be said for the evidence of domestication of African crops. We know the wild progenitors of many of the crops grown in the Sahara and in sub-Saharan Africa are found today only in Africa, so they were probably domesticated in Africa. Yet disappointingly little evidence of the process has been found. This paper cannot answer many of the questions that have been raised regarding the place, time, and circumstances of the origin of African plant domesticates. Nor can much be said with certainty about the relationship between the introduction of southwestern Asian domesticates to Africa and the

development of African domesticates. But several areas for which some evidence is available will be discussed. These include:

1. early evidence of agriculture in Egypt,
2. the introduction of barley and emmer wheat to Egypt,
3. differences in adaptations of southwest Asian and African crops,
4. economies in the Sahara during the period of establishment of agriculture in Egypt,
5. early direct evidence of African crops,
6. implications of the evidence of economic change at the site of Dhar Tichitt,
7. the process of cereal domestication,
8. areas of origin of African domesticated plants,
9. the importance of harvesting technology in the origin of African domesticates.

21.1 EARLIEST EVIDENCE OF AGRICULTURE IN EGYPT

The earliest well-documented evidence of grain agriculture in Africa is from Egypt. Grain bins containing carbonized barley and emmer wheat were found in settlements at Fayum, Merimde and Badari, dated around 4 000 B.C. for Fayum A and Merimde (Flight 1973) and somewhat later for Badari. Inhabitants of Fayum A settlements apparently lived in shelters constructed of temporary materials since no evidence of permanent dwellings has been found (Caton-Thompson & Gardner 1934). The temporary shelters and bones of sheep/goat and cattle suggest at least a partially nomadic life style. But grain agriculture was also practised, presumably by sowing seed along the receding margins of the lake at Fayum as the dry season progressed and along the banks of the Nile as flood waters receded at riverside settlements. At Merimde, plants and animal remains and tools similar to those of Fayum are associated with permanent, oval, semi-subterranean dwellings built of mud, suggesting a settled community.

Cultural equipment at early Egyptian agricultural sites was in part African in nature, consisting of the local upper Palaeolithic bifacial elements and microlithic forms that persisted into later predynastic times. But Asiatic elements were also present in the adzes, sickle blades, hollow-based arrowheads, pottery, and bones of domestic sheep/goat and cattle (Clark 1965, 1971). It is generally accepted that the plant and animal remains were introduced from Asia, not only because they appear in the archaeological record in southwestern Asia at least two millennia earlier, but also because extensive wild populations of emmer wheat, barley, and sheep probably were not present in Africa at this time (Zohary 1969:54; Clark 1971). It is still not clear whether or not cattle could have been domesticated in Africa where two kinds of wild cattle occur (Clark 1971). The mixture of African and Asian elements in early agricultural settlements in Egypt strongly suggests that people who grew the crops were not all migrants from Asia. It is more probable that small numbers of people moved from southwestern Asia to northern Africa and Europe bringing their domesticated plants and animals with them and that local people in Egypt and other places adopted the agricultural system and some of the associated tools and technology.

For some time, it was assumed that the early Egyptians who took up agriculture had a simple hunting and gathering economy before the arrival of Asian crops and domesticated animals. This assumption was based on evidence now known to be incomplete that Egypt was a homogeneous and conservative culture area. This assumption had to be reassessed when archaeological surveys of sites along the Nile during the building of the Aswan dam revealed abundant evidence of cultural complexity (P.Smith 1965). Especially significant is evidence from the Kom Ombo plain near the First Cataract of the Nile (P.Smith 1976a) and from Egyptian Nubia that several distinct Upper Palaeolithic blade industries existed contemporaneously along the Nile in the time between 15 000 and 10 000 B.C. (Wendorf & Schild 1976). Many different micro-environments were exploited, in some cases so efficiently, that it appears some sites were occupied the year around (Churcher & Smith 1972; Churcher 1972). The people were able to support themselves by exploiting the resources of the river, migrating bird life, and game animals as these became available during different seasons of the year. Furthermore, it appears that during the period from 15 000-10 000 B.C., the grain of wild grasses was an important food source for people living along the lower Nile. The evidence consists of large, heavily used, upper and lower grindstones and stone blades bearing sickle sheen (a patina most probably produced by deposition of silica as grass plants were harvested) (Wendorf, Said & Schild 1970). Furthermore, the teeth of people inhabiting Upper Palaeolithic sites were worn down in a way suggesting that a large proportion of the diet came from gritty, stone-ground grain (Clark 1971).

One of the harvested species may have been wild barley if we are correct in concluding the climate was cool with winter rain between 15 000 and 10 000 B.C. (Wendorf 1970). Furthermore, sickle sheen on the blades suggests the grasses harvested were in the same subfamily of grasses as barley. Harvesting of grasses of the other, mostly tropical subfamily of grasses, probably would not result in production of sickle sheen on the harvesting tool blades such as the sheen found on many of the blades found in Nile sites. This is because far fewer stalks of panicoid grasses would need to be harvested (since each stalk has thousands of grains), so less silica would be deposited on harvesting tool blades (Harlan, personal communication). Thus, the sickle sheen evidence and presumed climatic conditions suggest that the use of a festucoid grass such as barley is much more probable than the use of tropical species such as *Sorghum* and *Pennisetum* at this time.

The communities along the Nile in the 15th to 10th millennia B.C. were apparently sufficiently successful to allow large human populations to build up. This is indicated in part by the large numbers of people interred in cemeteries from this period surveyed along the Nile (Wendorf 1968). It has been suggested that high population densities at this time must have encouraged increasingly deeper levels of exploitation that may have approached the beginnings of animal and plant domestication (Clark 1971). However, peoples along the Nile either never achieved plant domestication or failed to develop the initial steps into an enduring agricultural system. Why they apparently did not develop agriculture is one of the intriguing questions that cannot yet be answered. Perhaps diverse resources along the Nile were so abundant that people never

needed to resort to food-procurement practices as labour-intensive as agriculture (Clark 1971). Or possibly the climatic change following 10 000 B.C. resulted in decreased populations of wild grasses and decreased dependence on this food source before a critical level of interdependence was established between human communities and the grains they harvested. Another possibility is that the first steps toward domestication were made but have not yet been found in the archaeological record. The last is certainly a real possibility because very little is presently known of the cultures of the Nile Valley from about 10 000 B.C. to the beginning of the predynastic (Clark 1971).

Desmond Clark (1971) has suggested that even if peoples living along the lower Nile did not develop a successful agricultural economy of the sort developed in southwestern Asia, their very deep levels of plant and animal exploitation and their almost sedentary pattern of life pre-adapted them for an agricultural way of life. Clark argues that agriculture would not have been accepted as readily as it apparently was if it had not been preceded by experiments in stock-keeping (H.Smith 1969) and by extensive use of wild grains and cultivation of indigenous Egyptian plants (as demonstrated by remains in stomach contents in predynastic burials (Dixon 1969) up to Old Kingdom times). This suggestion is certainly supported by evidence of behaviour of peoples in recent history. Crops and some agricultural techniques have been readily exchanged among agricultural peoples, but true hunter-gatherers and herders have generally resisted efforts to encourage them to take up agriculture.

If it is true that early Egyptians had independently made steps toward plant domestication before the introduction of southwestern Asian domesticates, evidence of the process may yet be found. Thus the possibility cannot be discounted that early Egyptians did develop their own domesticates, but later gave up local cultigens in favour of more productive southwestern Asian crops.

21.2 THE INTRODUCTION OF BARLEY AND EMMER WHEAT TO AFRICA

A period of increased rainfall in northern Africa occurred between 5 500 and 2 500 B.C. There is not much doubt that during this period herders were able to move freely between southwestern Asia and the Sahara along the Mediterranean littoral (Reed 1969). With facility of movement, cultural exchange was undoubtedly much more frequent between Asia and Africa and among parts of northern Africa. For this reason, it is probably not coincidental that this is the time when it appears emmer wheat and barley were introduced into Egypt and a remarkably successful and enduring system of agriculture was established along the Nile based on these two crops.

It might now be asked why emmer wheat and barley were such successful crops in Egypt but not transmitted further south to other parts of Africa. Aside from the hindrances to communication between Egypt and other parts of Africa that have helped maintain the cultural separateness of Egypt (Trigger 1965), there are some straightforward ecological and physiological factors that must be considered.

21.3 DIFFERENCES IN ADAPTATIONS OF SOUTHWEST ASIAN AND AFRICAN CROPS

Barley and emmer wheat are species adapted to the Mediterranean region. They are members of the subfamily Festucoideae of the grass family, Gramineae. Species in this subfamily are found predominantly in areas with cold or cool seasons. Vegetative growth in this group requires relatively cool conditions and is usually supplied by rains that come in winter or snow that melts in spring (Gould 1968:101). By late spring or early summer, enough vegetative growth has occurred to support formation of flowers and fruit production. Flower production is initiated by a period of long days as daylength increases in spring and also requires vernalization, that is exposure of plants to cold temperatures (Vince-Prue 1975:263). By summer, when the habitats of many festucoid grasses are hot and sometimes very dry, grain is mature and the reproductive cycle is complete. Natural selection has resulted in species genotypes that germinate, grow, and flower at appropriate times of the year for cold, temperate, and Mediterranean regions.

The same set of responses to seasonal changes in daylength is inappropriate for grasses growing in the tropics. This is because rainfall near the equator comes during the summer months (Tothill 1948:70). During the winter and spring months, the time when festucoid grasses are genetically programmed to grow and reproduce, there is usually no rain at all in the tropics. Furthermore, festucoid grasses are very susceptible to plant diseases of the humid tropics. This is because they have undergone no selection for resistance to tropical disease organisms. The evolutionary history and adaptations of festucoid grasses thus make it impossible for them to be grown successfully anywhere in the tropics except in the mountains and in dry areas where plant diseases are not a problem and only if water can be provided for irrigation in winter months.

The domesticates of the African tropics had to come from species in the grass subfamily Panicoideae. Species in this group dominate in tropical and subtropical parts of the world. They tolerate extremely high temperatures during the growth season, and, in fact, require high temperatures for good growth. Vegetative growth is supported by rains that come in the summer months near the equator. By autumn enough vegetative growth has occurred to support flower formation and production of grain. The short days that come in autumn provide the environmental stimulus that initiates flower formation. This ensures that flowering (which requires dry weather for pollination) will occur after the height of the summer rainy season. The adaptations which enable the growth cycle of panicoid grasses to fit optimally with the rainy season in the tropics make it impossible for most panicoid species to reproduce at higher latitudes because the short days that initiate flowering are soon followed in the temperate zone by killing frost.

In summary, the difference in the time of rainfall in the yearly cycle of tropical and non-tropical regions has selected for drastically different plant species responses to changes in daylength with changes in seasons. This is the most basic reason why plant groups which have evolved in one climatic belt usually cannot be grown in another. The adaptations and physiological responses acquired in the millions of years of evolution outside the tropical zone have precluded the adoption of festucoid species such as wheat and barley throughout Africa. These species did flourish in Egypt and in the oases of the Sahara, however, because the climate here was dry enough that plant diseases were not a problem and water could be supplied during the normal rainy season of the Mediterranean zone by planting after Nile floods or by irrigation in winter using water from desert springs.

21.4 ECONOMIES IN THE SAHARA DURING THE PERIOD OF ESTABLISHMENT OF AGRICULTURE IN EGYPT

During the time that agriculture based on barley and emmer wheat was being established in Egypt, the Sahara supported populations of presumably nomadic peoples who lived by herding and gathering (or possibly raising) plant foods. Remarkable paintings depicting the Saharan herders and their cattle offer us some tantalizing clues to their way of life (Lhote 1959). The artistic evidence for herding and earlier periods of hunting in the Sahara is unquestionable. However, the painting some have interpreted as indicating agriculture might just as well represent people harvesting wild grasses (Clark 1971). Whether or not people living in the Sahara actually raised domesticated cereals cannot be established with certainty until carbonized remains of domesticated cereals are found. However, there is good evidence in the form of grindstones and blades with sickle sheen that they did at least harvest significant amounts of wild grain. Economies in the Sahara during the 'Neolithic Wet Phase' were successful enough to support large numbers of settlements in areas such as the Maghreb in eastern Algeria (P.Smith 1976c), the Dungul and Kurkur Oases of Libya (Hester & Hobler 1969), the Tibesti mountains of Chad (Hugot 1968), parts of Tunisia (Camps 1974), and Nabta Playa in the Western Desert of Egypt (Wendorf et al. 1976). However, at the end of the 'Neolithic Wet Phase', population levels in the Sahara dropped.

21.5 EARLY DIRECT EVIDENCE OF AFRICAN CROPS

In the light of very good evidence for agriculture based on southwestern Asian domesticates in Egypt around 4 000 B.C., it is perplexing to find the earliest substantial direct evidence of African domesticates no earlier than about 1 000 B.C. The evidence consists of impressions of *Pennisetum* identified by H.Jacques-Felix in pottery associated with the site of Dhar Tichitt in southcentral Mauretania. The site, investigated by Patrick Munson (1976), provides an archaeological record of changes in the economy of peoples living in an environment that changed radically with fluctuations in climatic conditions in and near the Sahara Desert.

The Akreijit is the earliest phase in the sequence, ^{14}C dated around 1 750 B.C. (This date seems suspiciously late considering archaeological and environmental data, so the Akreijit may well be earlier than the carbon date). Archaeo-

logical material from this phase is not extensive but what is present shows no evidence of food production. There is no evidence of grain impressions in pottery. It is assumed that the people lived by hunting and gathering in view of the large numbers of projectile points and rock paintings of game animals that are probably associated with this phase. Fishing undoubtedly was also important since the site was located on a lake shore. A few small milling stones suggest some use of hard seeds, but certainly not food production.

The Akreijit was followed by a very arid period during which the lake dried and the site appears to have been uninhabited. Artifacts similar to those found at Dhar Tichitt were found at sites near Nioro just south of the Mauritania-Mali border (Vaufrey 1947) and near Bamako, Mali (Szumowski 1956), suggesting the Akreijit people may have moved south during the dry period. When rainfall increased around 1 500 B.C., Dhar Tichitt was occupied again by peoples whose artifacts suggest they were related to the earlier inhabitants of the site.

In the following 400 years, artifactual styles evolved and settlements shifted as the lake beach receded, but the economy throughout this period was based on essentially the same components. In addition to hunting and fishing as before, the people were now also raising cattle and goats. Plant foods were also important as indicated by plant impressions in pottery and large numbers of grindstones. Furthermore there appears to have been a shift in emphasis in the species of grains used for food with time.

During the Khimiya, Gougou and Nkal phases (1 400-1 100 B.C.), 99% of the grain collected (i.e. 66 out of 67 identifiable impressions) was *Cenchrus biflorus*. This species has a relatively large edible grain (3.2 mm in length) that is widely collected as a famine food up to the present (Chapelle 1957:192; Dalziel 1937). But numerous sharp spines on the bracts surrounding the grain make it unpleasant to handle and undoubtedly discouraged domestication. Just one of the impressions from this time period is of *Pennisetum*, the same species that gave rise to the domesticated grain known as bulrush millet or pearl millet. It could not be determined, however, whether the single impression is of wild or domesticated grain. It is presumed the grain was wild. (The morphological characteristics of wild and domesticated cereals will be discussed later.)

The following Naghez phase (dated 1 100-1 000 B.C.) was clearly derived from the preceding Nkal Phase, but is different in many ways from the preceding phases. There appears to be an increased reliance on plant foods as indicated by increased numbers of grindstones, which were larger than those used in earlier times, and by increased numbers of small collecting stations. There were also increased numbers of grain impressions in pottery representing a larger number of species. Among these are 75% *Cenchrus biflorus*, 9% *Panicum laetum*, 12% *Brachiaria deflexa*, and 3% *Pennisetum*. The wild or domesticated status of *Pennisetum* could not be established, but it is clear, whether or not some of the species were domesticated, that the bulk of the pottery impressions, and hence presumably the food sources, were from wild *Cenchrus biflorus*. It is presumed that the increase in the use of plant foods in the Naghez Phase was related to decreasing availability of fish as the lake dried up. Sites during this period were relatively large (one site was 1 200 m long and 300 m wide) with stone masonry construction.

In the following Chebka Phase (1 000-900 B.C.), *Pennisetum*, now with morphological characteristics of a domesticated cereal, represents 61% of the total identifiable plant impressions in the pottery. *Cenchrus biflorus* still is important with 34% of the total, and *Brachiaria deflexa* is a minor component of the total at 5%. Despite increasing aridity, villages of the Chebka phase are four times greater in number than those of the preceding Naghez phase, suggesting increased population levels.

By the Arriane phase (ca. 900-200 B.C.), 82% of the pottery impressions were *Pennisetum*, and in the following Akjinjeir phase (700-400 B.C.), *Pennisetum* accounts for 90% of the pottery impressions. The end of the cultural sequence at Dhar Tichitt around 400 B.C. can probably be attributed to two factors. The first factor is the increasing aridity of the region as indicated by evidence of true Saharan plant and animal species including addax, jerboa, and *Panicum turgidum*. The presence of these species suggests annual mean rainfall was less than 150 mm. The second factor is the invasion of Libyco-Berbers armed with metal weapons.

21.6 IMPLICATIONS OF THE EVIDENCE OF ECONOMIC CHANGE AT DHAR TICHITT

The Dhar Tichitt sequence provides evidence relevant to several hypotheses and models formulated in the study of origins of agriculture in Africa and in other parts of the world. Some of these hypotheses and models will be discussed as they apply to the archaeological sequence at Dhar Tichitt.

At the outset, it should be noted that people living at Dhar Tichitt during the earliest phase undoubtedly made their living in the same way as other people living along lakes and waterways throughout much of northern and eastern Africa from 9 000 B.C. to around 2 000 B.C. Similarities in pottery and bone tools of sites on lake shores and rivers suggest that fish and game resources were exploited in a similar manner throughout 'middle Africa'. Sutton (1974) has suggested that large and stable waterside communities made up an 'aquatic civilization' whose people independently invented pottery for use in preparation of food and used bone harpoons to capture fish and game animals. Though the waterside communities of middle Africa flourished for many millennia, they were obviously in trouble with the onset of desiccation in northern and eastern Africa. Especially vulnerable were communities on small, rainfed lakes.

The apparent long-term stability of waterside fishing and hunting economies in Africa and the change in the economy of these communities after the onset of desiccation can be viewed as evidence in favour of the explanation of economic change outlined by Lewis R. Binford (1968). Binford suggests that there is a selective advantage to manipulation of the natural environment to increase food supplies only in times when an established equilibrium system is upset. Binford's hypothesis argues against earlier assumptions that agriculture was an inevitable stage in human progress, 'the culmination of ever increasing cultural differentiation and specialization of human communities (Braidwood 1960:

135). According to the Binford model, agriculture is instead considered a human response to the 'threat of a diminished food supply, coming from an increase of population through immigration, or from a decline in local flora due to climatic or physiographic change' (White 1959:285). White, Binford and others have reasoned that agriculture is a labour-intensive (hence undesirable) means of providing food that would not have been adopted unless human groups could no longer support themselves by traditional means.

Recent models to explain economic change, such as those of Binford, rest on a new assessment of the botanical knowledge of preagricultural peoples that grew out of studies of modern-day hunter-gatherers. Hunter-gatherers have a vast knowledge of plants and animals in their environment. Furthermore, it is clear that they understand simple principles of plant propagation (Downs 1964; Gregory 1886; Harlan 1975a:22-26). For this reason, it can no longer be supposed that the origin of agriculture was delayed until one group of people discovered the 'secrets' of plant propagation. It is now thought that agriculture was adopted when resources that could be obtained by gathering became insufficient to support communities at previously established population levels. The new view of why people began farming is more consistent than the old view with increasing evidence, especially from Africa, that agriculture is not an idea that originated in one place and then diffused to others. It is beginning to look more as if plant domestication began in many places as people began to sow and harvest local indigenous species.

Returning to the Dhar Tichitt sequence, it appears that people who were able to make a living on the site were forced off the site by a period of severe desiccation. During this period of stress the people of the region adopted domestic animals and when the dry period ended, people related to the original inhabitants reoccupied the lakeside site. The economy of the new inhabitants was significantly different from that of their predecessors. The new inhabitants raised cattle and goats and collected large quantities of wild cereal grain as well as fishing and hunting. It seems significant that the new economy, which was more labour-intensive than the old one, was adopted during a time of environmental stress when wild food resources were diminished and probably were no longer sufficient to support previously established population levels. This part of the Dhar Tichitt sequence is certainly consistent with the Binford model.

The change in the economy at Dhar Tichitt did not lead to a stabilization in population size. During the period from 1 500-1 000 B.C. population size apparently grew in spite of shrinking water resources. Soon after 1 000 B.C., the lake apparently ceased to be a permanent body of water so that fish disappeared and game resources were certainly diminished. The people compensated for the loss of aquatic resources by intensifying wild cereal gathering activities, as indicated by larger numbers of grindstones, increased numbers of grain impressions in pottery, increased numbers of wild grain species in pottery impressions and increased numbers of small collecting stations.

The increased number of sites in the Chebka phase suggests that the human population was still growing. The appearance of domesticated *Pennisetum* in pottery impressions at this time is certainly consistent with hypotheses suggesting that agriculture was adopted as a means of supporting a community no

longer able to support growing numbers of people by traditional food gathering techniques.

Wild plant and animal remains after 1 000 B.C. show rainfall was low, something between 150 and 175 mm, probably not enough to support a rainfed crop of *Pennisetum.* This suggests the people may have practised a method of agriculture characteristic of the western Sahel zone known as 'décrue'. The method involves sowing seeds or planting seedlings at the edges of internally drained lakes, wadis, or rivers that shrink as the dry season progresses (Drouhin 1944; Harlan & Pasquereau 1969). Needless to say, the amount of labour needed to operate such a system is considerable. The carefree days of hunting and fishing at Dhar Tichitt were over.

If population levels had not steadily risen after the reoccupation of Dhar Tichitt around 1 500 B.C., the story might have been very different. The people may have been able to support themselves without agriculture. How can we account for population size increases despite decreasing resources? Why was an equilibrium not reached in which the people were able to support themselves by hunting and a limited amount of gathering as well as herding? One factor we might consider is the sort of food made available by herding and extensive gathering of wild cereals. It has been suggested by Philip Smith (1976b:21) and others that the ready availability of animal milk and cereal mush might have been more favourable to infant survival than diets provided by a strict hunting and gathering economy. This would result in rising population levels. Furthermore, there is a significant difference in practices of hunter-gatherers and food-producers (both herders and farmers) with regard to family size. Hunter-gatherers consciously limit family size and in so doing usually manage to keep population levels well below the carrying capacity of their home territory (Birdsell 1968). An important reason for limiting family size is that gathering most wild foods and hunting require experience and skill, especially where large game animals are involved. Children, in such a situation, cannot help much in the food quest and are not an economic asset. In food-producing communities, on the other hand, there are many tasks requiring little skill and experience that can be done by children. In such communities children can be an economic asset. Hence certain kinds of food-producing systems may select for large families (P. Smith 1976b:21). In such situations population levels will rise and exceed the natural carrying capacity of the land.

Is it possible that it was the adoption of herding and extensive use of wild cereal grains that initiated the population growth indicated in the archaeological record at Dhar Tichitt? If so, this change in the economy may have resulted in the necessity for increasingly labour-intensive practices to provide sufficient food for a growing population. This trend eventually resulted in the highly intensive interaction between plants and people that we call agriculture.

The Dhar Tichitt sequence contains all the stages one might expect in an independent transition from a food-collecting to a food-producing economy. But Patrick Munson, the investigator, suggests that the time interval from the beginning to the end of the sequence is too short for this to be the case. He suggests that agriculture may have been adopted from some other part of Africa, possibly the Sahara highlands, by people living at Dhar Tichitt. When

we consider the amount of time generally believed to have elapsed in similar transitions in southwest Asia and Mesoamerica (more in the order of millennia than in hundreds of years), the Dhar Tichitt transition is extremely rapid. But if the adoption of more intensive means of food production is a response to stress in an economic equilibrium, would we not expect the rate of response to be related to the impact of the stress? Perhaps a 500 year transition period is not unbelievable considering the magnitude of stress that must have been placed on communities within the Sahara and the Sahel as desiccation proceeded. As nomadic herders were forced out of the desert, and lakeside communities found themselves without water resources, the population pressure on the margins of the desert must have been considerable. Furthermore, a century for an annual plant represents one hundred generations, and a great deal of evolutionary change can take place under strong selection in one hundred generations. The significance of the sequence at Dhar Tichitt will not be resolved without more archaeological evidence of what people in the Sahara highlands and other suspected 'hearths of domestication' were doing throughout the Holocene.

We might also ask at this point if there is any evidence that the idea of agriculture, as it was practised along the Nile in Egypt, was transmitted in some way to the people who domesticated tropical African crops. Again, this is the sort of question that is impossible to answer on the basis of available evidence. But it may be worth considering that 'décrue' methods of agriculture practised in the western Sahel are not very different from post-flood planting techniques practised along the Nile, since both involve planting on previously inundated soil. Is this evidence of diffusion of ideas throughout the Sahara or simply evidence of development of similar ways of dealing with similar environmental situations? The importance of techniques practised in Egypt or possibly the Sahara in the origins of tropical African plant domesticates cannot be evaluated with certainty. However, we can with some confidence discuss the process of domestication as it must have happened wherever cereal crops were domesticated.

21.7 THE PROCESS OF CEREAL DOMESTICATION

In order to discuss how a domesticated cereal is derived from a wild cereal, it is important to consider two of the most important characteristics of domesticated cereals, one structural and one ecological. The most significant structural difference between a fully domesticated cereal and its wild relative is most apparent when plants with mature grain are compared. One can easily see that grain from the wild plant falls readily from the supporting branches of the inflorescence (the flower and grain-bearing structure) while grain does not fall free from the inflorescence of a fully domesticated plant. This is a small difference but highly significant to the harvester. If a farmer is to harvest all of his cereal crop he needs to sow a plant that will not scatter its grain on the ground over a period of days, as wild plants do, as the grain reaches maturity.

The needs of a farmer are exactly contrary to the needs of a wild plant population. Wild plants of all sorts throughout the plant kingdom have incredibly

diverse morphological adaptations that enable propagules to be disseminated by animals, wind or water, that all begin by releasing the seed-bearing structure from the parent plant. If a plant in a wild population did not disseminate its seed, all the seeds would fall and germinate in the same place and none of the progeny would reproduce because none would be able to capture enough sunlight to grow. Hence, there has been very strong natural selection for efficient seed dispersal mechanisms in wild plants.

The dispersal of seed from a wild plant is facilitated by formation of an abscission zone, consisting of several layers of specialized cells formed at the base of the seed-bearing structure. When seeds are mature, cells in the abscission zone become structurally weak by dissolving their cell walls. As a result, the stalk of the seed-bearing structure detaches from the parent plant (Esau 1961:324). Formation of the abscission zone and dissolution of cell walls in cells of this zone are controlled by one to several genes (Harlan, de Wet & Price 1973). In domesticated cereals, cells in the region where an abscission zone normally forms do not dissolve their cell walls and the seed-bearing structure does not detach from the parent plant. Genetic studies have shown that non-dispersal of cereal grains is a recessive character. In recessive genotypes with non-dispersing characteristics, the genetic message to dissolve cell walls in the abscission zone is defective and is not carried out.

One might now reasonably ask how cereals domesticated in different parts of the world all come to have the same non-dispersing characteristic. Looking at the question from the point of view of an evolutionist, one can hypothesize a simple sequence of events that could have occurred and probably did occur without the conscious intent of plant domesticators all over the world.

The human communities that domesticated plants no doubt had gathered the grain of wild plants for a long time before the process of plant domestication began. They also surely knew, long before the beginnings of agriculture, that the grain they used for food could produce new plants. Grain accidently lost during food preparation would have easily been observed sprouting at old homesites. We can also be sure they did not go through the trouble of planting grain as long as they could gather enough grain to meet their needs. However a time came when, for some reason, wild stands of cereals were not sufficient to meet the needs of the community and people began to sow some of the grain they harvested, to provide a greater harvest the next season.

Sowing wild grain is an important step in the domestication process but will not in itself lead to domestication if the grain sown is gathered by stripping grain off the plants or by sweeping up the grain after it has fallen to the ground. Among groups who harvested in this manner, domestication of cereals was never achieved. If domestication of cereals is to be achieved, two things must be done. First, people must begin regularly sowing and harvesting wild grain. It is important that the seed stock that is sown must be taken from the harvest of the previous year. When this is done a new population of the cereal is established that is subject to human selection as well as natural selection. The second thing that is important in selection for a domesticated cereal is the manner of harvesting. If grain is harvested by stripping grain off the plants or by sweeping fallen grain from the ground, no genetic change occurs in the cereal population. The

human harvester is affecting the cereal population in no way different from the forces of natural selection, so there is no change in selection for natural dispersal mechanisms. In order for the cereal population to be changed genetically, the human harvesters must set up a situation in which naturally dispersing plants are not selectively favoured. This is exactly what happens when whole stalks of grain are harvested and sheaves of grain are carried away from the field to a storage area. In this method of harvesting and handling the harvest, the plants that contribute the most grain to the harvest and to the seed stock for the next season's planting are those that do not readily disperse their grain. Inflorescences that disperse their grain contribute less to the next generation because much of the grain is lost in the process of handling the harvested sheaves of grain. When whole inflorescences are harvested and transported to storage areas, unconscious selection will favour the mutants constantly produced in any natural population that do not drop their grain. In such individuals, the genes that control formation of an effective abscission zone are recessive and the grains do not disarticulate. Non-dispersing plants are selectively favoured because fewer grains of these plants are lost during harvest and transport of harvested sheaves of grain. Thus, when non-dispersing mutants appear in planted and harvested populations, they naturally contribute a larger proportion of grain to the harvest and to the seed stock for the next year's planting than do genotypes that shed their grain.

It is most probably in this way that populations of wild cereals were first domesticated. After the first step was achieved, it was only a matter of time before other characteristics of domesticated cereals, such as large grain, were selected in the cereal populations people were sowing and harvesting. Even large grain size could at first have been selected unconsciously, since large grains produce seedlings that grow larger and faster than seedlings produced by small grains. Seedlings produced by large grains thus have a competitive advantage in the cultivator's field. In a heavily seeded field, competition for sunlight and nutrients is intense and seedlings from large grains quickly overshadow those from small grains. The plants from large seeds are thus most likely to flower and fruit and make the greatest genetic contribution to the next generation. Of course, the selection process could have been speeded up if a prehistoric Norman Borlaug recognized the economic value of non-dispersing plants in a wild stand or in his cereal crop and planted these preferentially. But it should be stressed that no prehistoric genius of plant breeding is required for the domestication of plants. The process can be carried on unconsciously because non-dispersing plants are selectively favoured when the farmer plants seed from fields he has sown and harvested. The important thing is that the method of harvesting must involve reaping the whole inflorescence rather than individual grains that are released from the inflorescence (Wilke et al. 1972; de Wet 1975; Harlan, de Wet & Price 1973).

Though large numbers of wild grass species are harvested around the world, only a few species are recognized as important cereal domesticates. In Africa, for example, about 60 species of wild grasses are harvested regularly as wild cereals or famine foods (Busson et al. 1965; Jardin 1967), but no more than ten species of grasses became domesticates of significant economic importance.

Part of the reason why only a small number of species was domesticated is that many plant species that are harvested are not successful in habitats created by man. The ability to thrive in such a habitat is the second important characteristic of domesticated plants.

A cultivated field prepared by man for the crops he sows provides many advantages to the crop plants. The area is cleared, so crops that are sown receive full sunlight and do not have to compete with other plant species for water and minerals. But this habitat also presents some problems. Young seedlings are unprotected from heavy rain and from diurnal extremes of temperature. Species adapted to living under a protective canopy of trees have not undergone selection for physiological adaptations that enable plants to cope with exposure to full sunlight, heavy rains, and extremes of heat and cold. They cannot tolerate the extreme conditions of an open man-made habitat. For this reason, only a few forest understory species (coffee, among them) have ever given rise to cultivated plant populations.

Most domesticates have been selected from species adapted to natural situations most similar to a plowed field. Such species are known as natural colonizers. Natural colonizers inhabit open areas created by fires, landslides, and trampling of animals as well as erosion by streams and rivers. Such species have special physiological, morphological, and genetic characteristics that enable them to cope with the challenges of open habitats. One fairly common characteristic of colonizing species is production of large numbers of seeds, often with relatively large amounts of stored food. This adaptation has been selected because open habitats are usually temporary and colonizing species are often replaced by other species. The survival of colonizing species in geologic time thus depends on the production of vast numbers of seeds that are carried by animals, wind or water to other newly formed open habitats that are suitable for the growth and reproduction of the species. The reproductive capacity of colonizing species of grasses undoubtedly made them prime candidates for systematic harvesting among prehistoric human populations. Furthermore, when people began to sow the grains that they gathered, of all the species they gathered, the natural colonizers had the best ability to thrive in open man-made habitats.

21.8 AREAS OF ORIGIN OF AFRICAN DOMESTICATED PLANTS

Many different areas of origin of domesticated plants have been suggested for Africa, mostly on the basis of biogeographic distribution of crop plants rather than on substantial archaeological evidence. Some of the proposed 'hearths of domestication' such as the Ethiopian highlands will not be discussed here because crops most probably developed in Ethiopia such as tef, noog, and ensete (Harlan 1969) are of no economic importance outside Ethiopia and certainly are not grown in the Sahara or along the lower Nile. It has never been demonstrated that plant domestication in the Ethiopian highlands in any way influenced the course of plant domestication in the Sahara and subSaharan Africa and suggestions that widespread tropical African crops such as sorghum were domesticated in Ethiopia now appear untenable. Readers are referred to

Clark (1976b) for a recent review of evidence for plant domestication in Ethiopia and to Stemler, Harlan & de Wet (1975) for evidence and arguments against the origin of sorghum in the Ethiopian highlands. Other proposed areas of plant domestication including the highlands of the Sahara will be considered briefly.

As was mentioned before in the discussion of the archaeological sequence at Dhar Tichitt, it would be very useful to know much more than we do know about the economies of peoples living in the Sahara, especially in the highlands. As early as 1938, Chevalier suggested that some cultivated plants might have been developed in the Sahara, in times when rain was more plentiful. The idea continues to be favoured by both archaeologists (Munson 1976; Camps 1960, 1969; Hugot 1968; Hobler & Hester 1969) and botanists (Harlan 1975b; Brunken et al. 1977) but the fact remains that there is no substantial archaeological evidence of the domesticated plants themselves being used in the Sahara. An impression of grain on a potsherd from the site of Adrar Bous was at first considered to be domesticated sorghum but on further examination was determined to be most probably a wild grass grain (J.D.Clark, personal communication 1977). In the absence of real archaeoethnobotanical evidence we can only continue to build hypotheses that can be overturned by a single piece of real evidence. A magnificent example of the sort of evidence that is needed is an entire storage pit full of carbonized domesticated sorghum found by a team led by Desmond Clark at the site of Jebel et Tomat, south of Khartoum in the central Sudan. With this bountiful sample of the crop grown at the site, it was possible to state without a doubt that the inhabitants were growing domesticated sorghum. It is interesting that the sorghum grown at the site is more primitive morphologically than the sorghum grown in the area at the present, yet the storage pit was radiocarbon dated 245 ± 60 A.D., a surprisingly recent date (Clark & Stemler 1975).

Returning to the question of a possible centre of domestication of African plants in the Sahara, there can be little doubt that changing temperature and rainfall conditions in northern Africa, and especially in the Sahara, during the Holocene must have had a great impact on people living in northern Africa. But there are several plausible models to explain how the people living in and around the desert might have responded to changes in the environment and changes in demography during the Holocene.

Hester & Hobler (1969) suggest on the basis of investigations in the Libyan Desert that desert dwellers inhabiting much of the Sahara may have been cultivating food plants near desert playas as early as 6 000-5 000 B.C. The evidence consists only of grindstones, unfortunately, rather than charred domesticated grain, so it is possible that people could have been gathering the grain instead of growing it. Hester & Hobler consider the typology of stone implements of desert peoples and peoples living along the Nile to be different enough to suggest separate cultural traditions. They conclude that in times of aridity desert dwellers withdrew to better watered areas of the desert in the highlands, rather than to the Nile. These investigators suggest that in dry intervals in the Holocene, the Saharan highlands may have been a 'Saharan fertile crescent'. It is thought that savanna plants and animals that expanded to the north during moist intervals were able to survive on higher mountain ranges during dry

periods and provided the raw material for plant domestication. If it is true that desert people and savanna plant species were both present in the Saharan highlands during dry periods, then it is possible that the highlands could have been the place of origin of some African domesticates. The biogeographic distribution of pearl millet (*Pennisetum americanum*) is the most convincing botanical evidence for a centre of plant domestication in the Sahara (Harlan 1975b). But the biogeography of other African crop plants is not consistent with a hypothetical area of origin of all African crops in the Sahara.

On the basis of a review of systematics, biogeography, and ecology of crop plants of Africa, J.R.Harlan (1971) has concluded that there is no evidence that there was a single centre of origin of African crop plants in the Sahara or anywhere else for that matter. There appears to be a very broad zone of plant domestication that stretches from east to west in the Sahel, savanna, and savanna-forest ecotone south of the Sahara and probably another region of domestication including the Ethiopian highlands and possibly also the East African highlands (where *Eleusine coracana* was probably domesticated (Hilu & de Wet 1976a, b). But such zones cannot be considered a centre in any accepted sense of the word. The evidence suggests instead that people all across Africa, in a wide range of climatic zones, domesticated many different species native to different ecological zones and to different regions in Africa. This is the only model that can reasonably explain the existence of the many different locally important crops, with different climatic adaptations that are found in Africa. Some African crops, such as *Digitaria exilis, Digitaria iburua, Brachiaria deflexa* and *Oryza glaberrima,* for example, are grown in limited areas in West Africa (Harlan 1975b). It is difficult to imagine how the domestication of these crops could have taken place in the same area where highland eastern African crops such as tef or *Eleusine* were domesticated.

In the case of some other cereals, such as *Pennisetum* and *Sorghum,* the wild relatives and domesticates are much more broadly distributed geographically and have wider ecological adaptations. It is more hazardous to speculate on areas of origin for these crops. In the past various writers have suggested they could have originated as far west as the bend of the Niger River (Murdock 1956) or as far east as the Ethiopian highlands (Vavilov 1951). More recent analyses suggest areas of origin somewhere between these geographical extremes (Harlan 1971; Harlan & Stemler 1976), but much more archaeological evidence is needed before very much can be said about the places of origin of many tropical African crops.

The 'non-centric' pattern of plant domestication described by Harlan is highly consistent with a model outlined by Desmond Clark (1976a) to interpret evidence of human responses to climatic change in the Sahara. It has been observed that people living in lakeside communities that existed in the foothills of the Saharan Atlas mountains and more central and eastern parts of the desert around 6 000 B.C. used tools of the sort found earlier in the Maghreb and Nubia. It is believed that the economies of all these communities were based on fishing and exploiting hippo and large land mammals. The pottery made during this period may have been used to cook fish or to store grain, but no abundant evidence of the grain used has ever been found. There are only fragmentary

clues, such as the small number of grain impressions in pottery from Adrar Bous that suggest wild sorghum or *Brachiaria* may have been collected. Pollen evidence such as that from Amekni and Meniet cannot indicate with certainty what sorts of grain were used because pollens of domesticated grasses and their wild relatives cannot be reliably distinguished.

Though there is no indisputable evidence of plant domesticates in the Sahara, there is evidence of domesticated animals in rock art dated to the 5th and 4th millennia. Also bones of domestic cattle have been found in sites in the Acacus Mountains dated ca. 4 000 B.C., at Adrar Bous ca. 3 800 B.C., at Meniet ca. 3 450 B.C., at Arlit in the Tilemsi Valley ca. 3 200 B.C. and at Dhar Tichitt in Mauritania ca. 1 500 B.C. (Clark 1976). The carbon dates suggest that cattle herding was first practised in the north and gradually spread southward. Fruits of *Celtis* and *Zizyphus* are sometimes found stored in pots in Neolithic sites suggesting that wild plants were gathered and processed using grinding stones also found at the sites. The evidence suggests a gradual transition in the Sahara from hunting and fishing to herding and gathering, probably related to the gradual desiccation in the desert and resulting disappearance of aquatic fauna.

The desiccation that had proceeded gradually with periodic returns to moister conditions became critical around 2 000 B.C. Desert herder-collectors were forced to move beyond traditional transhumance routes into the uplands of the Aïr (where there was little archaeological evidence of human occupation before the late Neolithic), to Nubia, where evidence of C-group herders appears around 2 000 B.C., and into Egypt, where historical sources date invasions by Libyans between 1 300 and 1 210 B.C. When the desert herders moved out of the desert and into the surrounding Sahel and savanna zones, they came into contact with people whose cultures and economies were markedly different from their own. There is no reason or evidence to suggest the contact initiated anything but a peaceful symbiotic relationship of the sort that still exists at the present between the pastoral Fulani and their Hausa neighbours. In this co-operative relationship the Fulani purchase sorghum, pennisetum, and other crops from the Hausa in exchange for meat, milk, and butter. Part of the reason why this arrangement works is that the transhumance patterns of the Fulani bring them into Hausa territory during the dry season after the crops have been harvested. In this way Fulani cattle do not damage the crops but merely graze on harvested fields. In this way the cattle actually benefit the farmer by helping to clear the fields and by depositing manure.

The people whom prehistoric desert herders encountered in the Sahel and savanna were probably not yet cultivators, but surely must have harvested the vast stands of *Sorghum* and *Pennisetum* that surrounded them. They were probably able to harvest enough grain for trade as well as for their own use. It might be imagined that the exchange of agricultural products and the adoption of animal husbandry to some extent by savanna peoples provided sufficient food supplies to allow population growth of both the herders and savanna gatherers.

Higher population levels at the periphery of the Sahara and climatic deterioration resulting in decreased harvests of wild grains may well have been the reasons why people living in this zone all across Africa took up agriculture to

provide more food. This is the simplest explanation of the evidence at Dhar Tichitt and there is no reason to believe the same thing was not happening in other parts of northern Africa. Early methods of cultivation of wild grasses may have involved nothing more complicated than sowing grass seeds along wadis, river banks, and temporary ponds that disappeared as the dry season progressed (Portères, personal communication). This is the method of planting used by the Tuareg today (Nicolaisen 1963). From such beginnings, more labour-intensive and productive techniques were developed to provide more food in a period of decreasing rainfall. In such a situation it would not have been long before sowing and harvesting of cultivated fields set up selection pressures that led to the development of cereal populations that did not disperse their grain. Once this level of domestication was reached, selection for other characteristics of domesticated cereals such as large grain size must have proceeded rapidly.

21.9 THE IMPORTANCE OF HARVESTING TECHNOLOGY IN THE ORIGIN OF AFRICAN DOMESTICATES

One of the most perplexing aspects of the origin of true African domesticates is the evidence that domestication of African cereals is a very recent phenomenon, possibly as recent as ca. 1 000 B.C. It is impossible to resist the temptation to offer a comment on the apparently late development of African domesticates considering what has already been said about the process of domestication. If it is correct to suppose that domestication did not begin until people began harvesting whole grass inflorescences, then perhaps the domestication process may have been held back, at least to some extent, by the need for an efficient harvesting tool. Harvesting inflorescences of small festucoid grasses such as wheat and barley is far easier than harvesting panicoid grasses such as sorghum and pennisetum. This is because sorghum and pennisetum have stalks much thicker and stronger than wheat and barley. Harvesting whole inflorescences of wild sorghum and pennisetum requires a very good cutting tool, perhaps a much better tool than anything produced until relatively late in the history of man in Africa. Furthermore, it may be possible that people from the Sahara were involved in initiating the domestication process. Saharan peoples may have introduced a superior cutting tool or the idea of harvesting whole grass inflorescences (the technique suggested in the Sahara rock drawing showing people harvesting) during the period of contact with savanna peoples.

21.10 THE 'NON-CENTRIC' PATTERN OF PLANT DOMESTICATION IN AFRICA

The hypothesis that demographic pressure around the Sahara in a period of desiccation led to increased manipulation of wild plants and finally to domestication as elaborated by Clark (1976) is consistent with the apparently 'non-centric' pattern of African plant domestication suggested by Harlan (1971). The

sequence of events suggested to Clark by the data would have resulted in many places of origin of crop plants all along the southern margin of the desert because populations throughout this zone undoubtedly experienced demographic pressure resulting from incursions of desert herdsmen. We would expect that people from east to west, along the margin of the desert, responded in a similar manner with more intensive manipulations of local plants that led in many cases to domestication. Undoubtedly greater success was achieved in plant domestication in parts of the savanna located along rivers and in places where water accumulated during the rainy season because these are the places where early attempts to cultivate wild grasses must have been most successful.Hence, it is not surprising that near the Senegal and Niger rivers and near Lake Chad we find that a great diversity of crops of local importance are grown. These include *Digitaria iburua, Digitaria exilis, Brachiaria deflexa,* and *Oryza glaberrima* (Harlan 1971). In areas of the savanna that must have been less hospitable during the period of plant domestication because of isolation from permanent waterways, we find less evidence of large numbers of local domesticates.

It is not yet clear who did the actual work of plant domestication, but the general aversion to cultivation demonstrated by modern herding peoples suggests that the more sedentary dwellers of the savanna are the ones most probably responsible for the origin of the domesticated plants of tropical Africa.

21.11 SUMMARY

In summary, it should be re-emphasized that much more direct evidence of domesticated plants is needed before we know when, where, and why the crops of Africa were domesticated. Evidence available at the present is sufficient only to suggest the following:

1. African agriculture is based on crops domesticated both in Africa and in southwest Asia.

2. The most important domesticated plants of lower Egypt and the Sahara were probably domesticated in southwestern Asia and introduced to Egypt around 4 000 B.C. when 'pluvial' conditions made possible free movement of people and domesticated animals between southwest Asia and Africa.

3. Around the time that agriculture based on barley and emmer wheat was being established in Egypt, the Sahara was occupied by people living in lakeside communities, who made their living by fishing, hunting, and gathering wild plant foods. There is no direct evidence that people living in the Sahara were growing domesticated cereals, but gradually some of them began raising domesticated animals.

4. Carbon dates of Saharan sites containing bones of domestic animals indicate that herding became important first in the northern Sahara before 4 000 B.C., then gradually spread southward.

5. Movement of herder-collectors from the desert to surrounding regions, as desiccation of the Sahara became critical around 2 500 B.C., may have affected people in the surrounding areas in several ways:

5.1 The contact probably introduced stock-keeping to hunter-gatherers who lived in the savanna. Stock-keeping among the savanna peoples may have encouraged population growth.

5.2 Demographic pressure was created at the margins of the Sahara as a result of the influx of herder-collectors and perhaps population growth among the indigenous peoples.

5.3 As population levels around the Sahara rose and wild plant food supplies decreased with desiccation, indigenous savanna hunter-gatherers began sowing and harvesting native wild grasses in their efforts to provide more food. In so doing, they began the process of cereal domestication.

5.4 Herder-collectors from the Sahara may have been responsible for the introduction of a new way of harvesting grain or for the introduction of a tool that could be used to harvest whole grain inflorescences. The use of an efficient tool for harvesting whole grass inflorescences was an essential step in the domestication of African cereals.

6. Direct archaeological evidence of domesticated forms of native African grasses appears in the archaeological record only in relatively recent times. Pottery impressions of domesticated *Pennisetum* are carbon dated around 1 000 B.C. at the site of Dhar Tichitt in Mauritania, and carbonized domesticated *Sorghum* is carbon dated around 245 A.D. at the site of Jebel et Tomat in Sudan.

7. If the apparent recency of domestication of African cereals is real, and not a result of insufficient evidence, it may be a result of the following conditions in tropical Africa:

7.1 Supplies of wild plant and animal foods in tropical Africa may have been so abundant that there was little incentive to employ labour-intensive means of food production until the period of desiccation, that forced people out of the Sahara and caused increased population pressure in surrounding regions.

7.2 Until an exceptionally good cutting tool was developed or introduced in the African savanna, it was probably much more efficient to harvest wild African grasses like *Pennisetum* and *Sorghum* by stripping grain off the inflorescence than by harvesting whole inflorescences. This is significant because the process of domestication could not have begun before people began harvesting whole grass inflorescences. Harvesting with a cutting tool exerted a new set of selective pressures on populations of grasses that were sown and harvested that resulted in plants that did not naturally disperse their grain. This was the crucial step in the process of domestication of African cereals.

8. The geographic distribution of African domesticates suggests that people all across the African savanna, south of the Sahara, engaged in the process of cereal domestication. No single proposed 'centre of origin' or 'hearth of domestication' can reasonably account for the large number of African domesticates with very different geographical distributions and ecological adaptations.

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22

Human populations and cultural adaptations in the Sahara and Nile during prehistoric times

Populations humaines et adaptation culturelle au Sahara et au Nil durant les temps préhistoriques

Dans ce chapitre sont abordés les problèmes de l'interprétation du comportement humain et des associations culturelles dans le désert bien qu'après les artifacts découverts, la vallée du Nil semble être la seule région d'Afrique du Nord à avoir été occupée par l'homme de façon continue depuis l'Acheuléen supérieur (>200 000 ans B.P.). Cependant les outils de pierre en eux-même apportent peu de renseignements sur les fondements économiques de leurs auteurs, sauf s'ils sont en relation directe avec d'autres ustensiles ou des restes alimentaires. Pour les industries les plus anciennes, il est difficile d'obtenir des conclusions valables. Pourtant dans le Paléolithique le Moustérien fournit les premiers indices de migrations du Maghreb à travers le Sahara de l'Ouest jusqu'au Nil égyptien et en sens inverse. Puis, durant l'Atérien, on peut distinguer deux provinces majeures, l'une au Nord, l'autre au Sud du Hoggar. Cette opposition bien marquée devient de plus en plus importante dès qu'apparait l'Epipaléolithique et la tradition pré-agricole saharo-soudanaise à l'Holocène inférieur. Une limite allant du Hoggar et du Tibesti septentrionaux jusqu'au désert égyptien (approximativement en suivant le Tropique) et correspondant à la limite écologique entre les pluies d'hiver et les pluies d'été nous apparait être aussi une frontière culturelle. A la fin du Pléistocène, le Sahara a été réoccupé à la fois depuis le Nord-ouest et depuis le haut Nil vers le Sahara central et méridional. Un mouvement vers le Nord a probablement eu lieu en provenance des savanes mériodionales, régions qui sont devenues très importantes d'ailleurs quand la dessiccation du Sahara a forcé les peuples d'éleveurs vers le Sud autour de 4 000 ans B.P. Il n'est pas encore possible d'établir avec certitude que la culture des plantes domestiques en Afrique a ses origines dans le Sahara bien que les quelques datations disponibles le suggèrent et que les plaines d'inondation fertiles le long du Nil ont peut-être rendu la domestication des plantes quelques peu accessoires ici. L'évolution de sociétés plus étroitement structurées le long du Nil autour de 12 000 ans B.P. a dû exiger un emploi encore plus intensif des ressources qui aurait pu engendrer des manifestations précoces et assez importantes de culture et d'échange. Le problème fondamental pour la Préhistoire de l'Afrique du Nord reste l'étude approfondie des sites d'occupation d'âge Holocène inférieur et les origines de la culture dans la vallée du Nil.

22.1 INTRODUCTION

Its natural ecological richness, as shown by the record of its geological history and prehistory, has made the valley of the River Nile probably the sole region of North Africa to have experienced more or less continuous occupation by man from the time of the Middle Pleistocene when the makers of the later Acheulian tool-kits left numerous evidences of their presence there in the form of handaxes and other artifacts, dating probably to some 200 000 or more years ago. The coastal zones of Atlantic Morocco or the Mediterranean coasts of Cyrenaica are among other highly favourable geographical regions where a long record of prehistoric occupation is preserved. Here, however, as in the more interior parts of the continent, the record is incomplete and more than one cultural hiatus is suggestive either of temporary abandonment of the region by man or of the possibility – as in the case of the coasts – that the evidence for those times is now buried by the rise in sea level since the maximum of the Last Glacial.

For much of its course northward to the coast after it leaves Equatoria where it has its sources, the Nile flows through that vast arid belt between 15°N and 30°N which, to the west of the river, is known as the Sahara desert. Today, this region receives an average of under 250 mm of rain a year and the water in the Nile comes, not from tributary streams in Egypt and the Sudan, which are dry, but from tropical East Africa. Three quarters of the water comes from the highlands of Ethiopia via the Blue Nile and the other quarter, via the White Nile, from Lake Victoria. Its climatic history (see Chapters 4 to 6) shows that considerable fluctuation in the amount of water coming down the river – reflecting tropical climatic changes – took place in later Pleistocene and early Holocene times. This, together with intermittent local rainfall, lowered temperature, cloud cover and other climatic factors affecting the local ecology of the valley, is likely to have had its effect on the biota, including the human population. When large parts of the Sahara were too arid to sustain human settlement, the Nile Valley was never sufficiently inhospitable to prevent man from being able to occupy it successfully. To what extent the valley acted as a refuge during times of climatic adversity in the desert and as a reservoir for repopulation of the Sahara and deserts to the east of the Nile in times of climatic optimum, is not known. If, however, early historical evidence can provide any indication, movement of animal and human populations out of the eastern parts of the desert into the Nile Valley in prehistoric times are certainly to be expected.

During times of climatic amelioration – increased rainfall and lower evaporation – the Sahara desert must have been, for the later Quaternary hunter/gatherer populations, one of the optimum habitats in the continent. The large Ethiopian game animals re-occupied the desert; the streams draining from the central Saharan massifs and the numerous, lake-filled depressions provided abundant water while the rainfall, derived in part from tropical monsoons and tropical depressions (Maley 1977), supported large areas of open grass and tree savanna all set within the general desertic milieu. The extent to which prehistoric hunter/gatherers availed themselves of these optimum conditions is attested by the numerous evidences of their occupation in the form of stone, bone

and pottery artifact assemblages, associated with food waste, preserved at the living sites. Their rock art gives indications of ceremonial and ritual beliefs and burial practices and religious structures further extend understanding of the early Holocene populations.

Quaternary evidence from the Sahara in the form of sediments, pollen, diatom and geomorphological sequences (see Chapters 2 to 6) shows that climatic conditions in the desert have undergone a series of changes from periods of extreme aridity to others when surface water supplies and vegetation cover provided near optimum conditions for hunters and later pastoralists. Where radiocarbon dates are available, these fluctuations can be seen to have lasted for several millennia. However, where sequences are known in greater detail, it would appear that periods of climatic optimum were not as long as was first believed from the few radiocarbon dates that are generally all that are currently available today (Chapters 3, 5 & 6); even so, the most rapid changes must be reckoned in centuries at least. Hunter/gatherers are as much a part of the ecosystem in which they operate as are the geographical features or the animals and plants, so that it can be assumed that they will make adjustments comparable to those made by the other components of the biome which expand into new, perhaps empty regions when the conditions are favourable and fall back onto the reservoir areas at times of adversity.

Reservoir regions can be seen as the Mediterranean and sometimes the Atlantic littoral including the Jebel Akhdar in Cyrenaica and the slopes of the Atlas range in the Maghreb, as well as the valley of the Nile and its southern tributaries, the Sahel and Sudanic vegetation zones of West Africa and the massifs of the central and eastern Sahara – the Hoggar, Tassili/Acacus, Tibesti, Aïr, Adrar des Iforas, Ennedi and Darfur (Figure 22.1). Some of these cooler and better watered mountain and plateau areas can be expected, although the evidence still largely remains to be adduced, to have enabled some human settlement to have persisted throughout the times of greater desertification when other parts of the Sahara were too arid to support hunter/gatherers and the animals and plants on which they depended for subsistence. The extent to which, during times of increased desiccation, ground water may still have been available in the depressions such as Siwa, Kharga, Dakhla and Wargla, where the most important oases are situated, remains unknown. The evidence from several localities in the western desert of Egypt, however, suggests that, at the height of the dry periods, the oases there were uninhabited.

The artifacts and associated remains that have survived from earlier prehistoric times are essentially those connected with subsistence pursuits – they are the more durable and, thus, surviving parts of the group's material culture and are concerned with hunting, collecting, food preparation and various other domestic avocations including the manufacture of a technologically very simple equipment. There is almost no evidence that provides a clue to social organisation, ceremonial life and ritual beliefs before the Neolithic. While, therefore, the artifact assemblages can afford the prehistorian a better opportunity to construct models to explain past economic behaviour, there is almost nothing available before the Neolithic that can show the social structure or ethics of the group and any attempts to reconstruct these must have more substance in sup-

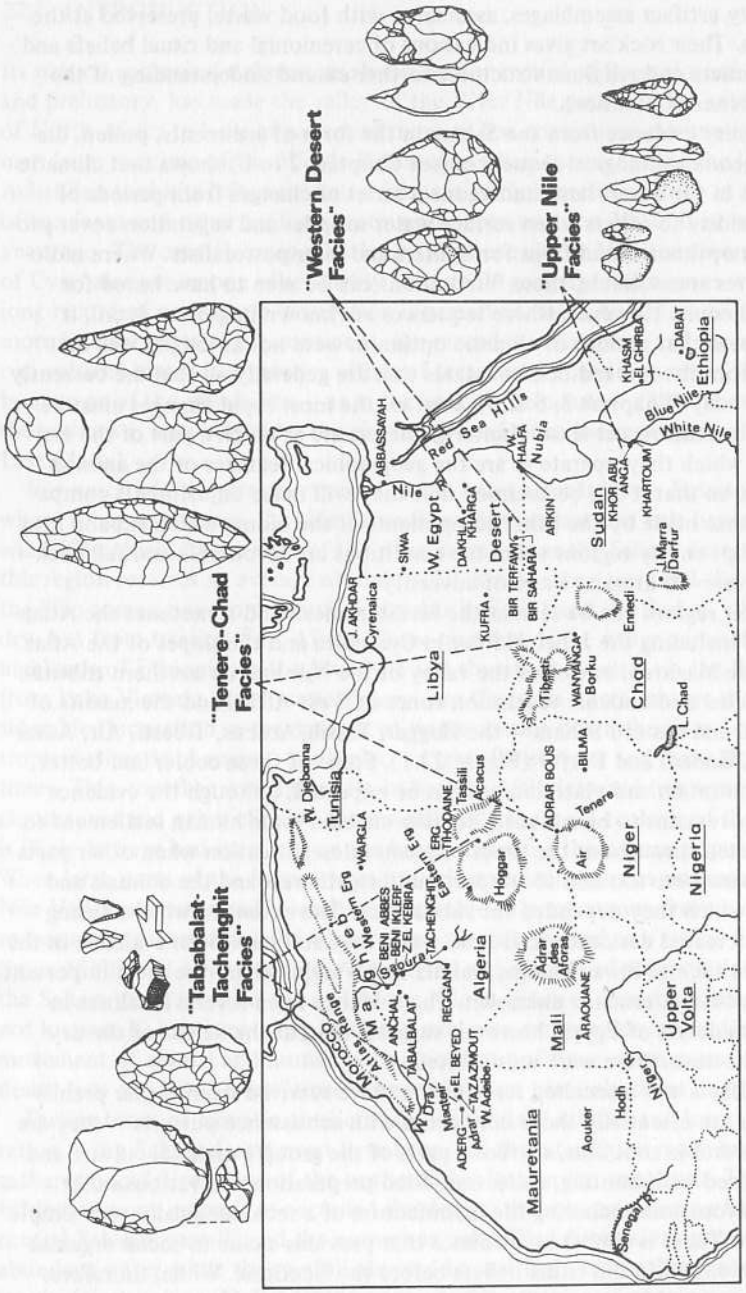


Figure 22.1 Topographic features, Lower Palaeolithic sites and some possibly identifiable 'facies' of the Acheulian Industrial Complex in northern Africa.

position than in reality until spatial analysis and ethno-archaeological findings become more precise and more reliable.

Although the artifacts in their context still reveal to the prehistorian comparatively little about such aspects of human behaviour as group organisation and ideological beliefs, they can be effectively used to contribute to an understanding of levels of technical achievement. The morphology of the artifacts, the kinds of stone and bone tools and pottery as well as studies of the manufacturing waste from the workshop areas, can help in identifying tool function and sets of activity-related artifacts. Again, a study of changes in artifact types, in form and style through both time and space, can help towards identifying changes in activities or variation in the emphasis given to them by a group. In addition, by comparing the composition and stylistic attributes of discrete artifact assemblages, it becomes possible to recognise technological entities – sometimes having regional significance – which, when a time depth exists, take on the appearance of a 'tradition'. When space is considered in such context, it may be possible to draw boundaries between similar artifact sets which might also – though not necessarily – have had ethnic implications.

There are many levels of detail and sophistication on which this kind of analysis could be carried out but, so far as Africa is concerned, it is as yet, in most instances, confined to the most elementary, namely the identification of areas of broad technological and typological similarity on the basis of the presence or absence of certain forms of artifact. Thus, for example, the grouping of numerous assemblages with similar artifacts may demonstrate that they belong in a specific – say, an Aterian – Industrial Complex or Techno-Complex. A map of this distribution can then be drawn. The major, technological entity can be sub-divided and regional 'facies' and/or 'Industries' can be identified on the basis of form, style, technique and general contemporaneity. Thus, there are recognised by some authors, for example in the instance quoted, a 'Moroccan facies', a 'Djebanna facies' or a 'Saharan facies' of the Aterian Industrial Complex.

Further, ethnography shows it to be a valid assumption that different activities often necessitate different sets of artifact forms. This means that the prehistorian has further to determine whether, for example, two contemporaneous and related Archaeological Occurrences with differing tool-kits represent two different activity facies of the same population or whether they should be associated with different populations. Again, there is the need to determine whether, where two or more such tool-sets are found together on the same site, their presence represents a 'base camp' situation where a single group was practising a range of participant activities or, alternatively, whether it might better be interpreted as due to intermittent, perhaps seasonal, occupation by two different populations. For example, the Mousterian of Acheulian Tradition, the Typical and Denticulate facies of the North African Mousterian, have been interpreted as activity related sets but the lack of chronological precision in identifying 'contemporaneous' assemblages must leave open a doubt that something more than a reflection of subsistence activities may be involved here.

Any attempt to interpret the pattern of human settlement in the Sahara and the Nile in prehistoric times must, therefore, take these considerations into

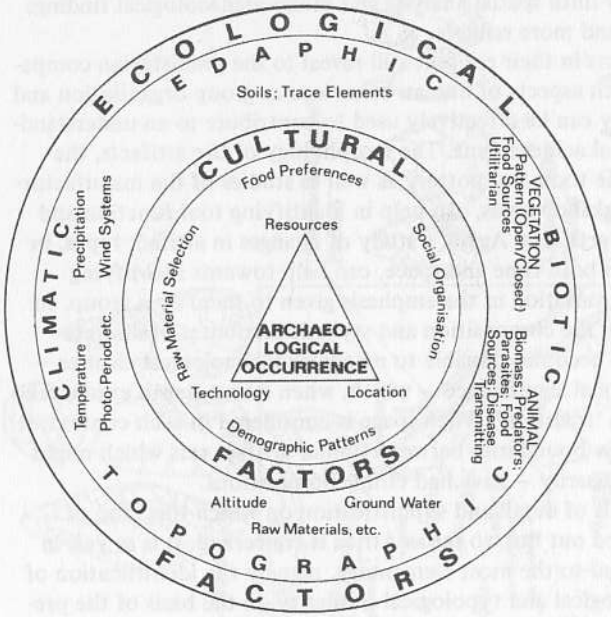


Figure 22.2 Diagram to show some of the ecological and cultural factors contributing to the location and nature of Archaeological Occurrences.

account. Indeed, it will only be after a much more precise knowledge of stylistic variation, function and spatial and temporal association becomes available that interpretations of changing technological patterns can be made with greater confidence in their validity.

Another problem in any demographic interpretation is the 'patchy' nature of the research. Although parts of the Nile Valley have been relatively intensively surveyed, nothing whatsoever is known about many other parts. Similarly, research in the Sahara is equally patchy and much less intensive and a great deal of the material finds consist of little more than stone artifacts and pottery. Nevertheless, very many sites are known and, where these can be stratigraphically and/or radiometrically dated, it is still possible to say something about them at a general level and, where plant and animal data are also associated, to attempt to interpret their artifact composition and location in relation to the climatic and environmental conditions under which the sites were occupied.

The preceding diagram (Figure 22.2) helps to illustrate some of the main factors – ecological and cultural – that affect the nature of an Archaeological Occurrence, that is to say, an assemblage of artifacts and associated remains in geological context that are the product of the activities of the past human occupants. The way all these ecological and cultural factors interact determines the basic behaviour pattern of the human population and so the composition of the Archaeological Occurrence that represents the surviving part of the technology.

Seasonal, climatic and environmental changes affect food gatherers and food producers in different ways but, so far as hunter/gatherers and nomadic pastoralists are concerned, such seasonal changes affect the availability of food resources and usually necessitate some movement and relocation which may take on an ordered pattern of transhumance. In the same way, the long periods of climatic amelioration or deterioration attested for Quaternary times, or significant and persistent changes in other ecological or cultural phenomena, can be expected to have affected radically the way of life and technology of the prehistoric populations of the fragile biotic zones of the Sahara and Sahel by inducing the people to make longer term readjustments and major relocations.

Some general understanding of the distribution of the larger game animals can be obtained by correlating several lines of evidence such as the food remains associated with prehistoric occupation sites, the geographical distribution of representations of these animals in the paintings and engravings dating to the time of the early Holocene climatic optimum, from historical records and from the present-day distribution of the large Ethiopian land mammals (Mauny 1957). However, surveys to assess the dietary potential for prehistoric human populations and the availability of animal and plant resources in a region still remain to be undertaken for most parts of North Africa. Almost no Site Catchment studies are yet available from which to gain some insight into what resources may have been available for exploitation from a given site, or where, when and in what quantity the resources were made use of. The review presented here can, therefore, do little more than examine the archaeological content and distribution patterns in time and space in the Nile Valley and the Sahara and consider some hypotheses that might explain these patterns in terms of economic and, possibly, social behaviour. Such tentative hypotheses concerning prehistoric life styles rest also upon the data provided by the scanty palaeoecological evidence, the knowledge of present-day distributions of plants and animals, the seasonal movements of present-day and historic nomadic pastoralists and knowledge of the food resources of some of the existing inhabitants along the Upper Nile and in the desert. The geographical patterning also provides some possible clues as to the general directions from which ideas and technology may have been diffused or along which the human groups may have moved when repopulating the desert.

22.2 ARCHAEOLOGICAL DISTRIBUTIONS IN THE SAHARA AND THE NILE

Other contributors to this volume have discussed in varying detail the archaeological evidence and patterning of the Neolithic in the Sahara and the Nile so that it is not necessary to repeat this here. Less emphasis has, however, been given to the earlier cultural material and, in an attempt to show the extent to which the regional patterning recognisable in later prehistoric times, may also be visible in archaeological evidence from earlier periods, a review of some of this is presented below.

22.2.1 *Pre-Acheulian occupation*

The recovery of core/choppers of Oldowan type in secondary contexts in conglomerates and other residual, coarse-grained sediments in early geomorphological situations, has led to claims for a Plio-Pleistocene age for these artifacts and to the suggestion that the makers of the Oldowan Industrial Complex may have occupied the desert some 1.5-2.0 m.y. ago, contemporaneously with the well-known occupation sites in the East African Rift. It would not be surprising if this were so during an early period of climatic amelioration, since tools of such a kind occur in localities on the Atlantic coast of Morocco (Biberson 1961) and in the eastern Atlas (Arambourg 1949; Arambourg & Balout 1952), in contexts indicating an antiquity that antedates the appearance of the Acheulian Industrial Complex. A dozen or more sites are recorded from the Sahara. The more convincing of these are the sites in the Wadi Draa in southern coastal Morocco (Biberson 1967:462), those in central Mauritania at Wadi Adeibe (Biberson 1967:466) and, in particular, those in the Saoura Valley in the northwest (Chavaillon 1964:68,122) where they are associated with a climate passing from semi-arid to sub-arid and a floristic composition dominated by Atlas forms but with some tropical genera (Beucher 1975:197-8). It was on the basis of a collection of flaked cobbles from the plateau surface at Reggan by the depression into which the Saoura drains, that the typology was established (Ramendo 1963) which is in general use in northwest Africa for these pre-Acheulian artifacts. But, until assemblages are found in primary, undisturbed context, claims for a Plio-Pleistocene age for these artifacts should be treated with caution since core/choppers of these forms can occur at almost any time in prehistoric as well as ethnographic contexts. No 'Oldowan' sites or assemblages have been reported from the valley of the Nile.

22.2.2 *The Acheulian Industrial Complex*

The earliest evidence for any widespread occupation of the desert by prehistoric groups belongs to the time when handaxes and cleavers of the later stage of the Acheulian Industrial Complex were being made and some 140 or more sites are known, mostly from the central and western Sahara. In the Nile Valley, northward from Kashm el Girba on the Blue Nile and Khartoum on the White Nile, fewer than 25 sites are recorded though it is clear that here, as within the desert, others will be found when further survey takes place. Most African prehistorians distinguish only two sub-divisions for the Acheulian – a Lower (or Earlier) and an Upper (or Later) facies – the latter showing generally more refinement in the form of the finished tools than does the former although certainly assemblages with better made, or poorly made, tools are also time transgressive.

Outside the Moroccan coast, most of the artifact assemblages for which an Earlier Acheulian age is claimed are, as yet, inadequately tied into the geomorphological evidence and no primary context sites of this time are known from either desert or Nile. Handaxes and other tools assigned to an Earlier Acheulian have been recorded in secondary context in terrace gravels and 'laterites' in the wadis of southern Morocco (Biberson 1967:467), in conglomerates in central Mauritania (Biberson 1967:467-8) and in the Saoura Valley where they were

associated with periods of increased humidity (Chavaillon 1964:123, 149). In Egypt, the handaxes from a site at the 'Abbasyyah quarries outside Cairo are claimed to represent an Earlier Acheulian stage (Huzzayin 1941:182-5). In the Nubian section of the Nile, some unstratified but homogeneous assemblages of bifaces from the surface and talus slopes of the plateau edge and inselbergs have, on typology and 'état physique', been classified as Lower and Middle Acheulian (Guichard & Guichard 1968:148-75). There is, however, a strong probability that these may be no more than workshop sites adjacent to the outcrops of raw material, in this instance, ferruginous quartzite, that forms the capping to the escarpment and which breaks away to form a mass of 'pre-worked' quarry detritus in the pediment that resulted as the scarps retreated.

The best evidence for earlier human occupation in the desert comes from the Saoura though, again, the artifacts are found only in geological context. As in many other Saharan valley systems, a number of terrace, lacustrine and dune features are preserved in the Saoura Valley and the geomorphological study of the sedimentation cycle, pollen and other evidence, permits reconstruction of the palaeo-climatic sequence. Where these sediments also contain certain artifact assemblages, the basis exists for knowing the environmental conditions under which their makers lived. This palaeo-climatic evidence shows the nature of the prehistoric settlement in the valley at times coincident with the humid phases and the transition from more humid to more arid conditions. During such times, surface water must have been relatively plentiful and some open lake areas and swamps, similar to the present-day 'sebkhas', filled parts of the depression. Eight such periods have been recognised between the late Pliocene and the early Holocene, with the earliest cultural manifestations appearing in the second of them (Chavaillon 1964:298-310). The Earlier Acheulian belongs in the end of the third and earlier part of the fourth 'more humid' phase. Pollen evidence suggests that the vegetation was dominantly one of Mediterranean type though semi- to sub-arid forms occur; tropical species are rare and are represented only by drier loving plants (Beucher 1975:263-4).

Characteristics of the Earlier Acheulian are a general economy of flaking in the production of the bifaces, resulting in wavy cutting edges; pointed handaxes with chisel-like ends and trihedral-sectioned, pointed and pick-like forms. From what has been said, it can be seen that some evidence exists to show that, during the earlier Pleistocene, groups of hominids making artifacts of 'Pre-Acheulian' and Earlier Acheulian form probably penetrated the desert, and, under favourable, sub-humid conditions, subsisted in some of the main drainage systems and depressions.

The Upper, or Later Acheulian, is very much better represented throughout the Sahara and along the plateau and piedmont bounding the valley of the Nile. Some localities are quarries for raw material; others are occupation sites which, from the freshness of the artifacts eroding from them, appear to have suffered little disturbance since they were abandoned, other than from the aeolian activity that is exposing them today. Very few of these sites have, however, been excavated and a knowledge of the contents of the assemblages depends usually on surface collections that are, all too often, selected.

Most of what can be said about the Lower Palaeolithic along the Nile comes

from 13 sites in Nubia near Wadi Halfa (Chmielewski 1968; Guichard & Guichard 1968). In addition, an Upper Acheulian associated with the oldest Nile silt deposits (of the Dandera Formation) has been reported (Wendorf & Schild 1975:128). These deposits reflect a river regimen similar to that of today with much water coming from the Ethiopian highlands. To the south, the site of Khor Abu Anga has yielded an evolving culture sequence beginning with an Upper Acheulian (Arkell 1949b).

In Nubia, the Acheulian occurs in the lower portion of the Older Pediments that are probably in part contemporary with early and, as yet, poorly known phases of Nile silt aggradation. All the pediment sites are workshops near quarries and they contain numbers of evolved handaxes – *ovate, cordiform* and finely pointed examples predominating – together with crude forms made on slabs of ferruginous quartzite. There are also many discs and choppers and some flake tools, mainly scrapers. Cleaver forms are conspicuous by their rarity. The large, proto-Levallois cores and flakes that are a feature of some of the Upper Acheulian assemblages in the Horn, East and Northwest Africa, are equally scarce or absent, though Levallois elements have been reported with the final phase. One interesting excavated site (c. 40 x 20 m in area and 5 cm thick) in wadi sediments adjacent to an outcrop of Nubian Sandstone (Arkin 8), consists of a thick concentration of artifacts and debitage in which eight subconcentrations were clearly distinguishable. Each of these was 6-8 m in diameter and culminated in a pile of artifacts in the centre. One of these subconcentrations, lying in a shallow depression, had relatively sharp limits and what appeared to be a semi-circular 'wall' of sandstone blocks suggesting the base of a possible windbreak. The whole area can be seen as a camp and workshop site which may have seen several periods of re-occupation (Chmielewski 1968:115-34). Quartz cobbles available in the wadi were preferred here over quartzite for tool-making. Unfortunately, no faunal remains have been found with any of these Upper Acheulian sites. The excavator suggests that the community occupying this site was probably a small one, judging from the size of the concentrations which are presumed to represent individual working areas.

When the style and form of the Later Acheulian assemblages in the Upper Nile are compared with those from other parts of the continent, it is apparent that they can be grouped into a regional facies, the pointed handaxes being, perhaps, earlier and the ovate forms with choppers a later expression. The northern limit of this 'facies' is not known but it does not extend westward into the Sahara and is present at least as far south as Khartoum. The suggestion has been made that it may extend eastwards to the Red Sea hills and the possibility exists that it could also extend onto the northern part of the Ethiopian plateau since the assemblage from the Dabat Plateau, near Gondar (Clark 1945), is characterised by comparable forms of handaxe. Whether this 'Upper Nile facies' covers so extensive an area as has been suggested, still remains to be convincingly demonstrated and, for the present, it can better be seen, perhaps, as a product of the ecological and cultural conditions pertaining along the upper reaches of the main river.

In the oases of the 'Western Desert' of Egypt, the Upper Acheulian is associated with springs. In the floor of the Kharga Depression, 210 km west of the

Nile, mound springs fed by artesian water were a focus for Acheulian activity. Here, concentrated in the 'eye' of one spring (K10) (Caton Thompson 1952:60-72), were found many pointed handaxes in chert, often with unworked butts. Curiously, there were almost no other associated tools or waste. It is clear that these bifaces had not been made at the site and that they must have been tools associated with one particular set of activities.

Very similar fossil spring vents occur in the desert to the south of Dakhla Oasis and some 400 km west of the Nile (Schild & Wendorf 1977:17-100). At three localities, five excavated vents, each forming a rough inverted cone some 2.5 m deep, produced as many as 7 000 artifacts coming from the 'eye' itself and the immediate surrounds. Primary flaking debris associated with unspecialised cores forms an important part of the assemblages, giving rise to a relatively small proportion of naturally backed knives and scrapers, in particular, denticulated forms. However, as at Kharga, by far the commonest shaped tool was the handaxe, mostly pointed examples with unworked butts, and backed bifaces (knives or Prodnik forms). That these tools were made elsewhere and brought into the sites is shown by the relative scarcity of handaxe trimming flakes. At least two different kinds of handaxe are represented, suggesting different uses. Unfortunately, however, the disturbed situation of the surface artifacts, the unsuitability of those from the vents themselves for edge-wear study and the lack of preserved faunal remains, make it impossible to advance any suggestions as to the functional nature of these tools. The excavators suggest that the localities may represent an occupation round a single spring pool and that this covered a considerable period of time.

To the south again, numerous Acheulian sites are recorded from the plateau flanking the depressions of Bir Sahara and Bir Terfawi (Schild & Wendorf 1975: 94-8). At the southern rim of the former, mound spring sites were located associated with Acheulian from the edges of spring pools; faunal material representing a medium to large ruminant, an equid (probably the wild ass) and ostrich eggshell were recovered from one site. The raw material used here was quartzite and, again, the greater proportion of tools are finely made handaxes; the plan form, however, is triangular and cordiform and the butts are thinned. These were found with flaking waste and a high proportion of this represents handaxe trimming flakes. There were also one or two side scrapers and five spheroids. This assemblage is very different from those from Kharga and Dakhla and the presence of rare, specialised (Levallois) cores suggests that it may represent a very late form of the Acheulian. The question might, therefore, be asked whether the similarities and differences exhibited by these Western Desert assemblages might not be explained as the products of two different populations having a common life-style but using different raw materials. Such might explain the observed differences in style and form of the handaxes which may have been further emphasised by the element of time.

Moving westward, the Upper Acheulian sites of the Central and Western Sahara appear to have more in common with each other and with those from western Africa than they do with assemblages from the Nile and the Western Desert. These last resemble more assemblages from the Maghreb where chert is the commonest raw material. In the central and western parts of the desert,

coarser-grained, hard materials were used, the commonest of which are metamorphosed rocks, especially quartzites and gneiss and various lavas (rhyolites and trachytes). Some 200 sites are recorded (Clark 1967: maps 12, 13), showing the Acheulian to have been widespread but very few of the sites have been excavated. These occurrences are mainly associated with fine-grained sediments laid down by former lakes and swamps in the depressions or with the older alluvial terraces and fan deposits connected with the drainage systems coming from the high massifs and other interior plateaux, the Saharan Atlas and the west coast drainage. Few Acheulian sites are known south of a line drawn through the southern Sahara, between 10°S in the west and 15°S in the east, a line that passes through Aouker, Hodh, Arouane, the Aïr, Bilma, Ennedi and so to Darfur (Figure 22.1). In the north, the Acheulian stretches to the Atlantic and Mediterranean coasts.

At some of these localities, such as those in the Mauritanian Adrar at El Beyed, the bifaces occur in their thousands which suggests that, in such favourable localities, the population responsible for them must have been a relatively stable one over a long period of time. With some of these Acheulian accumulations, faunas are present in sealed deposits although the precise relationships are generally uncertain and it is not known whether these faunal remains represent food bones on a living floor; nevertheless, they show the general nature of the animal communities available as food sources. At the Erg Tihodaine (Arambourg & Balout 1955), between the Hoggar and Tassili massifs, Upper Acheulian handaxes, cleavers and discoids were found eroding from old swamp clays filling a large depression. These were associated with a fauna consisting of an extinct elephant (*Elephas reckii*), zebra, the extinct giant buffalo (*Pelorovis antiquus*), aurochs (*Bos primigenius*), two kinds of hartebeeste and the wildebeeste (*Taurotragus derbyanus*), oryx, Dorcas gazelle, Barbary sheep and warthog (Camps 1974:42-5). This faunal composition indicates a habitat with much grassland, some woodland, permanent water sources in the more favourable parts and, not far away, more arid steppe and stony hills where the gazelle and Barbary sheep may more commonly be expected to have occurred. The fauna is a mixture of tropical savanna (Ethiopian) and temperate (Holoarctic) communities and gives an indication of the directions from which the Sahara was repopulated during periods of climatic amelioration.

Cleavers now form a significant part of the tool-kit and, although still relatively rare at the Central Saharan sites, they increase rapidly in the northern and western parts of the desert where a specialised method of prepared core was developed to produce the large flakes from which the bifaces were made. This form of the Levallois method, named Tabelbalat/Tachengit technology from two localities – Tabelbalat, west of the Saoura and Tachengit in the Tidikelt to the southeast – produced a 'pre-form' flake, shaped on the core before removal, so that little or no further modification was required to make an efficient tool. In the northwestern Sahara, this method is widespread giving rise to a number of different cleaver forms and various types of pointed and ovate handaxes. The cleavers generally preserve evidence of a thick, prepared striking platform and a proportion of the handaxes, like the cleavers, also preserve a considerable area of the main release surface of the large flakes from which they were made.

Very few quantitative studies of the central and western Saharan Acheulian are available. One such is that from the Erg Tihodaine where a metrical study on a group of 30 handaxes, randomly selected from 300, shows the predominant shapes to be cordiform and ovate (Oussedik 1972). This site, with its cleaver complement, is said to resemble those from Tabelbalat/Tachengit but no quantitative studies are as yet available to confirm this. Erg Tihodaine is some 900 km southeast of the Saoura sites and a further 200 from Tabelbalat. Biface form and technique suggest that a general affinity may exist between these sites but whether this has any significance beyond the adoption of a common technique for dealing with similar raw materials remains to be shown. Such technical and stylistic affinities, spread over such a vast region covering thousands of square kilometres and including the Eastern and Western Great Ergs, might also perhaps be an indication of the general direction of movement of related human groups repopulating the desert from the Maghreb in the wake of decreasing desiccation.

Another such study relates to Acheulian assemblages from round the edges of a swampy and lacustrine basin at Adrar Bous in the northern part of the Ténéré Desert. The three Acheulian occupation sites studied here were situated round the margins of a water-filled depression at the southern end of the massif. The artifacts are eroding from fluvio-lacustrine, silty clays. A variety of local raw materials was used – vitric-tuff, hornfels, rhyolite and granite. Again, the assemblages are characterised by a large percentage of bifaces – mostly handaxes, together with 12% of cleavers. In addition, discoids, picks and spheroids occurred together with a small number (12) of backed handaxes or knives of the form found at the spring sites in the Western Desert and in East Africa (Clark, Williams & Smith 1973).

Ovates and amygdaloids are the commonest kinds of handaxes with a smaller percentage of sub-triangular forms. The cleavers are U-shaped with carefully retouched butts and are always longer than the handaxes. There is appreciably less debitage than would have been the case if the bifaces had been made on the site and finds in the central massif show that they were manufactured there and carried down to the lakeside.

The number of associated flake tools – mostly side scrapers – is small and the cores and flaking waste (38% of the assemblage at one site) show them to have been made at the site itself. The bifaces were not made by the Tabelbalat/Tachengit method but small Levallois-type cores for the removal of small flakes are weakly represented. The quantitative analysis of the bifaces (Dietler & Reilly, n.d.) shows that there is no close resemblance with any of the other north African assemblages for which quantitative data exist. The handaxes bear some general resemblance to those from the Western Desert sites which, however, have no cleavers. There is also a general resemblance in components and types with the Acheulian from Borku (Arkell 1964) and it may be that later work will show assemblages in the Ténéré and Chad basin to be sufficiently homogeneous as to suggest the existence of a 'Ténérian or Chadian facies' of the Acheulian as is the case with the Neolithic there. Acheulian bifaces have been found in the Tibesti mountains and in the desert to the east and south. Lanceolate and ovate handaxes in quartzite occur by the well at Sarra, 300 km

south of Kufra Oasis and west of Tibesti. Again, at sites in the region of the Wanyanga Lakes in Borku between Tibesti and Ennedi, well-made quartzite handaxes of lanceolate, ovate and sub-triangular forms are associated with a few cleavers in terrace sediments adjacent to an outcrop and possibly represent a workshop site. At the little Wanyanga Lake, a number of small cordiform, ovate and sub-triangular handaxes from the 'reg' may represent an Evolved Acheulian transitional between the Lower and Middle Palaeolithic.

Further north and west, the Later Acheulian is characterised by the manufacture of large, relatively thin, end- and side-struck flakes from cores prepared by the Levallois method. Both the typical, radially prepared, proto-Levallois 'tortoise' form and the Tabelbalat/Tachengit pre-form cores in particular characterise this northwest Saharan 'facies' of the Upper Acheulian. In the Ougarta Mountains and the Saoura Valley, the Upper and Final Acheulian is well represented but the assemblages appear to be mostly in secondary context. The skill behind the Tabelbalat/Tachengit method and a high degree of refinement of the bifaces characterise this tradition. The assemblages are contemporary with the decline of a humid period and come from sites adjacent to the streams draining from the Ougarta Mountains, from re-entrants in the 'ergs' and from the floors of the depression in the Saoura between Beni Abbas and Reggan. In particular, they relate to the water and plant sources to be found round the small lakes in the valley bottoms. Bifaces made from blocks and large natural flakes from scree slopes resemble those from Adrar Bous in the generally small, pointed forms of the handaxes. Handaxes made by the Tabelbalat/Tachengit technique show varying degrees of retouch on the flake surface and are often cordiform and almond-shaped. Cleavers may vary in form but those with U-shaped butts are characteristic. Together with the bifaces are found a relatively small number of side- and end-scrapers on flakes, denticulate pieces and polyhedrons (Alimen 1956). One partly excavated but not yet analysed site (Anchal) in the Ougarta Mountains, was a workshop for bifaces as well as a living site. The finished bifaces are associated with many unfinished or broken examples, many hammerstones and much debitage from handaxe manufacture (Chavaillon 1964:149-52). This industry is said to resemble that from the Erg Tihodaine, some 800 km to the southeast, though whether anything more than general resemblance is involved remains to be shown. The Anchal Acheulian is characterised by finely-made, flat and pointed lanceolate handaxes and cleavers and, in this, it differs from the assemblage from Zaouia el Kebira, 90 km east in the Saoura Valley, differentiated by trihedral and 'pick'-like forms and side-scrapers on flakes. Some 12 km north again (Beni Iklerf), the same horizon has produced two associations – one in which handaxes strongly predominate and another, 200-300 m distant, with an abundance of cleavers. Again, in the Wadi Guir, one of the northern feeders of the Saoura system, some 130 km to the north of these last sites, the Acheulian bifaces were made from large cobbles occurring in abundance in the wadi terraces, instead of from natural flakes from screes as were used in the Ougarta Mountains, and this resulted in other stylistic variations.

In the western Sahara, Acheulian assemblages are known from the terraces of former rivers, the stony plateaux ('regs'), old lake sediments and quarry/

workshop sites. The best known of these localities are the wadi sites in Morocco and those in the Mauritanian Adrar. In both these regions, the Later Acheulian is characterised by the use of the Levallois method and by the general use of soft hammer retouch flaking, giving rise to the many very flat, cordiform and ovate handaxes and cleavers and an increased frequency of small flake tools. In the Moroccan Sahara, the assemblages have not been found in a stratified context but, in the Adrar, a stratified sequence has been observed associated with the 'middle terrace' of the wadis and with sandy, lacustrine sediments in shallow depressions on the edges of sandy 'ergs' such as at Aderg, or in the troughs between the dunes of the Maqteir. Again, the relative paucity of flaking waste shows that the bifaces were carried onto the sites which, with their range of smaller tools, polyhedrons, etc. can be seen as living areas rather than as workshops. The quarry sites (e.g. Tazazmout es Srkir and El Beyed) are associated with huge quantities of angular blades and natural flakes of quartzite which, together with the debitage from human flaking, form the pediment of the scarp overlooking the Baten depression. These localities have produced many large ovate and lanceolate handaxes made on very large quartzite flakes and, here also, the large, specialist Levallois cores are met with (Biberson 1967:464-70).

Stylistic variation in contemporary biface assemblages may in time, following quantitative study, provide an indication of possible regional groupings but, first, it is also necessary to identify and make allowance for the range of variation that different activities can bring about in the artifact sets. The evidence for the Middle Pleistocene so far suggests that, of the different assemblage patterns from east and southern Africa, variations on the Acheulian and Developed Oldowan traditions, those most frequently met with in the Sahara and Nile are, on the one hand, those in which the biface categories are by far the commonest form of shaped tool and, on the other, those in which bifaces and small tools are more or less equally abundant. The chopper/small tool facies with few or no bifaces, well known in sub-Saharan Africa as the Developed Oldowan tradition, is not yet reported from the Sahara in this time range, so far as this writer is aware. However, in the Nile Valley, one assemblage from Nubia (Arkin 8) has more or less equal percentages of bifaces and 'chopper' elements (Chmielewski 1968:124-5).

In the vicinity of Jebel Marra in Darfur, Developed Oldowan/Acheulian core/choppers, flakes and polyhedrals have been found in gravel stratified beneath ash deposits from the Jebel Marra volcano; also in contexts associated with leaf impressions of oil palm and *Combretum* and, at another locality (Kebkabiya), with diatomite in an old lake basin (Williams et al., this volume). The apparent absence of the Developed Oldowan tradition from the desert may, therefore, be more inferred than real and, because of the general lack of stratigraphy or other means of dating, it is possible that some of those believed earlier assemblages, designated as Oldowan or 'Pre-Acheulian', might perhaps turn out to be this missing element from the Middle Pleistocene in the Sahara.

What this preponderance of biface forms means in terms of behaviour cannot be determined until something is known about the function of these earliest 'standardised' tools – from edgewear studies which may also, perhaps, help to

explain why they are sometimes found in considerable concentrations. Unmodified flakes, scraper forms and some heavier duty equipment (core/choppers) appear more often to be the tool-kit associated with butchery in sub-Saharan Africa but, while the light duty equipment (flake knives and scrapers) is also present at the Sahara and Nile sites, it does not dominate these as it does some of the east and south African sites. The great range of environments that the makers of the Later Acheulian Industrial Complex are known to have occupied (almost all habitats except the glaciated areas to the north and the lowland and montane forests in the tropics) indicates that these groups were highly adaptable. However, the relatively limited range of major tool categories suggests that the methods of exploitation of resources were, in general, similar and unspecialised, whether the people were living in the temperate forests of Europe or the range of habitats offered by the African and Asian tropical savannas. Biological factors may have imposed these limitations on *Homo erectus,* the hominid responsible for this relative uniformity in the cultural traditions of the late Lower and Middle Pleistocene. This does not, of course, preclude the recognition of stylistic variability in the handaxe and cleaver forms. Although this may have been induced in the first instance by the size, form and texture of the raw material used, it can probably, nonetheless, provide, through the technological and idiosyncratic preferences that are manifest in this lithic component, some indication of the area of country over which a population responsible for such a 'local tradition' once ranged.

Theoretically, therefore, prehistoric assemblages should lend themselves to interpretation at several different levels – at that of the Industrial Complex, that of the regional Industry, that of the local group and, finally, at the level of the individual which should be possible by comparing the flaking waste and retouched tools from two or more contemporaneous workshop concentrations.

At the broadest level, we have already seen how the Acheulian Industrial Complex is spread generally throughout the Sahara and Nile. But we are in difficulty when we try to identify regional facies or 'industries', since few quantitative studies exist and insufficient survey has been done to enable the boundaries of such possible entities to be drawn. The lithic assemblages suggest, on the basis of technique, typology and style, that in time it may be possible to identify a southern 'Nilotic' facies in a region that includes that part of the main river from Nubia to Khartoum. Another possible regional facies is that of which the Adrar Bous and Borku assemblages are characteristic; another that using the Tabelat/Tachengit method of specialised flake production, extending from southern Morocco to the Saoura and, perhaps, to the Erg Tihodaine; the Western Sahara might contribute yet another facies (Figure 22.1). Even if these facies are shown to have reality, they may reflect no more than the preferred ways of using different kinds of raw materials. More successful, perhaps, will be attempts to define the boundaries of smaller entities which might be seen as the products of single populations in limited territories. Indeed, it is on the successful identification of numbers of these units that the reality of any broader, regional facies/industries will be established.

From the little substantive evidence on the behaviour of the populations responsible for the Later Acheulian assemblages, it can be shown that they generally belong to a time of more humid conditions in the desert when the hominid groups were able to spread widely in the Sahara occupying the water courses, penetrating the Sand Seas (ergs), and camping round the borders of small lakes and swamps that filled depressions between the dunes. Although the climate never seems to have become more than semi-arid, the grass and tree cover supported a range of Ethiopian and Holoarctic large mammals, including elephant, and also large grazing animals which must have provided the main source of protein for these early hunter/gatherers.

Home ranges of the early human populations in the Sahara can be expected to have varied, as did those of the gregarious game animals, whose range would have depended on the seasonal availability of plant food and water. During the dry season, both game and man can be expected to have stayed near water but, whenever temporary water sources and water-providing plant foods became more widely distributed after rain, animals and humans would have moved out into a much larger area – onto the regs and into the ergs, abandoning altogether their dry season range. Such movements with the coming of rain can also be expected to have taken place rapidly. In East Africa, elephants are recorded as moving 80 km in eight days to an area that had recently received rain and it would not be a difficult matter for a hunting/gathering group, with little in the way of personal gear, no stock to care for, and restricted only by the pace of the young, to have followed game movements of this kind (Moss 1975:31). The mean home range of elephants in the Tsavo National Park in Kenya is a little over 1 555 km^2. Much of Tsavo and Amboseli National Parks receive between 254 and 305 mm of rain a year but, during a 'humid' period in the Sahara the most favourable rainfall figure is not likely to have been higher than the lower of those quoted for Kenya (i.e. 254 mm), so that the ranges of the large gregarious game animals and, it may be postulated, of the prehistoric hominids also, can be expected to have been comparably more extensive in the Sahara than those of hunter/gatherers living in the richer tropical environments of East Africa.

If the Acheulian hunter/gatherers followed seasonal movements of the large gregarious game animals – elephants, equids, bovids – then they could have moved 200 or 300 km in the course of a year, though the average range was probably much less. So far as the Nile is concerned, the model envisaged is of individual groups, each exploiting a section of the main river as well as the grassland and desert of the outer plain, pediment and plateau edges. Such territories at that time may even have been relatively restricted in area. Whether, in the Western Desert, the oasis depressions each supported more than one group is unknown though the spring vents and mound springs previously mentioned can probably be identified as core areas in the territories of free-ranging hominid groups. The different composition of the assemblages and the 90 km separating the two Saoura sites from that at Anchal, might be interpreted as indicating that these assemblages were made by two different hominid groups. On the other hand, the distance is not too great to suggest that they could be the product of a single group which, during the rains, moved out into the ergs and to the Ougarta Mountains where the raw material quarries were and, as the dry season advanced, fell back on the permanent water sources in the valley of the Saoura.

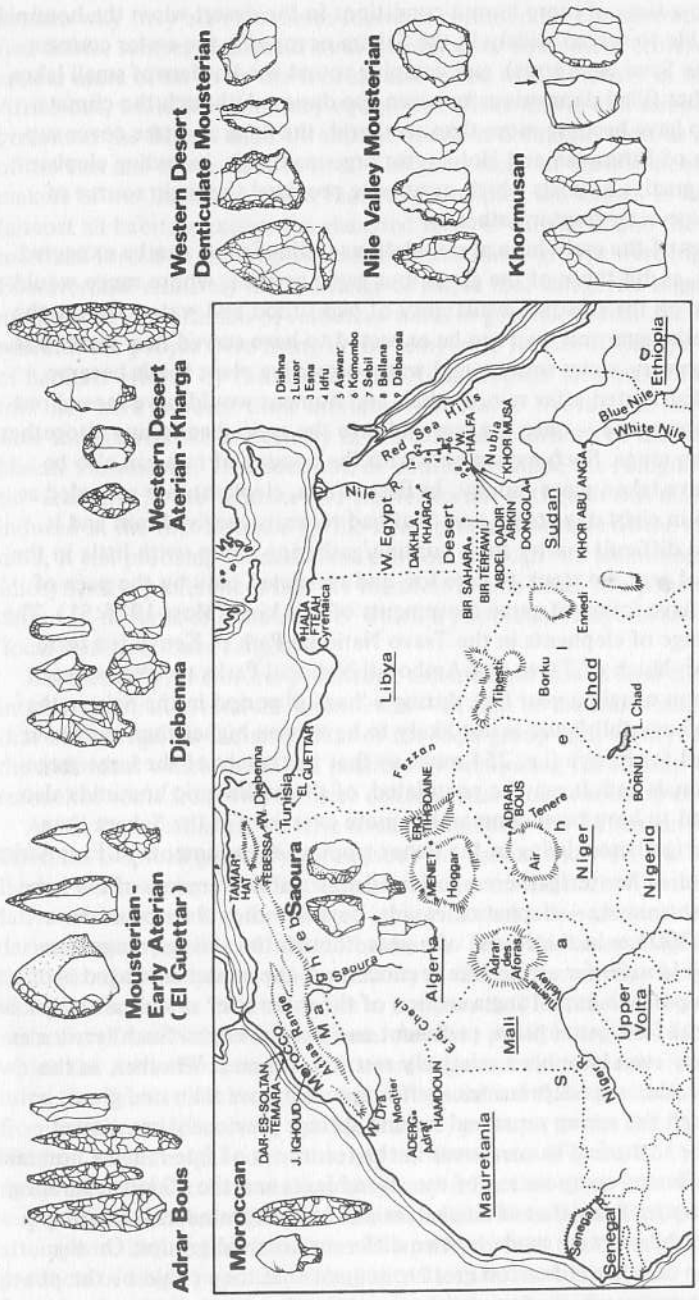


Figure 22.3 Middle Palaeolithic (Mousterian and Aterian) sites and localities, some regional artifact forms and possible extent of the Aterian tradition.

Answers to these and similar questions must await detailed regional surveys, excavations of primary context sites and quantitative studies still to be undertaken. Already, however, at this early time, regional differences between the Upper Acheulian assemblages in the Nile and the desert indicate that, while the life style was probably similar, the hominid populations were sufficiently adapted to their habitats and sufficiently isolated from each other to have developed distinctive ways of making bifaces and standardised, preferred styles which, over time, can be seen to form regional traditions.

22.2.3 *The Middle Palaeolithic in the desert*

The end of the Middle Pleistocene is coincidental with an arid period during which sands blocked the wadis and covered the fluvio-lacustrine sediments with which the artifacts of the Acheulian Industrial Complex are associated (Chavaillon 1964:187-8; Clark et al. 1973). The springs in the Western Desert also dried up (Schild & Wendorf 1975:89; 1977:14-17) and it is clear that the human populations were forced to vacate most of the localities they had occupied in the desert during the previous humid period. However, certain assemblages with numbers of small cordiform and triangular handaxes, some small cleavers and a quantity of light duty tools made on primary flakes produced by the Levallois method are known from a few sites in the Sahara as well as in the Maghreb where, in coastal Morocco, they date to before the time of the Last Interglacial transgression beach (Ouljian). Such assemblages come from sites in southern Morocco, the Mauritanian Adrar and on the edge of the erg El Maqteir (Biberson 1967:470-1). They are also known from the Libyan desert east of Tibesti (Arkell 1964) and, typologically, they resemble the Mousterian of Acheulian Tradition from Europe. They cannot be satisfactorily dated but they may be later than the Acheulian and earlier than or contemporary with the facies of the Nubian Mousterian from the Nile near Wadi Halfa, which is distinguished by the presence of small bifaces of Acheulian type. If man was still able to subsist in certain 'retreat areas' in the Sahara, these must have been few and far between and the overall population density drastically reduced. However, with the return of more humid conditions during the Last Interglacial and the earlier part of the Last Glacial, groups were able to spread out once more and repopulate many of the localities occupied by the makers of the Acheulian tradition. Where assemblages of the two traditions are found in stratified context, as in the Saoura (Chavaillon 1964:195-6), at Erg Tihodaine (Arambourg & Balout 1955) or Adrar Bous (Clark et al. 1973:264-8), they are separated by a geological break during which arid interval sterile deposits of windblown sands or talus accumulated.

A greater number of localities in the Sahara have yielded Middle Palaeolithic assemblages than are known for the Acheulian (Figure 22.3). These can be grouped into two major 'provinces' – those in the eastern parts of the desert and those from the centre and west. In both cases, the basic technique for the manufacture of the light duty tools that characterise them, is by the use of the Levallois and disc core methods. The first indication of this dichotomy makes its appearance, as we have seen, in the Upper Acheulian but it becomes much

more apparent with the Middle Palaeolithic (or, south of the Sahara – the Middle Stone Age). Most, or all, of the Middle Palaeolithic can now be seen to lie at the lower limit, or beyond the range of the radiocarbon dating method and today it is now more usually thought to date to between c. 100 000 and c. 40 000 years ago although it is possible that in some regions, for example the Upper Nile Valley, it may have continued for a while longer. The climate in the desert at this time was again more humid, temperatures were cooler, evaporation rates were reduced by the increased cloud cover and ground water again became relatively plentiful in the wadi systems and fossil lake basins throughout the desert (see this volume: Chapters 5 and 6). Vegetation patterns are best known from the northwest, the central region and the Lake Chad basin. Nearer the Mediterranean coast, colder and drier conditions coincided with periods of aridity within the lower altitude regions of the desert and in West Africa generally. In the mountain massifs, on the other hand, the lower evaporation rate allowed rainfall to run off the mountains to maintain a more regular and extensive flow of water in the wadis that have their source in the mountains. During the time of the Last Glaciation in Europe (±75 000-10 000 B.P.), the pattern that emerges for the Sahara is one of drier areas between the stream courses but wetter river valleys. No close correlation between glacial conditions in Eurasia and wetter and drier fluctuations in the tropics is possible at this stage, however, except that, at the time of maximum cold in Europe, the conditions in low latitudes were those of extreme dryness (Van Campo 1976).

In the northern Sahara the autochthonous vegetation is composed chiefly of temperate, although sub-arid, Mediterranean forms (e.g. *Artemesia* and other Umbelliferae) also occur. There are also some semi-arid Mediterranean species (*Alnus, Ulmus*) growing close to the water in the depressions while tropical forms from the south are confined to those that were already adapted to desertic conditions, such as *Acacia raddiana, Combretum* sp. and *Cassia* sp. (Beucher 1975:264-9).

In the mountain massifs of the central Sahara, Mediterranean evergreen trees (cypress, *Olea, Quercus,* etc.) became re-established and, if it is permitted to extrapolate from the Holocene evidence from the Chad basin, Sahelian and Sudano-Guinean vegetation spread northwards, the former being more important at the beginning and end of the period of high lake transgression and the latter, together with mountain elements from Tibesti, becoming important during the middle period of the transgression, due to changing wind and rain systems (Maley 1977).

Taking an overview of the Middle Palaeolithic in North Africa, it can be seen to be represented by two or more facies of the Mousterian – as this is known in Europe – or the Levallois-Mousterian, as it is termed in the Middle East. In the Nile Valley, certain local characteristics make it possible to identify regional Mousterian variants and the same is true of Cyrenaica and the Western Desert of Egypt. In the Maghreb, however, the situation is somewhat different. While the Mousterian in the Nile and Cyrenaica seems to have persisted without any very significant changes up to its replacement by Upper Palaeolithic technology, in the Maghreb, a Mousterian stage and facies appear to have been replaced relatively early in the later Pleistocene by a complex/tradition known as the Aterian. Only a few sites of the Maghreb Mousterian are known but they provide sufficient reason to believe in its existence. It is characterised by an industry approximating to the typical Mousterian of Europe with many side-scrapers, points, denticulate pieces, intentionally backed flakes and a Levallois element. The limited distribution of this 'Mousterian' tradition – mostly in Morocco and Algeria – by comparison with the number of sites yielding Aterian artifacts, suggests that the beginning of the Last Glacial may have seen a significant reduction in population in the plateau regions of the Maghreb. During the Würm the High Atlas became glaciated, vegetation belts were lowered by more than 1 000 m and grassland replaced forest over large areas of the plateau. For much of this time the lowered temperatures and increased windiness and aridity may have made the plateau a relatively unfavourable region for hunter/gatherer communities (Ferring 1975), which might be expected to have moved down to the warmer sea coasts to localities on the narrow coastal plains now covered by the sea.

The Aterian is generally believed to have its origin in the Mousterian of the Maghreb and this appears to be borne out by the relatively long, stratified sequences at some sites (e.g. in Morocco) and by the typological and technical developments shown by the assemblages (Camps 1974:23-36). Like the Mousterian, the Aterian makes use of the Levallois and disc core techniques and the same kinds of flakes and tools found with the Mousterian occur also with the Aterian. In addition, however, and in particular with the later assemblages, there is an important 'Upper Palaeolithic' component in the Aterian consisting of end-scrapers, borers, burins, etc. To this there is added the artifact form that chiefly characterises the Aterian, namely the tanged tool. Often grouped under the term 'Aterian point', these implements may be classified as points, convergent, end- and side-scrapers and various other tool forms and it is clear that the tang is a specialised, local invention to facilitate hafting the stone cutting/scraping parts of a tool in the most efficient manner. Incidentally, it is the earliest unequivocal evidence for simple compound tools in which more than one material is used.

The Aterian is found spread throughout the Sahara north of the 15°N parallel, extending from the Atlantic coast in the west to the oases of the Western Desert though not, it would seem, into the valley of the Nile. The Aterian has been described as a desert-orientated adaptation and there is no doubt that it was very successful in spreading quickly to many of the lower altitude parts of the desert. Here it was concentrated on open sites along the stream courses and round the many lacustrine and swampy depressions in what now is often completely waterless desert. The inference is that the Aterian evolved in the highlands and spread to the desert and, while the evidence suggests that this was probably so, the few radiocarbon dates available show no significant differences from those coming from the Maghreb. The Aterian abounds in southern Morocco in what was formerly Spanish Morocco, in the Algerian Sahara (e.g. the Saoura Valley, Erg Chech, etc.); in the Tilemsi Valley; in Adrar des Iforas; in the Ténéré; in Borku and the Chad basin; in the Fezzan; in the Libyan 'Sand Sea' and in the oases of the Western Desert of Egypt (Clark 1967: Map 16).

As with the Acheulian, it is possible to see in North Africa several regional forms of the Aterian though these now have greater clarity. In the desert at this

time major 'culture areas' can be distinguished. The Aterian from the northwest echoes the earlier Acheulian resemblances noted between the Tebessa region of eastern Algeria, the Saoura and the Erg Tihodaine and the Hoggar (e.g. Meniet). Sites to the north and west of the massif show characteristics similar to those of the Upper Aterian, the 'Djebenna facies' of eastern Algeria, which has relatively high values of tanged forms and denticulate pieces, together with end-scrapers, relatively few side-scrapers and no bifacial lanceolate points.

In the southern and eastern parts of the Sahara a different facies is present. Here the unifacial, tanged forms become less common and, in their place, are bifacially worked and tanged tools, together with finely-made, lanceolate and leaf-shaped bifacial points. End-scraper forms, borers and burins predominate over side-scraper forms and there is often a significant blade element present, produced both by the Levallois method and by direct percussion.

These two huge, regionally distinguished, 'traditions' may, perhaps, reflect relationships with populations respectively to the north and south. In the northwestern Sahara these relationships would have been with the populations in the Maghreb from where the Aterian is believed to have come and, indeed, it may be suggested that, with the onset of the main Glacial, increasingly inhospitable conditions in the Atlas may have driven some of the groups there to spread into the desert. Relationships between the Aterian groups in the southern and eastern Sahara, on the other hand, were probably with populations in the northern savannas of Equatoria (Cameroon and Central African Republic) and West Africa, where the Lupemban Industrial Complex is characterised by many different forms of lanceolate and foliate point and where bifacial, tanged points appear in the final stage of the Complex.

When systematic ground survey and quantitative studies make it possible to use statistical and precise qualitative data to identify more localised expressions of the Aterian in the desert, we may be able to say something about the distributional range of smaller, kin-related groups. The differences in the assemblage composition from sites in such localities as those in the Saoura Valley, or in eastern Mauritania, where there are many tanged points, double-pointed bifacial forms and small handaxes, at Hamdoun where tanged forms are rare, in the Aderg where bifacial points almost completely replace tanged forms (Hugot 1967:540-1), or in the Ténéré where bifacial lanceolates and large, bifacial, leaf-shaped points with tangs, small bifaces and stone balls are characteristic (Hugot 1962:149-78), may in time show these to be regional facies but, for the present, without precise quantitative publication and the means of dating the components, it is not possible to do more than infer their possible existence.

One interesting development now generally in evidence by Middle Palaeolithic times, is the extent to which raw material was more carefully selected. Often the most homogeneous rocks – cherts, flint, vitric-tuff, fine quartzite, etc. – were only available in smaller sized pieces than were normally required for making a biface. Now, however, since the trimmed stone artifacts could be mounted as the working parts of compound tools, it was possible to be more selective of raw material as preferences dictated. This is well seen at Adrar Bous in the Ténéré where, although local vitric-tuff and hornfels were also used, a significant number of the trimmed tools were made from a fine-grained, silicified vitric-tuff that was imported from at least as far as 60 km away; this also tells us something about group movement.

Adrar Bous, incidentally, is the only site in the central or western Sahara which has produced stratified evidence for what may be a 'Mousterian facies' underlying the Aterian. It is characterised by large Levallois and non-Levallois flakes and blades with a minimum of retouch. Other surface finds of what have been called 'mousteroide' assemblages are known from the southwestern Sahara, in Mauritania and Senegal, but they have been viewed as representing rather an extension of a West African 'Middle Stone Age' into the desert than as assemblages that might antedate the Aterian (Hugot 1967:546).

In Cyrenaica, a Levallois-Mousterian makes its appearance c. 80 000 years ago and continues until 40 000 years ago when it is replaced abruptly by the Upper Palaeolithic (McBurney 1967:105-34). As in the Maghreb (Jebel Ighoud), the Levallois-Mousterian of Cyrenaica is associated with a Neanderthal population (Ennouchi 1962; Balout 1965). The physical type associated with the Aterian Compex is still very poorly known but recent finds from Morocco (Dar-es-Soltan and Temara) suggest that the Upper Aterian there was made by an early form of the rugged Mechta-Afalou race that populated the Maghreb in late Quaternary times (Ferembach 1976a, b). It seems likely, therefore, that it was during the later part of the Middle Palaeolithic that modern man replaced the Neanderthal population in northern Africa, just as was the case with the 'Rhodesioid' populations in southern Africa.

The Aterian seems never to have penetrated to Cyrenaica though its influence was certainly felt there and it is also rare in Tripolitania. Since it is very prolific in the Fezzan and in the Libyan 'Sand Sea', probably the northern limit of the Sahara was also the northern limit of the Aterian in Libya.

In the Western Desert of Egypt the Mousterian is well represented but is later replaced by the Aterian. The Mousterian here has been dated and is relatively well known (Schild & Wendorf 1975:73-4, 98-106). It occurs in lacustrine and shore deposits in the depressions fed by springs at Bir Sahara and Bir Terfawi and its appearance there follows a period of aridity during which the springs that had attracted Acheulian man, dried up. Five successive Mousterian horizons were recognised and the sites are all large, homogeneous occupation areas with considerable numbers of artifacts. The assemblages show a heavy preponderance of denticulate and notched forms which places them clearly in the Denticulate Mousterian tradition, although the Typical Mousterian forms also present at one site may have functional implications. It is of interest that this emphasis on denticulate forms associated with the Western Desert prehistoric populations extends right into the Neolithic. The Mousterian shared the depressions with white rhinoceros, camel, wild ass and giant buffalo, the remains of which are represented in food waste believed to have been thrown into the edge of the lake from a butchery site, probably well before 40 000 years ago.

At these sites the Aterian, in the second phase of lacustrine sediments, is separated from the Mousterian by a further period of aridity, shown by dune sands. At Bir Terfawi three horizons have yielded Aterian tools, one of these associated with a large concentration of butchered animal bones suggesting that the population killed and cut up the animals in the shallow waters of the lake. Besides the animals noted above, there are also present large and small

gazelles, warthog, jackal and ostrich; the retouched tools associated with this horizon are mostly large, denticulate forms. A date for the site is c. 44 000 B.P. The Aterian from these sites has many denticulate pieces and some 'typical' Mousterian forms, together with bifacial foliates and rare tanged tools.

Nearer the Nile, the oases of Dakhla (Schild & Wendorf 1975:67) and Kharga have again produced both Mousterian and Aterian assemblages, stratigraphically distinguished only at Kharga, where they are associated with mound springs in the depressions and tufa deposits from springs, round the scarp. This Mousterian made much use of the Levallois method and there are many unmodified or minimally retouched flake artifacts. At Kharga the Aterian is typologically late with many Levallois flakes and points, bifacial foliates and rare tanged points and end-scrapers. It is the furthest east that the Aterian has been identified with certainty. All these Western Desert sites show evidence for some local rainfall suggesting a dry steppe environment and shallow lakes and swamps fed by springs in the depressions which supported more abundant plant and animal life (Caton Thompson 1952:73-90).

From the Aterian sites in the Maghreb and from what little is known from other localities of the faunal remains associated with the Aterian in the Sahara, it is apparent that the same large Ethiopian and Holoarctic game animals as were present with the Acheulian again became distributed within the desert and so were available as sources of food for the Middle Palaeolithic populations. The fossil spring site at El Guettar on the northern fringe of the Sahara in southern Tunisia, has produced two kinds of rhinoceros, zebra, the aurochs, two species of hartebeeste, wildebeeste, an extinct gazelle, camel and the Barbary sheep. Again, the remains suggest that the hunters were exploiting the resources of several micro-habitats – the bottoms of the depressions, the grass plains and the rocky slopes of the desert ridges. The duration of Middle Palaeolithic occupation of the desert is unknown but it could have lasted some 30 000 years or more. It was probably brought to an end, however, around 40 000 years ago by the onset of another period of desiccation. In a number of localities – e.g. the Saoura, Adrar Bous, the Western Desert – the sections and horizons with the Aterian are heavily deflated by wind erosion and the artifacts often show severe polishing and re-sorting by the wind. In the Chad basin severe desiccation is attested for the period between c. 22 000 and 12 000 B.P. and dune sands extended southwards from the Sahara into Bornu and across the interior delta of the Niger (see this volume: Chapters 2, 3 and 6). In the northwestern parts of the desert, the onset of desiccation appears to have been earlier than in the south (Conrad 1969:257-74), so that a date of around 40 000 years B.P. for the end of the Aterian occupation in the Sahara appears reasonable and this is also confirmed by the dates from the Western Desert sites. Desiccation appears to have been particularly severe during the main maximum of the Last Glacial and it is probable that, at this time, the savanna animals and man moved out of the desert, even from the central massifs. Such a situation is likely to have led to increased densities of men and animals in the regions bordering on the Mediterranean in the north and the Sahel/Savanna zones to the south, as well as in the valley of the Nile. The desert appears to have remained inhospitable and unoccupied until c. 12 000 B.P. or later (Servant 1973).

22.2.4 *The Middle and Later Palaeolithic in the Nile Valley*

No occupation or workshop sites of the Middle Palaeolithic are known from the more northerly reaches of the Nile but, between Luxor and the Dongola reach to the south, in particular in Sudanese Nubia, the Mousterian is well represented and has been divided into three complexes – a Mousterian, an Aterian-related Middle Palaeolithic and the Khormusan Complex. These might be seen as three slowly evolving modes in a continuing Middle Palaeolithic tradition of long duration with no significantly recognisable breaks (Wendorf & Schild 1976:238).

The earliest, the Mousterian, more usually occurs on the tops and pediment slopes of the inselbergs and plateau scarps lying back from the main river. It belongs mostly to a time of intermittent soil formation in the younger and upper part of the Older Pediments. It is made up of three variants or facies – a Denticulate Mousterian in which denticulate pieces predominate as in the assemblages from the Western Desert; a Nubian Mousterian A, in which important constituents are side-scrapers and points of Typical Mousterian form together with Upper Palaeolithic elements (end-scrapers and burins); and a Nubian Mousterian B, similar to the last but with the addition of rare Acheulian-type handaxes. Except for the last, these assemblages show no recognisable time trends and it is possible that the characteristics that differentiate them have more of a functional origin and are, therefore, activity related.

The next Complex is believed to be contemporary with the Aterian in the Sahara. It is characterised by the presence of bifacial foliates and very rare tanged pieces and is, therefore, thought of as an Aterian-related Middle Palaeolithic. Levallois technology and typology predominate and some of the sites are workshops (Arkin 5 and Arkin 6A) where the foliates were made and all stages of the process are represented from crude 'Sangoan-like' primary forms to the finished tools (Chmielewski 1968:134-47). Also assigned to this complex is the upper of two occupation assemblages from a site (Khor Musa, Site 440) near Wadi Halfa. These are found stratified in the upper part of a fossil dune and covered by fluviatile silts now recognised as belonging with the oldest alluvial aggradation connected with the present Nile sedimentary sequence. This assemblage is, therefore, associated with a very early period of high Nile flooding, contemporary with increased humidity in the headwaters and, as we know from wadi activity, with some local rainfall also (Shiner 1968b, 2:630-7). The quantity of fish bones and paucity of mammal bones associated with this assemblage are significant corroborative evidence for that from Cyrenaica (Haua Fteah) and South Africa (Klassies River; Nelson Bay Cave, etc.) where the exploitation of fresh water and marine food resources is attested by this time. By contrast, the underlying Denticulate Mousterian industry, which may be contemporary with an arid climate, made almost exclusive use of wild cattle (*Bos primigenius*) for food. Similar assemblages occur also to the south in Nile sediments in the Dongola reach and again confirm the contemporaneity of this foliate-containing Middle Palaeolithic and Denticulate Mousterian with an early phase of Nile aggradation (Marks et al. 1971). In the foliate pieces, it is possible to see, as with the Aterian in the southern Sahara, some kind of affinity with the Equatorial Lupemban Complex. This becomes even clearer to the south, at Khartoum, where the Acheulian at Khor Abu Anga is superseded by an industry

with long lanceolates similar to the Lupemban forms in the Central African Republic and the Zaïre Basin. These appear to be equipment related more to the forest/savanna ecotone and their presence in the Nile Valley, as also in the southern Sahara, could be related, perhaps, to a northward fingering of the tropical forest belt along the Upper Nile. The vast area over which these lanceolates and associated forms of tool are found, may reflect the distribution of a widely used technology for the processing of certain resources such as might be connected with the hunting and butchering of large land mammals – elephant, buffalo and wild cattle – and the extension of this savanna-related technology into the central Sahara and Upper Nile might show also the expected limits of penetration northwards of influences and populations of the Equatorial savannas.

The latest Middle Palaeolithic-related complex in the Nile Valley is named Khormusan from a locality near Wadi Halfa (Marks 1968a: see also this volume). It is characterised by the continued use of the Levallois method and by many denticulated and Upper Palaeolithic forms, in particular burins. Found in the high Nile silts and associated dunes (Debeira-Jer Formation), the Khormusan was initially considered to be no older than c. 20 000 years B.P. More recent age determinations show, however, that the Khormusan is most probably also close to the lower limit of the radiocarbon method. The occupation sites are large and the way the artifacts were found to cluster in association with large hearths, suggests either repeated re-occupation or contemporaneous occupation by several family or activity-related groups. The makers of the Khormusan specialised in the hunting of the aurochs although fish were also eaten (Wendorf 1968a: 1044-5; Wendorf & Schild 1976: 239).

It is of particular interest that no assemblages resembling the Khormusan Complex have yet been found in the Western Desert, so that it appears likely it was confined to the Nile Valley and its stratigraphically later age may also make it in part, or wholly, contemporary with the arid episode that brought the Aterian occupation of the desert to an end.

Whereas all or most of the desert appears to be devoid of occupation sites relating to the period of severe desiccation that was contemporaneous with the maximum of the Last Glacial, a number of later Palaeolithic industries have been recognised in the valley of the Nile and there is evidence for more or less continuous occupation from the time of the Mousterian and Khormusan onwards. The cultural sequence in the northern parts of the valley, downstream from Aswan, differs in a number of respects from that found to the south in Nubia and the Sudan. In the latter section of the river, the old, specialised core technique of the Middle Palaeolithic first continues in a highly evolved and diminutive form. It is, however, now found side by side with a small blade technology and eventually becomes totally superseded by it. This tradition (Halfan Industry) is relatively well dated to between c. 25 000 and 15 000 years B.P. and belongs to a period of dune formation and Nile aggradation (Ballana/Masmas Formation). The sites are compact camps and the economy was based on both hunting and fishing (Marks 1968b). Downstream, in Egypt, and in marked contrast to the Halfan, is a very different industry of macrolithic proportions. This Idfuan Complex, as it is called, is known from Idfu and Esna and has two facies – one in which Upper Palaeolithic blade technology predominates pro-

ducing many Upper Palaeolithic forms (end-scrapers, burins, trimmed blades, bladelets, etc.) and a Halfan-related facies where the Levallois technique is more significant. The Idfuan dates to between c. 23 000 and 17 000 years ago and is, thus, contemporary in part with the Halfan. The sites are large, indicating frequent re-occupation and the economy was again based on hunting large game (aurochs and hartebeeste), together with fishing (catfish) and shell-fish (*Unio* sp.) collecting (Wendorf & Schild 1975: 138).

From about 18 000 years B.P. onwards, the stone artifact complexes became more essentially microlithic and several such are distinguished in Upper Egypt. All are based on a true bladelet technology or on a combination of this with a modified Levallois element. One such complex from the Esna area is the Fakhurian with many backed blades and borers. The sites are situated on the edge of the floodplain and also within the dune field. At the floodplain the food waste is dominated by fish remains together with hartebeeste, aurochs, gazelle and hippo while, at the dune sites, the hartebeeste and aurochs only are found. The Fakhurian is, in part, contemporary with the Idfuan but it is fully microlithic whereas the Idfuan is macrolithic and has different types of tools. This great divergence has led the excavators to suggest that the two Complexes were made by two ethnic groups with different lithic traditions (Lubell 1974).

The phase of dune building and Nile aggradation (Ballana/Masmas Formation) was followed by a period when the level of the Nile fell appreciably. In Upper Egypt only two assemblages are thought possibly to belong to this time. They are approximately contemporary and both are associated with the upper part of the Ballana dune deposits back from the main river; both are microlithic but each emphasises different types of tool. One makes use almost entirely of a fine marginal trimming or utilisation named Ouchtata retouch after a site in the Maghreb. The other consists largely of straight-backed bladelets and pointed forms. Both sites appear to have been hunting camps specialising in the hunting of hartebeeste, aurochs and gazelle. In Nubia at this time, three more lithic complexes have been recognised, all from the Wadi Halfa area and just upstream into Egypt. One of these, known from eight sites (Gamaian Industry), is a small flake industry with a moderate Levallois element and is associated with large mammals and fish. Another (Dabarosa Industry) is known from three sites and has many bladelets and points made by a modified Levallois technique; it dates between c. 15 000 and 18 000 B.P. The third (Ballana Industry) is known from four sites and is a micro-blade industry with various truncated, backed pieces and burins. This industry may be as late as 14 000 B.P. but it could also be older (Wendorf & Schild 1975: 142).

A further rise in the level of the Nile (Sahaba-Darau Formation) lasted from c. 15 000 to 11 000 B.P. and several more contemporaneous lithic complexes are known, one only of which (the Qadan Industry from Nubia) seems to have antecedants in an earlier complex (the Gamaian) (Shiner 1968a: 564-611). The Qadan dating from c. 14 000-11 000 B.P., is a microlithic flake industry known from 19 localities, mostly around ponds in the troughs between the dunes. The assemblages are quite variable. Although the microlithic technology and range of tools are similar, the proportion in which the various forms occur differs, perhaps reflecting seasonal or activity specialisations. The tools comprise small

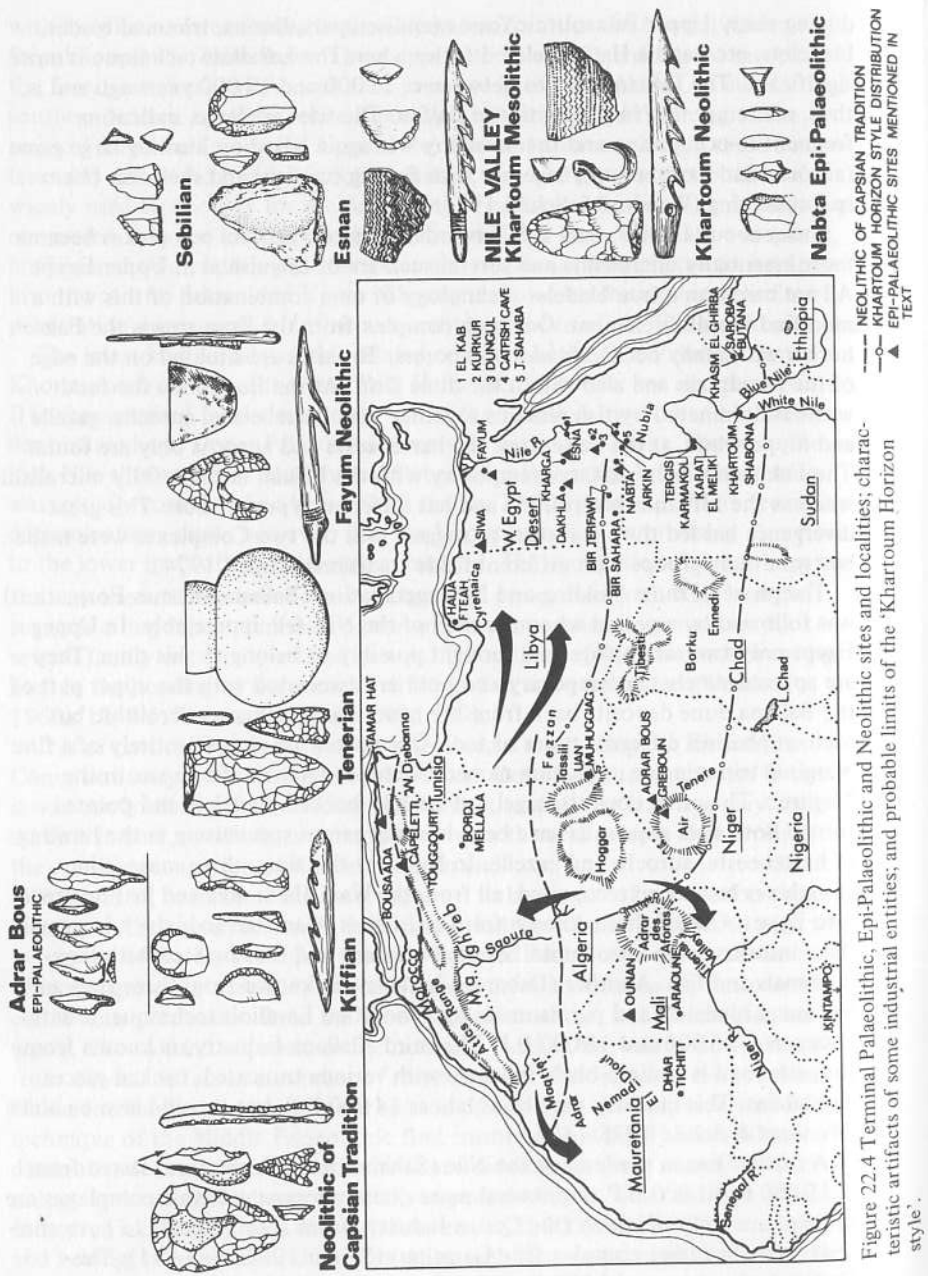


Figure 22.4 Terminal Palaeolithic, Epi-Palaeolithic and Neolithic sites and localities; characteristic artifacts of some industrial entities; and probable limits of the 'Khartoum Horizon style'.

scrapers, lunates and backed flakes, splintered pieces (? adze blades) and burins. The industries are associated with large mammal hunting, in particular wild cattle and hartebeeste, but also with extensive evidence of fishing. Of special importance is the wide use now made of wild grain, as evidenced by the numerous grindstones and microliths with so-called 'sickle-sheen'. The Qadan population must have been organised into relatively stable social groups with established territories, as the dead were now buried in cemeteries of which three have been investigated in Nubia (Wendorf 1968a; Greene & Armelagos 1972).

Another complex of this time is the Sebilian known from more than 17 sites stretching from Nubia to north of Luxor and exhibiting a lithic component and technology strikingly different from those of the Qadan so that two different populations are seen as having been responsible (Figure 22.4). The characteristic retouched tool of the Sebilian is the trapeze and the economy is related in particular to large mammal hunting – aurochs, hartebeeste and gazelle (Wendorf & Schild 1975:146-7). If the Sebilian is, indeed, an 'intrusive' element, then it may be connected in some way with the Tshitolian of Equatoria or with the microlithic industries of c. 12 000 B.P. from West Africa where the trapeze is, similarly, an equally significant piece of equipment (Shaw 1969).

From Aswan downstream to Dishna, north of Luxor, at least four other industries besides the Sebilian are known from this time. Excepting assemblages that bear resemblance to the Halfan from Nubia, these all make use of Upper Palaeolithic blade technology, usually, but not always, microlithic in proportions. This is not the place to discuss the lithic details that differentiate these industries but, like those of the earlier periods, these depend sometimes on the presence or absence of certain characteristic tools or techniques (e.g. the micro-burin method) or on significant quantitative differences. The Silsilian, Sebekian and Menchian are waterside sites in the former great embayment at Kom Ombo (P.E.L.Smith 1967). The populations made use of the resources of the river, of the gallery forest, the plains and the desert steppe. Some of them also made extensive use of wild grain as did the Qadan people. The Sebekian groups may have lived in near-permanent settlements, one such site dating to c. 13 000 B.C. The seasonal availability of the animal resources they used suggests that they were exploiting these on a year round basis (Churcher & Smith 1972). Silsilian sites also occur further upstream at Esna where there is also another complex, the Afian, in which a modified Levallois technique for small blade production still persists. As with the Silsilian, however, the micro-burin technique for making geometric microliths is also present (Wendorf & Schild 1976:280-1).

These Nile assemblages dating from c. 12 000 B.C. that make use of this technique are among the oldest in the world to do so. Its adoption is an indication of the invention of the composite tool, microliths being used to form the cutting parts and barbs of piercing weapons or the cutting parts of knives and harvesting equipment. The economy of the Afian groups round an interdune pond was based on hunting wild cattle and hartebeeste and on extensive fishing of Nile catfish. They do not appear to have collected wild grain as the equipment for this is lacking, although numerous grinding stones are found with a possible Afian assemblage from a site at Kom Ombo. Again, the question may be asked, does this indicate different seasonal use of resources?

Although somewhat later (10 500-9 500 B.C.), the lithic complex named from Esna and very prevalent between Idfu and Dishna, is particularly important for what it shows about social organisation and economy; it can be seen as the Upper Egyptian equivalent of the Qadan in Nubia. The sites are sometimes very large, suggesting either continuous and long-lasting settlements by a large population or relatively small settlements with much evidence of re-occupation. The Esnan is contemporaneous with the occurrence of an extensive fire that swept through this part of the valley at the end of the period of high Nile flooding (Sahaba-Darau Formation) about 10 000 B.C. The Esnan tools are macrolithic and made on Nile flint (Figure 22.4). The majority are end-scrapers, occasionally with notches, and denticulate pieces, burins and retouched pieces. Some 15% of these last at the sites near Esna show 'sickle-sheen' and there are also grindstones so that it is clear that the grain (provisionally identified on pollen as having been barley) found around the floodplain ponds, where these sites were situated, constituted a very important resource. Large mammal remains, especially aurochs and hartebeeste, abound at these sites but at only one are fish represented (Wendorf & Schild 1976:289-302).

It is interesting to speculate as to what the preponderance of end-scrapers and scarcity of backed bladelet forms may mean and, in this connection, it may be relevant to draw attention to the relationship in Ethiopia between end-scrapers and hide scraping which can be traced back from the ethnographic present as far as the later part of the Later Stone Age where high percentages of scrapers and low percentages of microliths are believed to be connected to the change from a hunting to a pastoral economy and so to the much more extensive use of hides (Clark, in press). If these end-scrapers with the Esnan were used for a similar purpose, it might be taken as an indication that this population was carrying out regular seasonal culling of the herds of wild cattle and hartebeeste with which they were associated, in the same way that it is claimed, with some justification, that the Ibero-Maurusian group that occupied Tamar Hat in eastern Algeria were already doing with Barbary sheep at an earlier time (Saxon et al. 1974:79-83). Faunal counts from the Esnan sites might show if this may, indeed, have been so.

After about 10 000 B.C. the Nile fell perhaps 30 m but very few sites are known from this time (Birbet Recession) because of the paucity of exposures. One site from the Esnan area dating to c. 9 600 B.C. is an Esnan-related industry but the commonest tools are retouched flakes and blades, followed by end-scrapers, notches and denticulates. Also present, however, were small numbers of Sebilian-type trapezes and geometrics together with two grindstones and several blade segments with 'sickle-sheen'.

It may be asked how all this diverse cultural evidence from the Nile Valley in the Terminal Pleistocene can be interpreted. Several features stand out. In the more southerly parts, the 'Middle Palaeolithic' Levallois technology persists for a time side by side with true small blade industries in the Upper Palaeolithic tradition. Further north in Upper Egypt, the Levallois technique seems to disappear earlier and its place is taken by a prismatic blade technology so unlike anything that had gone before that it is most probable that it is an indication of new population groups' having entered the valley from the north by 18 000 B.C. Thereafter, the flaked stone assemblages group into those that adhere more to

the blade tradition and others that sometimes continue to use a modified Levallois technology. At the same time there is clearly a general tendency for shaped tools and the primary forms from which they were made to become smaller and, finally, microlithic in proportions. There are, of course, exceptions, in particular those dictated by the choice of raw material, but it is not until the appearance of a village farming economy from c. 4 000 B.C. that this trend is reversed and macrolithic tools again become characteristic and important.

It will probably be some time before the significance of the differences in all these flaked stone industries becomes clear but at least a proportion of them might be explained as being activity-related. Sites occupied where grasses were not regularly exploited would not be expected to yield much in the way of grinding or harvesting equipment and the grindstones and pieces with 'sickle-sheen' can be seen as related to this particular set of activities. The lithic equipment connected with large mammal hunting is less easy to identify, though the Sebilian truncated pieces and trapezes and probably some of the backed bladelet forms might have a place here, as the cutting/piercing parts of fall traps and projectile weapons. Can other artifacts be related to the securing and processing of fish? Pointed, backed bladelets may be important here. What, again, was the function of the numerous notched and denticulate pieces which are almost ubiquitous since the Mousterian? Were they related to the processing of some kind of plant resources as food or to the manufacture of equipment which might include various kinds of traps, that could be used to secure large mammals and fish? These and other questions on late Pleistocene economies and social groupings cannot be answered without further research. It may, however, be safely concluded that at this time the Nile Valley was occupied by a number of relatively cohesive groups practising a generally similar economy based on the exploitation of resources from several micro-environments – animal protein from the Nile in the form of hippo, croc, turtle and fish, particularly catfish and Nile perch; from the gallery forest and plains, especially wild cattle and hartebeeste; and from the desert steppe and escarpment, notably gazelle and the Barbary sheep. The archaeological evidence shows that the resources of the river and gallery forest provided the protein and other nutrients that either greatly reduced, or entirely eliminated the famine months that are one of the main factors limiting population size. The people were thus enabled to develop a more sedentary way of life and a more closely structured social organisation. When the regular consumption of wild cereal grains, after about 15 000 B.C., became an important staple, it can be inferred that this rich protein and carbohydrate diet resulted in a shorter spacing between births and an increase in the number of children who survived which, in turn, brought about an increase in size of the group and so of the overall population of the Nile Valley.

The evidence suggests that the large sites associated with some of the Terminal Palaeolithic industries in the Nile Valley represent semi-permanent settlements of relatively large groups who may even have occupied some of them all the year round. Clearly, availability of resources in different areas of the habitat must have necessitated small-scale movements and erection of temporary camps to make use of the more essentially seasonal elements of their resources – for example, wild grasses; or fish in backwaters and ponds as the flood waters

receded from the plain. When the Nile was low the population was situated in more permanent, large base camps or settlements on strategic sites adjacent to the main river or to the permanent lagoons or embayments within the meanders. When the river rose over the flood plain, populations dispersed into smaller groups to occupy temporary camps near the seasonal seepage ponds and swamps back from the main river. From these camps the large game could be hunted and, as the water receded again, catfish, at least, might be secured behind weirs. As the plain dried out after the flood, the population would return to the base camp where cemetery areas were used for the regular disposal of the dead. Such a pattern anticipates that of the Sudanic and Nilotic peoples living along the Nile in recent times.

The extent to which climatic fluctuations and changes in the regimen of the Nile affected this pattern is difficult to gauge without closer chronological controls and more understanding of the technological and typological differences of contemporaneous cultural entities. It might, however, be expected that the later Pleistocene desiccation of the Sahara induced some of the populations in the desert to the east and west to move into the Nile Valley. In addition, the reduction of local rains that supported vegetation and permanent water in the wadis, as well as the periods of low Nile and restricted inundation of a much reduced flood plain, can be expected to have created pressures that brought about ecological disequilibrium leading to economic and social readjustments to maintain the population level and occupancy of areas of traditional usage.

The groupings might be expected to have become organisationally more closely knit and, possibly, endogamous units emerged that established and enforced traditional rights over hunting, fishing and harvesting territories. The evidence for the extensive fire that spread over some 160 km of the valley in Upper Egypt c. 10 000 B.C. (Wendorf & Schild 1975:136), may be an indication of the destruction of grain reserves, while the evidence of violent death exhibited by a significant percentage of those buried in the Qadan cemeteries at Jebel Sahaba in Nubia shows that some populations may have had to engage in organised warfare to protect their resources and settlements (Wendorf 1968b:991-4). The Nile Valley stands out, therefore, as providing an optimal habitat for Late Palaeolithic/Early Holocene hunter/gatherers in North Africa.

22.2.5 *The Final and Epi-Palaeolithic in the Nile Valley*

The early Holocene sites are associated with a further aggradation phase and high Nile (Arkin/Arminna Aggradation) which began about 9 000 B.C. and continued, with several minor recessional and aggradational sub-phases, up to c. 4 000 B.C. The only sites known to have been continuously occupied through this long period are round Arkin in Nubia, after which the industry is named (Wendorf & Schild 1975:159-62). The Arkinian tool-kit comprises micro-blades and small flakes, end-scrapers and backed bladelets together with some drills, lunates and other geometrics. There are also grindstones and implements with edge lustre. After 6 000 B.C., the number of sites known in Nubia becomes greater but the economy is poorly known. The industry of this time (Shamarkian), dating from 5 700-3 500 B.C., is composed mostly of the ubiquitous

backed bladelets and microflakes, reduced numbers of scrapers and denticulates and some side-struck flakes, drills, truncations and geometrics (triangles and rectangles). There are also present some pointed bladelets with basal retouch (Bou Saada points) and others having a stem, or tang, worked at the proximal end (Ounan points) (Figure 22.4). These last two forms are important since one or other, or both, occur, though never frequently, at sites ranging from Mauritania, Niger, Algeria and the Western Desert of Egypt and they can be seen as a manifestation of two rather specialised forms of equipment – perhaps as early forms of arrowhead since the bow and arrow was surely in use by this time. Grinding stones provide continued evidence for the use of grain but the amount of food waste in the sites is never great. Varying amounts of mammal and fish bones occur and one site has considerable quantities of the latter. Towards the end of Shamarkian times – c. 3 800 B.C. – pottery appears on the sites and there is a noticeable falling off in the stone technology. In sub-Saharan Africa, this breaking down of traditional lithic technology takes place about the time of contact with agriculturalists with metal tools and it is possible that this is also the explanation for the similar phenomenon on the Nubian Nile at this time.

Upstream, at the Second Cataract, a fishing camp of the time (5 110 ± 120 B.C.) in Catfish Cave, has backed bladelet forms similar to those with the Shamarkian but there are also numbers of uniserially barbed points together with large quantities of fish bones (Wendt 1966). The only other site on the Egyptian Nile from this time is at El Kab where two successive small-scale occupations (6 400-5 980 B.C.) have high percentages of pointed backed forms like those with the Shamarkian, together with fish bones (Vermeersch 1970).

In the Fayum Depression fed by floodwaters from the Nile, another, similar industry (Qarunian) is associated with two early high lake stands (Pre-Moeris and Proto-Moeris Lakes). These date between 6 150 and 5 190 B.C. and are relatively small camps with many curved and pointed backed bladelets, together with drills, some scrapers and very interesting barbed bone points made by removing the ramus from a catfish jaw and producing an oblique truncation at the base for hafting. Similar points, hafted as the heads of reed-shafted arrows, have been found in a First Dynasty tomb (Wendorf & Schild 1976:311-19; Emery 1938, Figure 13(3)). Since fish remains are exceedingly common at the Fayum sites (though bones of hartebeeste, gazelle, hippo and some wild cattle also occur) it is most probable that these sites are seasonal fishing camps and that fish may have been taken with bow and arrow besides other methods.

In the Fayum there is a gap of c. 1 200 years before the appearance of the Neolithic with domestic animals, grain and other plants. The culture is so markedly different from the Qarunian that it is likely that it was introduced by a new population of agriculturalists from the Nile Valley.

The contemporary populations in Sudanese Nubia appear to have continued the traditional way of life, for the lithic industries show no very significant break with what went before and appear as part of a long continuum to which pottery and some new lithic forms were added and to which there came also, in time, domestic animals before 3 000 B.C. The evidence suggests, therefore, that the Sudanese Neolithic is a locally developed economy. Shamarkian-type assem-

blages combine the traditional backed bladelets, chisels, trapezes and denticulates with new forms – flake adzes, bifacial tanged arrowheads and concavo-convex scrapers of Fayum-type. There are also two other cultural variants known from Nubia at this time. One is a micro-flake industry called the Abkan which has probable origins in the Qadan. This is a flake industry of small drills ('groovers'), lightly retouched scrapers and denticulates with some trapezes, triangles, lunate microliths and cord-decorated as well as undecorated pottery. The economy was based on fishing, perhaps with traps and weirs, on shellfish collecting and some hunting. The later levels of the sites at Abka have pottery similar to that of the other cultural entity recognised in Nubia at this time – the Khartoum Variant. This, in turn, has much in common with the Khartoum Neolithic from Esh Shaheinab and other sites north and south of Khartoum where domestic cattle and sheep/goat are present. It would seem, therefore, that stock-keeping, if not cultivation, became an additional form of livelihood on the Upper Nile sometime before 3 000 B.C. The Abkan flaked stone industry is similar to that found with the A-Group Complex in Sudanese Nubia which reflects contacts between this indigenous population of stock-keepers and the Old Kingdom civilisation in Egypt (Shiner 1968a:625-6).

The early Holocene cultural sequence in the Central Sudan is known from sites north and south of Khartoum, as well as from the Dongola reach in southern Nubia where the prehistoric assemblages make it possible to correlate the evidence from northern Nubia with that round Khartoum. The late Palaeolithic is, as yet, unknown here but, by 6 000 B.C., there was present a population living in large, waterside settlements and practising an economy based on fishing, hunting and the collection of molluscs (*Pila*, a large, semi-aquatic snail). This has been called the Khartoum Mesolithic (Arkell 1949a). It combines a flaked stone industry comprising geometric microliths (lunates, triangles, trapezes and rectangles) and drills, splintered pieces, large crescentic backed forms and some scrapers with uniserially and biserially barbed – and some barbless – bone points, together with large, deep, open-mouthed pottery bowls. Characteristic is a decoration of undulating (wavy) lines produced by dragging a catfish spine across the unfired clay and this was varied to produce punctate, undulating lines (dotted wavy lines); impressed comb (? and roulette) decoration of various kinds also occurs. This characteristic 'Wavy Line' and 'Dotted Wavy Line' pottery also occurs sporadically on sites in the eastern, southern and central Sahara, as do also the bone harpoons. These large settlements are thought to have been the base camps occupied for much of the year except when the rains in July and August made it possible to exploit resources more distant from the river and to follow the game into the Gezira and the desert west of the Nile. There is no evidence for any domestic animals and the game hunted consisted of elephant, hippo, a small buffalo, reedbuck, Nile lechwe, hartebeeste and other game animals of the Equatorial savanna. Besides hippo, the Nile provided crocodile, tortoise, catfish, Nile perch and other fish as well as large quantities of *Pila* shellfish which were sometimes stored in pits. The great quantity of grindstone fragments at these sites indicates the importance of the wild grains growing ubiqitously in the 'koris' and plains of the central Sahara (Clark 1973).

Interest has focused on the bone points and the pottery. The barbed bone

points ('harpoons') were, presumably, the piercing parts of spears and a possible proto-type for these, obtained by modifying catfish jaws and spines, has already been referred to. These bone points were sometimes quite large and it is clear that they could have been used against several different kinds of prey – hippo, crocodile, Nile perch and catfish in particular – and their use was not necessarily restricted to aquatic animals.

The pottery appears to be an indigenous development on the Upper Nile, probably in response to the need for more efficient ways of processing fish and molluscs. The method of dealing with the fish was probably little different from that described by Strabo and other classical geographers as in use among the *Ichthyophagi* on the Nile and Red Sea during the first few centuries before and after the beginning of the present era (Budge 1928). Much the most efficient way of processing large quantities of shellfish is to drop them into boiling water when they are easily removed from the shells.

It is not known when a Neolithic economy was first adopted in the Sudan, perhaps about 3 500 B.C., when domestic cattle and small stock made their first appearance there. The sheep/goat which occurs there must be assumed to have been obtained by diffusion from Upper Egypt, from an ultimate origin in the Middle East, since there are no native ancestors for these animals known from Africa. Cattle also are likely to have been introduced to the central Sudan from the north but it is quite probable that the local gene pool of North African wild cattle was the basis for the domestic breed along the Nile, as in the northern part of Africa generally (Arkell 1953:15; Clark 1976a:78-9).

Further south, in the Dongola reach between Nubia proper and Khartoum, there appears to be an hiatus between the last 'Middle Palaeolithic' industries with Levallois technique and the earliest ceramic occurrences. The reason for the absence of later Palaeolithic ceramic sites similar to those from the Wadi Halfa area and dating from c. 12 000 to 4 500 B.C. is unknown although ecological factors rather than conditions of preservation are likely to have been the cause.

The ceramic occurrences have been grouped into four entities on the basis of technique, typology and stylistic motifs on pottery (Shiner 1971 I:291-2). The traits that distinguish them apart are at the same time accompanied by other common factors which suggest that these industries are the product of closely related ethnic groups with a similar culture and pattern of behaviour. The ceramics are distinctive but, nevertheless, sometimes (Karmake Industry) provide evidence of a more extended relationship with the Khartoum Mesolithic and, later, with the more developed Esh Shaheinab pottery. This situation is repeated also in the region of the Upper Atbara close to the Ethiopian escarpment where the recognised groupings (Saroba, Butana, El Hagiz groups) present parallels (Shiner 1971 II:413-34). Again, the evidence suggests that this region was uninhabited or very sparsely occupied during the terminal Pleistocene until the coming of a group (Saroba) bringing traits that relate it to the Khartoum Mesolithic. Circumstantial evidence, like that for the later groupings recognised in the Dongola reach (Karat, Tergis, el Melik), point to the Butana Industry, dated to 2 400 B.C., as practising a Neolithic economy based on small stock raising. These Butana Industry sites are extensive settlements on mounds in the floodplain with deep occupational debris.

Clearly, all this late Pleistocene and early Holocene evidence points to a long period of pre-adaptation to agriculture along the Nile during which time local animals were manipulated in various different ways from systematic culling to capture and training; and, at the same time, great use was also made of the local wild grains which were regularly harvested and stored (Clark 1971).

22.3 THE LATE PLEISTOCENE AND EARLY HOLOCENE INDUSTRIES OF THE SAHARA

22.3.1 *Epi-Palaeolithic*

Between 22 000 and 12 000 years ago, the aridity accompanied by extensive aeolian activity in the Sahara enabled the desert to extend southwards into the Sahel and savanna, making the whole vast region unfavourable for continued settlement by human populations (Burke et al. 1971). No cultural assemblages are known that date to this time – contemporary with the main advance of the Last Glacial in Europe – and the severe deflation of the Aterian sites and wind-polishing of the artifacts testifies to the untenable conditions in such areas as, for example, the Ténéré. However, by about 12 000 B.P. in the terminal Pleistocene the climate again became more humid, the wadis began to drain water from the desert massifs into the depressions which were again filled with lakes and swamps; or the runoff from the massifs was discharged into the Niger and Chad drainage systems to the south (Street & Grove 1976). This abundance of water stocked the rivers and lakes with hippo, crocodile, turtle and fish, in particular catfish and the Nile perch. The lakes were highest around 9 000 B.C. and the vegetational changes that accompanied this early Holocene amelioration brought the large grazing and browsing animals to repopulate the desert once more. They were followed by groups of specialised hunter/gatherers and, after having been uninhabited for some 30 000 years or so, the Sahara now provides the best evidence yet available for human demography and behaviour in the desert in prehistoric times.

The earliest post-Aterian and pre-Neolithic assemblages from the desert date from the 7th and 8th millennia B.C. and are aceramic and Epi-Palaeolithic in nature. Very few of the sites so designated are stratified or dated and, compared with the number of Aterian and Neolithic sites, are very few in number, although others may well exist. This can probably be taken as an indication that, between the beginning of the 8th millennium and the earliest Neolithic at the very end of the 7th millennium B.C., the human population was in general thinly distributed in comparatively small groups.

These assemblages are particularly interesting since, on the basis of the lithic composition, they provide an indication, firstly, of the general direction from which this repopulation of the desert seems to have taken place and, secondly, within the more generalised nature of the Epi-Palaeolithic small blade technology, there can be now identified local stylistic differences and assemblage variability which may, perhaps, indicate discrete ethnic entities. In addition, the presence of certain specialised forms of retouched tools (e.g. Ounanian and Bou Saada points), which appear in small quantities at a number of these Epi-Palaeolithic sites throughout the extent of the desert, demonstrates that, not

only were the equipment and activities with which these specialised forms were associated in use all over this vast region (including also the Nile Valley), but that the populations responsible for them were adapted to a common, traditional life style.

The characteristic Ounanian points, comprising both tanged and shouldered forms, were first recognised at Ounan and again at Arouane in eastern Mauritania (Breuil 1930:463, 466), in the Fezzan and from four Algerian sites on the south side of the Atlas where the Bou Saada pointed blades with basal concave retouch also occur (Tixier 1955) (Figure 22.4). These forms are present also at two sites in the Ténéré – at Greboun and Adrar Bous – at the first of which they were associated with a micro-blade industry comprising burins, backed bladelets, drills, concave scrapers and notched and denticulated bladelets (Clark 1976b). In the Western Desert, 51 surface sites at Dungul, Dineigil and Kurkur Oases (associated with fossil playa deposits) have been grouped into what has been called the 'Libyan Culture' (Hobler & Hester 1969). Although the assemblages are probably mixed, they nevertheless again show features that preserve an aceramic sub-stratum of Epi-Palaeolithic and they may date between 5 950 and 8 300 B.C. The Ounan stemmed point occurs here, together with many denticulated and notched pieces, drills and other tools but no microliths. They are associated with camp sites the area of which is not usually very large and which exhibit features such as hearths and small circles of slabs of rock thought to be the outline of animal pens rather than dwellings. With the flaked tool assemblages are many grindstones indicating the importance of ground grain. Similar surface assemblages, mixed with Neolithic, occur also at Kharga Oasis where they have been named 'Beduin Neolithic' but the earlier, Epi-Palaeolithic sub-stratum can be distinguished by the presence of the Ounanian point, the trapeze and notched blades (Caton Thompson 1952:149-62). Again, in the 'Dyke area' south of Dakhla Oasis and at Nabta Playa, Epi-Palaeolithic assemblages have been studied (Schild & Wendorf 1977:113-140). That in the 'Dyke area' is a relatively discrete scatter associated with a cluster of large stones which possibly marked the base of a large tent or enclosure. The primary working of many of the cores had been done elsewhere and this was more typically an occupation site rather than a workshop. The micro-burin technique was used to break down the bladelets which were worked into geometric microliths – mostly scalene triangles. The commonest tools are denticulates and notched pieces but there are also some end-scrapers and burins as well as a few grindstones indicating that cereal grain was locally available. An assemblage closely comparable to the above was recently found at Kharga Oasis and is dated to the very beginning of the 6th or end of the 7th millennium B.C. (Schild & Wendorf 1977:141).

Three more Epi-Palaeolithic sites at Nabta Playa show various differences in the composition of the predominantly microlithic tool-kits but whether these reflect ethnic or activity differences or stylistic preferences through time, is not known (Wendorf et al. 1976:107, 110-11). Only one of these sites is dated – to between 7 410 and 6 630 B.C. One tool-kit emphasises pointed bladelets, isosceles triangles and Ounanian points; another straight-backed microliths and scalene triangles and the third, curved backed blades and lunates. Also present are ostrich eggshell beads and bone points. The usual notched and denticulate

pieces also occur but end-scrapers, burins and grindstones are rare.This emphasis on the geometric microliths as well as the bone points, suggests that these sites may have been winter hunting camps of small, perhaps family groups.

The Ounanian and Bou Saada points, which also occur with some of the terminal Palaeolithic/early Holocene industries of the Nile Valley (e.g. the Shamarkian) are an indication that the equipment and activities with which these specialised tools are associated, were part of the general way of life in the Sahara and parts of the Nile Valley between the 8th and the 6th millennia B.C. and probably earlier. The lithic components of the Nile industries are, however, sufficiently variable, not only within the valley itself but also when compared to the assemblage at the Egyptian oases, that they give the impression of being the products of relatively localised populations, sufficiently cohesive to have developed their own stylistic preferences and, at the same time, to reflect the range of different seasonal activities that were the basis for the Terminal Palaeolithic/Epi-Palaeolithic economy, namely a combination of large game animal hunting with fishing and grain collecting.

It is of interest that the nearest comparisons for the Epi-Palaeolithic in the Egyptian oases are not in the Nile Valley but in the eastern Maghreb where, in Tunisia, Upper Capsian sites occur with similar high frequencies of notched and denticulate pieces and scalene triangles (Schild & Wendorf 1977:143-4). This, together with the wide distribution of the specialised point forms noted above, not only implies that these hunting groups must have been highly mobile, covering when necessary considerable distances between one hunting area and another. It is, however, also an indication that this Epi-Palaeolithic tradition was carried into the desert by groups repopulating the Sahara from the north, from the eastern Maghreb and, perhaps, Cyrenaica. The numbers of scalene triangles, trapezes and lunates also strongly suggest that, by this time, the main hunting weapon was the bow and arrow.

While the western oases nearer the Nile (such as Kurkur, 55 km west) could have been seasonally occupied by groups coming from the river, presumably for hunting, and even those below Dungul (130 km west) might also have been visited in this way; the more distant oases such as Kharga (210 km), Dakhla (400 km), Bir Terfawi (385 km) and Bir Sahara (435 km) and the well areas and playas are much less likely to have been regularly visited by groups from the Nile in prehistoric times and all of them can be expected to have supported their own local resident populations.

None of these Terminal Palaeolithic/Epi-Palaeolithic sites in the desert that we have been discussing cover large areas or show overall dense concentrations of occupation waste as do some of those along the Nile. This might mean that the hunting/gathering groups in the desert, lacking the additional dietary returns from aquatic foods and with the impoverished nature of the terrestrial large mammal element, were organised around an economy based on hunting and grain collecting and probably lived in small, open and highly mobile communities. The composition of these groups probably changed rapidly and these smaller units can be expected to have come together into larger groupings for relatively short times each year for the same purposes as do the !Kung San in the central Kalahari today (Yellen 1977:36-49).

While this model is that which best fits the Epi-Palaeolithic in the drier parts of the desert, it underwent modification in those parts of the central and southern Sahara with major water courses, and round the lakes and swamps in the depressions. So far as this writer is aware, no large, aceramic sites have been found in these situations or in this time range in the Sahara. The one site with Ounanian points by the lake at Adrar Bous, was a dense but relatively restricted concentration (300 m^2) and it was not until pottery became available and the inhabitants began systematically to exploit water resources, that the settlements became larger. The artifact assemblages are grouped into what French scholars more generally term the 'Older Neolithic' based on the presence of pottery and ground stone, and anglophone workers term 'pre-pastoral Neolithic'.

22.3.2 *'Pre-pastoral Neolithic'*

The term 'Neolithic' is employed here in its original meaning – namely, for those cultural assemblages with pottery and ground stone. These pre-pastoral cultural entities comprise the 'Older Neolithic' of some French prehistorians and represent the earlier expressions of what has been called the 'Neolithic of Saharo-Sudanese tradition' (Camps 1974:223-40). There is, as yet, no evidence for any domesticated animals or plants in association with this 'Older Neolithic' and, since this has been described by other contributors to this volume (see Chapter 18), it is necessary here only to comment that it appears to be confined to the central and eastern part of the Sahara where it is best seen from sites associated with the lakes, playas and swamp areas that abounded in this part of the desert in the early Holocene.

Those expressions in the desert that date from the 6th and 7th millennia B.C. appear, on their technology, to have cultural affinities with the Early Khartoum tradition from the central Sudan. This can be seen from some of the pottery forms and decorative motifs and also from the barbed bone points which, from their distribution at lake-side sites, can be shown to be associated with fishing and probably also with hippo and crocodile hunting, since the size range of these 'harpoons' is very considerable. What has been termed the 'Khartoum Horizon' (Hays 1974, 1976) comprises widely distributed and distinctive industrial assemblages that were being produced over a comparatively short period of prehistoric time (>6 000-<5 000 B.C.). At one site in the Nile Valley (Shabona), an oval and shallow depression with pottery and other cultural remains looks very much like a 'fond de cabane' and some sites, e.g. Early Khartoum and Shabona, have produced lumps of what appears to be burned clay from wattle and daub structures. Certainly at this time, food was being stored in pits, for example, deep, conical pits, one metre in diameter, filled with *Pila* shells and shallow pits containing fish bone have been found. Collected grain may also have been stored in pits as in the Sudan today, or in above surface structures, as is done by the desert nomads (Clark & Stemler 1975).

In the more northerly parts of the desert at this time, it seems that the Epi-Palaeolithic continued, acquiring some new technological traits and evolving into the 'Neolithic of Capsian tradition' in the northeast (Roubet 1971), with various, more localised, expressions, such as the Sirtican (McBurney & Hey 1955:220-2), or that in Siwa Oasis (Hassan 1978) and later facies of the 'Libyan

Culture'. From the geographical extent of sites representing the 'Khartoum Horizon', there can be little doubt that they indicate a generally similar way of life based on seasonal hunting and wild grain collecting with the addition, where geographical circumstances made this possible, of the very important food resources of the lakes and rivers. These must have done much to reduce significantly the severity of the famine months (December to April) and to make possible larger and more permanent groupings. Since water sources were much less abundant at this time in the northern part of the desert, it was in the centre and south where the aquatic facies of the Saharo-Sudanese Neolithic became established. Thus, the dichotomy recognisable at this time between the 'Capsian'-related industrial entities in the northern parts of the desert and those of the 'Khartoum Horizon' in the centre and south, may have more than technological implications.

These 'Older Neolithic' communities must have been specialised hunters and fishers and, while the game, water and plant resources remained abundant as they did up to c. 4 000 B.C., reduction of the famine period can be expected to have enabled the populations to have become much more sedentary, to have developed a more regular system of seasonal transhumance and must also have encouraged larger groupings and an overall increase in population. If this interpretation has validity, then this favourable environment can be expected to have reduced the amount of random movement tied to rare rains and to have permitted a closer relationship between game herds and hunters to grow up. A situation similar to that at Tamar Hat in coastal Algeria can be envisaged where, from c. 20 000 to 16 000 B.P., the evidence suggests that the human populations were in symbiosis with the Barbary sheep herds, of which the systematic culling provided >94% of the mammalian food waste (Saxon et al. 1974:70). The early 'large animal' rock engravings of the northern and central Sahara and Egypt, which may be as early as 8 000 B.C., depict animals with collars and halters, together with the possible use of the lassoo or bolas for capturing them. This suggests that a regular system of taming may have developed by this time and also emphasises techniques that continued in use for religious purposes in Egypt through much of Dynastic time (H.S.Smith 1969).

It would seem that some of these specialised hunting groups in the drier parts of the desert (e.g. the southern parts of the Western Desert of Egypt) may have tamed and begun to breed the indigenous wild cattle and to have acquired a domestic ovicaprid by 6 000 B.C. (Wendorf et al. 1976:111-2). If genetic reasons rule out *Ammotragus* as having anything to do with the domestic sheep/goat of Africa, then the sheep/goat must have been acquired from populations to the north and east. The identification of domesticated barley at Nabta Playa (Wendorf & Hassan, this volume) also suggests a northern source, although it is not impossible that wild barley might still have been growing in southern Egypt at this time. It is significant too that *Sorghum* has also been identified from this site though it is not known whether it was domesticated. If it was growing here in the late 7th millennium B.C. and was not introduced, it may be taken as evidence of the northernmost extent reached by the dry savanna at this time.

This evidence from Nabta Playa is the earliest anywhere in the continent for domestic animals and plants. Its great importance, so far as the origins of food

production in Africa, in particular vis-à-vis the Nile Valley, are concerned, is discussed below. For the Sahara, however, it indicates that, from c. 6 000 B.C. onwards, some of the human populations were supplementing their food sources by stock herding and barley cultivation. During the next two millennia the herding, first of small stock (e.g. Haua Fteah, Cyrenaica, c. 5 000 B.C. and Capeletti, c. 4 500 B.C.) and, later, it would seem, of cattle (e.g. Uan Muhuggiag, 4 100 B.C. and Adrar Bous, 3 800 B.C.) spread widely in North Africa and the Sahara (A.B.Smith, this volume). Much less convincing is the evidence for grain cultivation in the Sahara before 1 100 B.C. (e.g. Dar Tichitt) (Munson 1976) and, more probably, the grain continued to be collected and stored as it still is by the present-day inhabitants of the desert (Gast 1968:389-400; Nicolaisen 1963:206-7).

Some populations, such as those responsible for the 'Neolithic of Capsian Tradition' in the northeastern Sahara, appear to have continued to practise a hunting/collecting way of life without stock herding (Camps 1974:220; Roubet 1971) and more than one exception of this kind can be expected, since the hunting way of life continued in some places into modern times as with the Nemadi of northern Mauritania (Gabus 1952).

22.3.3 *'Pastoral Neolithic'*

The richness of the biomass of the large game animals during the early Holocene is well seen in the very numerous depictions in the rock art so that it might be asked why it should have been necessary to turn to stock-raising in the first place. This question will not be answered until there is much closer correlation and control between climatic and environmental fluctuations and the record of changing resource uses and settlement patterning, as these are apparent from the archaeological sites. Suggestions that have been put forward (Clark 1976a) and based on the climatic record (Butzer, n.d.) as currently known from pollen and diatom studies (Servant et al. 1969; Maley 1977; Van Campo 1976) emphasise the importance of increasing desiccation in the desert after 4 000 B.C., which must have been responsible for readjustments in game distribution resulting in more concentration near to the water sources and so to closer proximity to the human settlements. At the same time, climatic and biotic pressures, as well as improved technology and strategies for food-getting, can be expected to have led to depletion of the major food resources that had enabled the larger groupings and greater population densities to grow up in the lake basin and stream valley habitats. Although it would have placed a certain restriction on personal liberty, the acquisition of stock would also have made it possible to maintain and even to increase population densities by providing a 'stored' source of animal protein that would have significantly reduced the problem of the famine season, not only through the regular supply of meat it made available but, also, through the use of milk and blood. It is not known when the milking trait was introduced into North Africa but there is pictorial evidence that it was practised in Egypt during Old Kingdom times (Simoons 1971).

At the same time as the food supply was made more secure, pastoralism can be expected to have enabled regular use to be made of pasture lands which curtailment of water sources rendered only marginally favourable for hunter/

gatherers, thus relieving the pressure on grazing and other resources of the 'core area'.

Another significant result of a pastoral economy was the development of an hierarchical social organisation where livestock constituted wealth and served as a medium of exchange. The more rigid, patriarchal and closed kinship systems that were able to develop would have been ancestral to the indigenous pastoral societies of the desert in earlier historic times.

The main period of the Pastoral Neolithic in the Sahara was between c. 4 000 and 2 000 B.C. and much can be learned of the economy, customs and behaviour of the populations from systematic studies of the rock art which, with certain exceptions (Mauny 1952; Huard 1960), still remain to be undertaken. By 2 000 B.C. desiccation had developed to the extent that it must have been increasingly difficult to maintain herds of cattle in the desert. Large-scale movements of nomads into the Nile Valley from the Libyan desert are attested from that time onwards. Examples are the appearance of the C-Group peoples in the northern Sudan after 2 500 B.C. (Arkell 1961:46-50); of the 'Libyans' (Libu and Mashwash) who infiltrated into the Nile Valley on several occasions during the later part of New Kingdom times, as well as the invasion of Egypt by the 'Sea Peoples' during the reign of Merenptah (O'Connor, in press: 16, 28, 62, 121).

By 2 000 B.C., there were settlements of Neolithic cattle pastoralists in the Sahel (e.g. in the Tilemsi valley) and by the mid-second millennium B.C. the Kintampo Culture had appeared in Ghana. This was an indigenous savanna/forest ecotone culture where the people dug wells and lived in wattle and daub huts grouped into villages (Flight 1976:215-7; Dombrowski 1976). These occurrences are evidence that the Saharan influences were being felt around 2 000 B.C. in the savanna zone and it can be inferred that the traditional way of life of the hunting/gathering populations there was being subjected to pressures and economic modifications by the influx of people and animals from the desert. These pressures led to the domestication of a number of the more important local plant foods that were the traditional staples in the tropical savanna from Senegal to the Horn of Africa.

Some Neolithic populations were able to survive in the desert by withdrawing onto the diminishing water resources. Such groups, as at Dar Tichitt, were able to maintain their identity for c. 1 500 years after the resources of the lakes had disappeared. They subsisted by grain cultivation and collection and cattle herding until the migration of ancestral Lybico-Berbers with metal weapons, horses and chariots brought Neolithic culture in the Sahara to an end after c. 850 B.C.

22.4 THE PHYSICAL TYPES OF THE POPULATIONS

The more than 50 burials, in various states of preservation known from the Saharan Neolithic, show predominantly Negroid features (Chamla 1968). They are relatively robust, however, and Chamla considers them to have more in common with the Epi-Palaeolithic populations of Nubia from the Jebel Sahaba cemeteries, than with the more slender West African Negro physical stock. This Saharan skeletal material relates, geographically and culturally, to the area that

has been designated as the 'Neolithic of Saharo-Sudanese tradition' and, as yet, none of the remains found and described from the desert are associated there with the 'Neolithic of Capsian tradition'. In the Maghreb, however, the physical type associated with this 'tradition' belongs to the Mediterranean gene pool which is closely related to the older, Mechta-Afalou race of Northwest Africa.

If the evidence of the rock art is admissible here, both Negroid and Mediterranean features are shown in the paintings and engravings in the Central Sahara. It would, therefore, seem that the Saharan Neolithic populations were wide-ranging. It is possible, however, that the southern limit of the winter rainfall area was also an ethnic boundary between the Mediterranean peoples on the north and the Negroid populations to its south with, in the central parts of the desert, a good deal of interaction.

It is, perhaps, unwise to place too much emphasis on any physical interchange that might have taken place until such time as more material is forthcoming. In this connection, it is of interest that Anderson (1968:1035) believes that the Jebel Sahaba skeletons from the Nubian cemeteries show the closest affinities with the Mechta-Afalou population of the Maghreb. On the other hand, Chamla appears to consider them as being ancestral to the Sudanese Negro. Such seemingly conflicting views would be reconciled if these two roughly contemporaneous populations can be seen as representative of the more generalised physical stock that was present throughout most of north Africa in the terminal Pleistocene. From this stock, as a result of more specialised behavioural practices and, in particular, of dietary changes caused by improved nutritional levels in the early Holocene, the genetic differences that distinguish the populations of North and sub-Saharan Africa in early historic times, began to emerge.

22.5 SOME SUGGESTIONS ON LAND USE AND POPULATION STUDIES IN THE SAHARA IN PREHISTORIC TIMES

Site location and resource use must be viewed in relation to the whole ecological system of which the prehistoric populations were an integral part. This approach was first employed by Vita-Finzi & Higgs (1970) and by Hole et al. (1969) and is designed to show what resources were available at a given site and which of them were, in fact, selected for exploitation. To a major degree, the annual location of the human population depended on the behaviour of the plants and animals on which they lived so that it is necessary to be able to reconstruct the habitat and biomass before any more realistic understanding of land use patterns will be possible.

In the absence of any habitat analysis for any archaeological locality in the Sahara and with only incomplete palaeo-ecological evidence, it is not possible to test convincingly the validity of the hypothetical patterns that follow. The study of site catchment (Higgs & Vita-Finzi 1972) or habitat analysis (Foley 1977) of core areas where key sites are located, should be feasible by combining use of remote sensing satellite photography, ground survey and palaeo-botanical data. This should make it possible to reconstruct the different vegetational zones, potential plant productivity and animal biomass. With a number of such case studies that can be correlated with archaeological data on food waste and tech-

nology from the sites themselves and on adjacent sites, it should be possible to say something about the territorial range of hunting/gathering and pastoral groups, based upon the availability of food sources and the energy provided by the gathered foods as compared with the output of energy necessary to acquire them. The following suggestions as to the home ranges and groupings of prehistoric populations are made on the basis of what is known about the behaviour of the animals found in their archaeological food waste and on observations of present-day movements and resource use by some peoples of the Sahara and Sahel.

From the Acheulian to the Neolithic, by far the greater number of sites known are situated in proximity to former river and stream courses, lakes or playas. The habitat used by the prehistoric populations occupying these sites throughout this long period, must have consisted of a 'core area' which comprised the permanent water source(s), sometimes with a variable zone of *Acacia* and other woodland and a narrow belt of alluvial grasslands. Beyond this, a more extensive area of grassland can be expected to have covered the intermittently dry stream courses and the upper slopes of the basin or valley. Beyond this again is the desert which might take the form of a piedmont zone of dissected scarps and isolated hills giving onto flat, gravel-covered plateaux (regs) or mobile dune fields (ergs). Each of these zones supports different plant and animal populations, and faunal assemblages from prehistoric sites show that each of these habitats was made use of. For example, taking the Acheulian and Aterian faunal assemblages from Erg Tihodaine, it can be seen that elephant, buffalo and wild cattle were taken from the woodland and grassland where water was readily available and fish, hippo and crocodile were also to be had in the open water sources of this zone. The dry grassland and scrub supported eland, zebra, hartebeeste, warthog and white rhino while the regs and dune fields are the habitat where oryx (and addax) Dorcas gazelle and Barbary sheep are more usually found.

As yet we have no counts for numbers of individuals, or age and sex details, for any Saharan site but the lower limits of present-day animal groupings, taken from Dorst & Dandelot (1970) may give some indication of availability and the habits of the different species in various niches in the Sahara, as set out in Table 22.1.

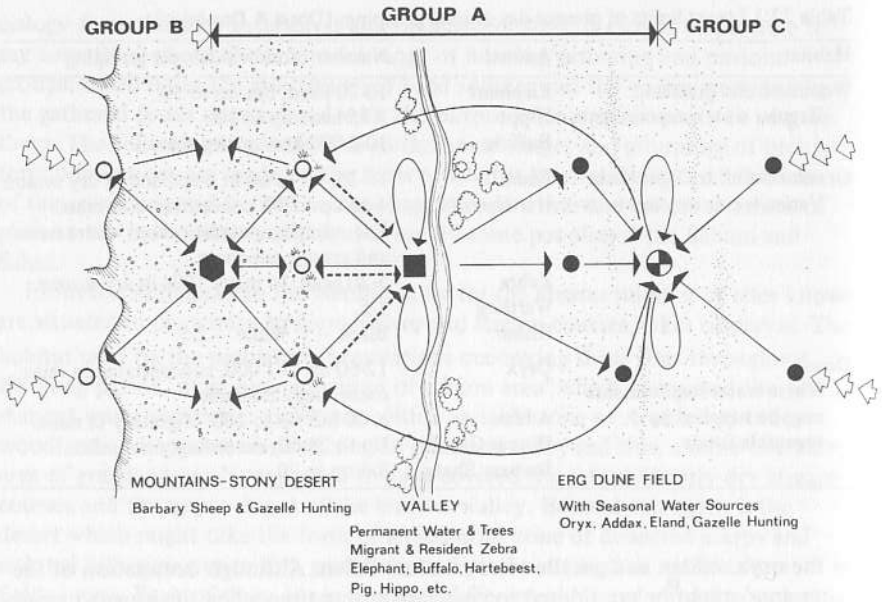
It will be clear from the above vegetational zoning and availability of food animals, that the catchment or 'home range' of Saharan hunter/gatherers would have consisted of a 'core area', utilised regularly, and an outer range used irregularly as circumstances dictated. The 'core area' would have been centred on one or more permanent water sources where one, or perhaps several strategically situated base camps were occupied during the famine season when, plant foods being scarce, the animal populations would also have been concentrated in this core area. The base camps may, of course, also have been occupied at other times. North of the Hoggar, the period of stress would have been during the cold, winter months (December to March) after which sporadic rains can be expected. South of the Hoggar, where the Mediterranean system is replaced by the zone of summer rains, the period of stress would be the hot and end part of the dry season. The 'outer range', which was much more extensive, was used intermittently following the movements of widely ranging game animals such

Table 22.1 Lower limits of present-day animal groupings (Dorst & Dandelot)

Habitat	Animal	Number of individuals per grouping
Woodland and grassland: Regular water requirements	Elephant	10-20 head, but up to 50.
	Hippo	5-15 head up to 30.
	Buffalo	10-2 000 head in dry season.
Grassland and dry light bush: Varied water requirements	Eland	15-25, up to 60 in woodland in dry season.
	Hartebeest	4-15 up to 30, concentrated in rains. Exceedingly nomadic except where water and grazing adequate.
	Zebra	5-20 head, to many 100s in dry season.
	Warthog	1-5.
	Rhino	Black – 1; White – 2-5.
Desert: Where water requirements may be supplied by vegetable foods	Oryx	12-60 up to 1 000, concentrated in rains; exceedingly nomadic.
	Addax	c. 20 but up to 200. Migratory in rains.
	Dorcas Gazelle	Up to 20-60; exceedingly nomadic.
	Barbary Sheep	3-6 up to 20.

as the oryx, addax and gazelle after rain had fallen. Although occupation of the 'core area' might be considered to correlate with a time when the hunting groups were more concentrated at the base camps, larger groupings can be expected to have come together for communal drives when the highly migratory desert animals were concentrated in the erg or reg areas after rain. Such communal hunting drives were later supplemented with game traps of the kind known from the Western Desert (Hobler & Hester 1969:125) and were probably conducted as are those described for the Teda (Chapelle 1957:202-6). At other times of the year the people can be expected to have been dispersed into small family or kin groups for individual hunting. These smaller units may have been very similar to the small camps described by Schild & Wendorf (1977:113-21) in the Western Desert or to the camp of the Neolithic of Capsian tradition at Borj Mellala in the northwest (Tixier et al. 1976).

We have no reliable way of knowing just how many individuals occupied camps of this kind. However, data provided by a study of residence dynamics among the nomadic Ouled Sayah in the region of Touggaourt in the Algerian Sahara may be relevant here (Pelligra 1975) although, in this instance, higher densities must be expected in view of the stock-herding and date palm plantations on which the Ouled Sayah economy is based. Their territory covers more than 800 km^2 and includes the Wadi Rhir, the erg to the east and a stony mountainous region to the west to which they move in the spring when water and grass are to be found there. Some 5 000 nomads live in this territory where there are ten encampment areas, two in the mountainous part, three in the wadi and five in the erg but only one is of any great distance from the wadi. Camps may have from 10 to 25 tents, set wide apart. One family lives in a tent which is estimated to contain, on an average, five individuals. What emerges clearly from this study is the way in which family units and single individuals move about within the territorial range. Marriages, hospitality, war, etc., bring people together and grazing requirements and other economic and social reasons cause



Legend

1. Dry season camps of dispersed family units (Group A) close to permanent water in core area: local foraging only.
2. Mobile transitory camps, two or more family units, for hunting in *erg* after beginning of rains.
3. Concentration of larger groups by temporary water sources for communal hunting of migratory game and interaction with other bands (Group C), other groups (open arrows).
4. Regrouping in early part of dry season into temporary camps by piedmont springs for Barbary sheep and gazelle hunting.
5. Visits to sources of raw materials for stone working, pigment, etc. and interaction with other groups (Group B), other groups (open arrows).
6. Falling back on permanent water of the core area as the dry season advances.

Figure 22.5 Model for prehistoric hunter/gatherer movements in the Sahara.

them to split up so that the situation generally is one of high mobility, the camps continually and rapidly fluctuating in size and composition. This situation is not unlike that described by Yellen & Harpending (1972) for the !Kung Bushmen. The Ouled Sayah population is more sedentary in the winter but this may be due to their occupation with the date plantations during that season.

Prehistorians should, therefore, bear in mind that a single camp site covering a relatively restricted area may represent only one of several other, widely dispersed family units constituting a single encampment. The high mobility of individuals and groups appears to be a general pattern among desert nomads. It is, perhaps, this phenomenon that is reflected in the technological traits that are shared by widely separated sites of the Epi-Palaeolithic and Neolithic complexes, thus confirming the relative rapidity with which innovations and technical advances were transmitted throughout the desert.

Before the Neolithic, the available data are quite inadequate to enable any quantified estimate of group size to be undertaken for any cultural entity. There is, as yet, no means of knowing whether the apparently large accumulations of Acheulian and Aterian artifacts in the desert were the result of one or many seasons' occupation of a site. The latter, however, seems a more reasonable suggestion since the high artifact density shown by the majority of these sites is more likely to represent continued re-occupation of 'core area' base camps to which hunted animals were brought back for butchery and distribution. Any hunting population lacking the relative security that domestic stock and date palms provide for the Ouled Sayah can be expected to have been appreciably smaller, perhaps less than half, and, during the Middle Palaeolithic, the same home range probably held no more than 100 individuals. Acheulian and Middle Palaeolithic sites vary considerably in the area covered and the density of artifacts. The size ranged from 16 m^2 to 31 415 m^2 for the Middle Palaeolithic in the Nile where also high artifact density is correlated with multiple re-occupation. It is suggested that sites of 250 m^2 may have been occupied by a group of one to five families (Hassan, this volume). The relative scarcity of Epi-Palaeolithic sites in the desert suggests that densities at this time may have been appreciably less than this, though the larger areas covered by sites of the terminal Pleistocene in the Nile Valley appear to show that it became possible for greater population densities to build up there. Estimates of from 5 to 40 persons occupying a basic nuclear settlement have been suggested (Hassan, this volume) and an increase in the overall number of sites in the Nile Valley at this time also reflects an overall population increase. In addition, the climatic amelioration of the terminal Pleistocene/early Holocene can be expected to have encouraged rapid re-occupation of the desert by any overflow from the region of the Upper Nile so that groupings of similar size at the lakeside base camps where fish and wild grain were plentiful would not be unexpected.

22.6 A MODEL FOR HUNTER/GATHERER LAND USE IN THE SAHARA

A model for the pattern of land use and interaction of hunting/gathering populations in the Sahara during the late Pleistocene/early Holocene might be construc-

ted on the basis of the movements and behaviour of ethnographic groups using the desert and the northern and southern Sahelian regions today (Figure 22.5). Such peoples as the Hoggar Tuareg (Nicolaisen 1963; Gast 1968), the Teda (Chapelle 1957), the Ouled Sayah Beduin (Pelligra 1975), the woDaaBe Fulani (Dupire 1962) or the Nemadi (Gabus 1952) might be taken as examples. Of these, only the last still live by hunting and gathering, or did until quite recently. The others are all pastoralists who have adopted a close symbiotic relationship with cultivators, if they do not now sometimes themselves cultivate. In general, however, it is permissible to assume that seasonal movements which are dictated by the grazing and water requirements of their domestic herds will be broadly similar to those of the game animals, since the seasonal regimen of resource availability can be expected to have remained essentially the same.

Although four, sometimes, five, seasons may be recognised on the basis of climatic phenomena and resource availability, the two most significant periods, that control the entire life of the people, are the dry season and the rains. The dry season is cold at the beginning and is also a time of scarce resources or even famine; the rainy season is much shorter and is a time of relatively abundant, temporary water sources, plant foods and grazing for stock. Such rain as does fall on the desert, in those regions lying north of the 20° parallel, occurs generally in January and February. South of this line, the rain falls mostly in July and August.

Pastoral populations and the Nemadi hunters usually fall back on their permanent water sources as the dry season advances and, by December with the arrival of the strong southerly winds (harmattan, etc.) that blow from the north right across the continent, the cold season sets in. Pasture is dried out by these winds and water supplies dwindle and, as the season advances, the temperature rises and it becomes a time of great heat. The latter part of the dry season is also a time when the reserves of stored food have to be drawn on in order to survive. Indeed, in the Sahara as it is today, it is unlikely that pastoral nomads could continue to exist were it not for the milk and milk products of their herds.

In western Mauritania, the Nemadi who have spent the dry season in proximity to their permanent water sources (wells), usually in old, dry alluvial depressions and close to the escarpments, move, with the coming of the rain in January and February, out into the waterless erg to hunt addax, oryx, dorcas gazelle and other game that collect there for the grazing and such ephemeral water sources as may be found. This is the time of extended hunting expeditions – of over 300 km in one direction – whereas, during the dry season, hunting trips are of short duration and within no great distance from the permanent water.

A generally similar regimen of movement is found among the pastoral nomads of the southern and central parts of the Sahara and Sahel. During the dry season, the population is isolated and split up into a number of small family groupings and carries out only short journeys round the wells, searching for pasture. In the cold period, the people use the pasture furthest from the wells first, gradually falling back on that closer to the wells, or other permanent water sources, as the dry season advances. In contrast, during the rainy season, they are more or less continually on the move to the playas which provide temporary water

sources with good grazing in their vicinity. This is also the time when fruits, leaf relishes, roots and wild grains become available and are collected. Larger groupings are now the rule and this is the main period of interaction for exchanging news, information and goods. It is during this time also that weddings are arranged and dances and important feasts and ceremonies take place and groups and individuals may walk long distances to take part in these festivities.

The distance which a group may have to move between its dry season (permanent water) camps and its rainy season area depends, of course, on the ecological nature of its terrain and some groups need to move far less than others. Among the woDaaBe Fulani in the Sahel, for example, some groups in more favourable circumstances never have to move very far from permanent lakes while those who need to pasture their stock on the salt grass growing round the playa lakes may have to move several hundred kilometres.

In a prehistoric context, therefore, it can be expected that the cold and dry months of the year would have been the time when kin-related groups would have split up into semi-isolated family units coming together again during the rains and the season of the wild grain harvest for social interaction and communal hunting. The high mobility recorded by Yellen (1977) and Lee (1972) for the !Kung San in the Kalahari also appears to be true of the Nemadi in Mauritania (Gabus 1952:52-3) where there were four groups having their permanent water bases on the Hodh and Adrar escarpments bordering the western limits of the El Djouf depression, a distance of some 600-700 km. During the rains, they move out into the erg and mobile dune areas in the Djouf to hunt and enjoy the 'vie sociale' of the dunes.

On the assumption that the prehistoric populations of the Sahara, like those of the ethnographic present, would have made use of two or three different kinds of habitat, it can be expected that each prehistoric group would have had a 'core area' occupied during the dry and cold seasons, and other areas – stony desert ('hamada'), piedmont and mountain ridges and plateaux and fixed and mobile dune areas (ergs) – to which they moved during the more humid part of the year. Figure 22.5 has been drawn to suggest the way in which groups might have made use of these different habitats and the various resources available there. Emphasised here is the contrast between cold/dry season and more humid/rainy season occupation; the high mobility and wide range of different units composing the band; the importance of the communal hunting and general socialising and exchange that takes place during the 'rains'; and the opportunities for regular interaction between individuals and family units with groups from other bands. This kind of model for social and economic organisation can be modified to explain the repopulation of the desert with the return of more favourable climatic conditions at the end of an arid episode. It also shows the way in which information and artifacts might be transmitted over considerable distances in a reasonably short time, since individuals moved over several hundred kilometres.

It might be asked to what extent such a model would be changed by the existence of lakes with abundant fresh water, fish and other resources. Without studies of prehistoric land use patterns and quantitative estimates of nutritional values, no reliable answer can be given. It is even possible that the most favour-

able localities might have seen the growth of permanent communities of fishermen who exchanged their fish for meat and other goods with the mobile bands of hunters. This seems less likely, however, before the advent of pastoralism and, for the 'Older Neolithic', it is more probable that the general pattern of life would have been similar to that suggested in the model but with the period of stress during the cold and dry season considerably reduced or even eliminated.

22.6.1 *Pastoral Neolithic*

The addition of livestock would have made some larger groupings possible and probably gave rise to a further increase in the overall density of occupation. Home ranges must have varied considerably depending on the availability of water and grazing in the 'core areas'. Also, by reason of the greater mobility necessitated by stock herding, interrelationship between population groups must have become easier and more regular. Besides resulting in a more organised system of transhumance, it can also be expected that as the herds, particularly cattle, increased in size, greater emphasis would have been placed on ownership of territories which were, at times, also defended, as the rock art appears to show. There is little means of establishing the size of nomadic, pastoral bands but one Neolithic site at Adrar Bous covered some 25 000 m^2 and must have been reoccupied many times.

Densities for the Pre-Dynastic cultivators in the Nile Valley would, it is believed, not be in any way comparable to densities in the desert since it remains to be confirmed that there was anything more than purely sporadic cultivation until the first millennium B.C. Of the 464 plants known to the Hoggar Tuareg, 80 produce parts that can be eaten and, of these, 10 are important – 3 grains (*Panicum turgidum; Aristida pungens;* and *Chenopodia vulvarium*), 2 leaves, 1 fruit, 2 roots and 2 parasites; most vegetables are also stored (Gast 1968:244). In times of plenty up to 1 000 kg of grain can be collected by a Tuareg family (Nicolaisen 1963:181) but, in times of famine, it is necessary to extend the territorial range. For example, in the 17th century, the Imenames Tuareg ranged, not only over the whole of the Hoggar but covered the Adrar des Iforas and a part of the Aïr and Ajjer as well, a vast area of about three million square kilometres (Gast 1968:245). The richer, early Holocene environment of the Sahara is unlikely to have dictated annual movements of such magnitude, which were also probably encouraged by the rewards to be obtained from raiding. Seasonal movements, however, such as those of the WoDaaBe Fulani (472 500 km^2) (Dupire 1962:81, Map 3) would not be unexpected and would be dictated by the needs of their herds. Possibly, for the Neolithic pastoralists in the desert (4 000-2 000 B.C.), kin-related encampments might have consisted of between five and 15 families or some 25-75 individuals.

Cattle pastoralism and the increased desiccation that was coincident with it is likely to have introduced an element of competition for grazing between the domestic herds and the wild game. It might, therefore, be possible that the numerous arrowheads and microliths associated with the Neolithic settlements of this time are not only an indication of the continued importance of hunting and wild meat resources. Hunting obviously reduced the necessity to slaughter domestic animals, except for ceremonial or religious purposes, but this 'weaponry' element might also be evidence of a significant attempt to increase the availability of grazing for the stock by reducing the game herds. Milk and milk products would have enabled the pastoral populations to counteract to some extent the disappearance of surface water supplies though, while cattle remained the most important domestic animals, it was never possible to be very far from a water source.

The Neolithic Saharan pastoralists can, therefore, be considered to have followed a broadly similar pattern of land use to that proposed for the hunter/gatherers. The transhumant movements can be expected at first to have been more erratic than they later became after the traditional movement pattern was established, only to be disrupted again with the increasing desiccation that drove some cattle pastoralists out of the Sahara into the Sahel/savanna and the valley of the Nile. Here they established with the inhabitants of those regions symbiotic relationships similar to those which had pertained with the fishers and hunters in the desert and akin to those that pertain today throughout the whole of the West African Sahel and savanna.

22.7 CONCLUSIONS

In-depth studies of prehistoric sites where organic remains are preserved (e.g. Deacon 1976) show that little can be learned about the economy from a study of the stone tools themselves. While these remains, in general unspecialised, can be assumed to have been used in various selected ways to simplify the food quest, it is only when they are found in direct relationship with food or other processed materials that it will be possible to make any reliable generalisations about what most of these tools were used for and so of what the economic base of the group probably consisted. Technology and stylistic variation might provide evidence for cultural entities, especially if the boundaries can be established. Here again, however, the need to ensure contemporaneity and to assess the influence that different raw materials may have had in modifying technique and stylistic modes is apparent. It is possible that the different facies of the Acheulian may, in time, come to be recognised as something more than technological variations (Figure 22.1). During the Palaeolithic, the Mousterian of the Maghreb, Cyrenaica, the eastern Sahara and the Nile Valley can, similarly, be regarded as showing considerable variation between the different tool-kits (Figure 22.3). At the same time they exhibit obvious, broad general affinities, the one facies with the other (Crew 1975) and give the first indication of an east/west or west/east movement from the Maghreb across the Western Sahara to the Egyptian Nile, or vice versa.

With the appearance of the Aterian it is possible to distinguish several different facies (see above pp. 546-550) but also two major divisions become apparent. The first of these lies north of the Hoggar and does not appear to extend into the Western Desert of Egypt. The second lies mostly south of the Hoggar and extends eastwards to include the Western Desert oases. This broad dichotomy becomes even more apparent with the appearance of the Epi-Palaeolithic and pre-agricultural Saharo-Sudanese Neolithic tradition. The first is found mostly in the north, while the second stretches across from the Sudanese Nile to include

the central and southern Sahara. Although less well known prehistorically, the western Sahara shows more general affinities with the northern traditions than with those in the central Sahara.

Of particular interest is the evidence from the Western Desert sites reported by Wendorf & Schild where the Early Khartoum tradition does not extend to the more northerly Western Desert oases (e.g. Kharga, Dahkla, etc.) and it seems possible that a cultural boundary can be recognised here which can probably be connected with the ecological boundary between the zones of winter and summer rains.

Bearing in mind the east/west vegetational zonations and the way these induce east/west movements of people and animals, it is possible to speculate that the Sahara may have been repopulated at the end of the Pleistocene from two main directions. These are: from the north, in particular from the northwest and, secondly, more specifically, from the Upper Nile in the Sudan westwards and northwestwards into the southern and central Sahara. This hypothesis takes no account of any possible repopulation from the southern savannas but, as yet, we have no evidence as to the form this might have taken since virtually no dated sites from this time are known from the northern part of the West African savanna. We may be reasonably certain that movements into the desert indeed took place from this direction because of the numerous depictions of individuals with negroid physical and cultural traits in the rock art of the earlier Holocene. These regions became particularly significant later, after increased desiccation in the desert triggered the southward movement of pastoralists into the savanna after, and probably also before, 2 000 B.C.

This overview has stressed the problems of interpreting human behaviour patterns and cultural associations in the desert rather than attempting to give answers which cannot be provided at this time because of the incomplete nature of the available evidence. The suggested broad patterning that is now beginning to show up needs to be critically examined and, when studies of prehistoric sites in relation to the whole ecological system of which they are a part, begin to be made, it should be possible to understand much better the nature of the changing behaviour patterns through time and also the extent to which the Nile Valley initiated or was the recipient of food-producing economy.

Although the oldest dates for domesticated animals and plants in Africa come from sites in the Sahara, it should not be lost sight of that the significant ones come only from two or three sites. While taking note of their possible implications, therefore, it would be unwise to accept these implicitly until more dates from newly excavated sites of the 8th to the 5th millennia B.C. in the flood plain of the Nile become available for comparison. We already have the example of the faulty hypothesis of Bantu origins and movements, founded on inadequate radiocarbon dates, that serves to warn against too hasty an acceptance of the Saharan origins for domestication in the north of Africa which these few dates imply. It is clearly a possibility that the economic richness of the flood plain reduced or removed entirely incentives to develop agriculture there but, on the other hand, if the socio-economic pattern along the Nile in the terminal Pleistocene has been interpreted correctly, then the larger and more rigidly structured societies that developed there by 10 000 B.C. must have been faced with a continuing need to expand their economy and territory to keep pace with increasing population size and an ever more intensive use of resources. The most important single piece of research needed in North African prehistory today is a systematic study of early Holocene settlement and the origins of domestication in the valley of the Nile. When the results of such a study become available much of the present uncertainty will disappear.

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Epilogue

An important conclusion to emerge from detailed multidisciplinary investigations of long continuous sedimentary sequences in Africa and in the adjacent oceans is the high degree of climatic variability evident at all scales of time.

In the comparatively uniform marine environment, careful study of the sediments, microfossils, and isotopic composition of long cores has enabled the reconstruction of temperature variations and of changes in global ice volume. Bearing in mind the very slow rates of deep sea sedimentation, the dominant periodicity to emerge is the 100 000 years cycle during which the high latitudes were alternately ice-free and ice-bound.

In a wide range of African environments, each characterised by marked changes in former hydrological conditions, periodicities are clearly apparent at scales ranging from decade to century to millennium. The curves of lake level fluctuations presented by Servant and Servant-Vildary in Chapter 6 and by Gasse, Rognon and Street in Chapter 15 give a very good idea of this variability at different scales of time. That the last two million years have witnessed recurrent and widespread climatic variations now seems beyond dispute.

The impact of these cyclical and random variations of climatite upon the flora, fauna and man is reflected in the disappearance or migration of plants and animals throughout this time.

In the light of the essays in this volume, it appears that the response of prehistoric man has also varied. During the intervals favourable to life in the desert, we witness the emergence of relatively widespread and uniform cultural traditions. At other times, severe environmental constraints imposed a higher degree of specialisation and adaptation to specific local habitats. Those unwilling or unable to adapt to the social and ecological repercusions triggered off by the changing circumstances migrated or else became extinct.

It is perhaps not unduly fanciful to see in these constantly varying environmental pressures, the incentive or the cause which finally resulted in the first successful attempts at plant cultivation and animal domestication – in short, in the civilisation we know today.

Epilogue

Depuis que l'on s'efforce de rechercher de longues séquences sédimentaires continues et de les étudier en plus grand détail à l'aide de toutes les méthodes disponibles, un résultat convergent est apparu tant sur le continent africain que dans les océans voisins: celui de la grande variabilité des conditions climatiques et du milieu à toutes les échelles de temps.

Dans les océans, en milieu relativement homogène, le caractère continu de la sédimentation a permis par l'étude sédimentologique, paléontologique et isotopique des longues carottes de dégager l'allure générale de l'évolution des températures et du volume total des glaces sur le globe. Compte tenu des taux de sédimentation très faibles dans les grands fonds océaniques, c'est principalement depuis 700 000 ans au moins une périodicité de l'ordre de 100 000 ans qui apparaît et qui sépare les états d'englacements successifs connus par les hautes latitudes septentrionales.

Sur le continent africain, et dans tous les types de paysages locaux, des fluctuations très marquées apparaissent dans les conditions hydrologiques et donc dans l'environnement. Des 'périodicités' de quelques dizaines d'années, de siècles ou de millénaires ont clairement été mises en évidence. Les courbes présentées dans plusieurs articles de ce volume et notamment les courbes de variations du niveau des lacs par Servant et Servant-Vildary (chapitre 6) et par Gasse, Rognon et Street (chapitre 15) donnent une excellente image de cette variabilité sensible à différentes échelles de temps.

Le caractère permanent de ces variations climatiques étendues et répétées depuis plus de deux millions d'années est donc un fait qui semble solidement établi.

Ce sont ces variations cycliques mais irrégulières du climat que les êtres vivants, végétaux, animaux et hommes ont subies. Elles ont provoqué de déplacement ou le remplacement des végétaux et des animaux.

A la lumière des études présentées dans ce volume, il semble que l'homme préhistorique a réagi de manière assez variable. Durant les intervalles favorables à la vie dans le désert, on constate l'épanouissement d'une culture relativement uniforme et étendue.

Aux époques de dures contraintes exercées par l'environnement, il lui a fallu acquérir un plus haut degré de spécialisation pour s'adapter à des milieux spéci-

fiques et survivre. Sinon migrer ou disparaitre lorsqu'il n'a pu s'adapter aux répercussions biologiques et sociales de ces changements répétés du milieu.

Peut-être faut-il voir dans cette incessante pression de l'environnement le moteur ou la raison de ce qui a conduit l'Homme à l'élevage, à la culture, et finalement à la civilisation telle que nous la connaissons aujourd'hui.

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