DOUBLE SUPPLEMENT: DINOSAURS AND OTHER VANISHED SPECIES

VOL. 175, NO. 6 JUNE 1989

NATIONAL GEOGRAPHIC

The March Toward Extinction 662

MALTA CHANGES AGAIN 700

COMPUTER IMAGES: THE NEW CREATION 718

AT HOME WITH TIBETAN NOMADS 752

LIFE IN A NUTSHELL 783

OFFICIAL JOURNAL OF THE NATIONAL GEOGRAPHIC SOCIETY WASHINGTON, D.C.

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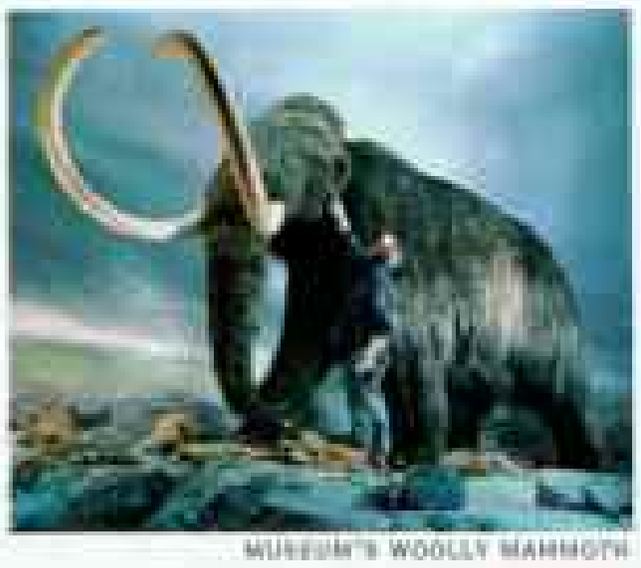


MUSEUM'S WOOLLY MAMMOTH

What Caused Earth's Great Dyings? 662

Since life began on this planet, at least five worldwide catastrophes have erased millions of animal species—and a sixth is under way. Rick Gore and photographer Jonathan Blair report the latest findings on these extinctions—evidence of climatic shifts and huge meteorite impacts. A double supplement focuses on the losses, from the dinosaurs to the vanishing species of today.

PROCESSION IN MALTA

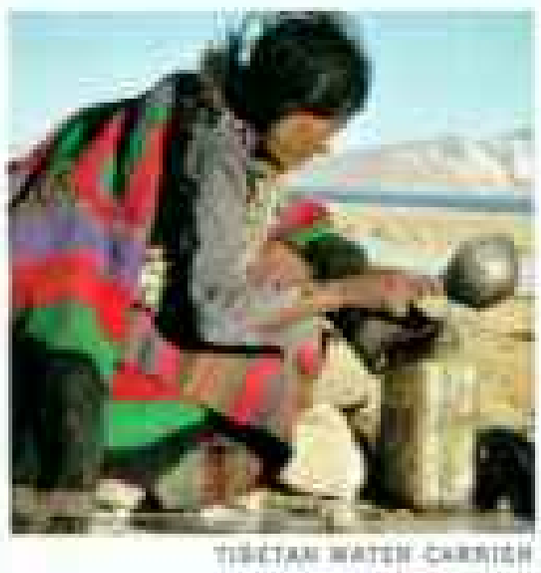
Malta: The Passion of Freedom 700

Under foreign rule for centuries, this Mediterranean island nation reflects a past patterned by Phoenicians, Carthaginians, Arabs, Knights of St. John, and the British. Now celebrating 25 years of independence, Malta takes a neutral stance in today's uneasy world, according to William S. Ellis. Photographs by Bob Krist.

COMPUTER GRAPHICS AT WORK

Images for the Computer Age 718

Author-photographer Fred Ward "flies" a jet fighter, peers into the human brain, and chuckles at the antics of an animated cartoon character to show us how computer graphics make impossible visions possible.



TIBETAN WATER CARRIER

The Remote World of Tibet's Nomads 752

On a bleak, windswept plateau in western China, one of the last great nomadic societies on earth survives as herders of yaks, sheep, and goats. Living for 16 months with these Tibetan nomads—who endured years of forced settlement in communes—anthropologists Melvyn Goldstein and Cynthia Beall find traditional ways reviving.

FLIGHT WORM

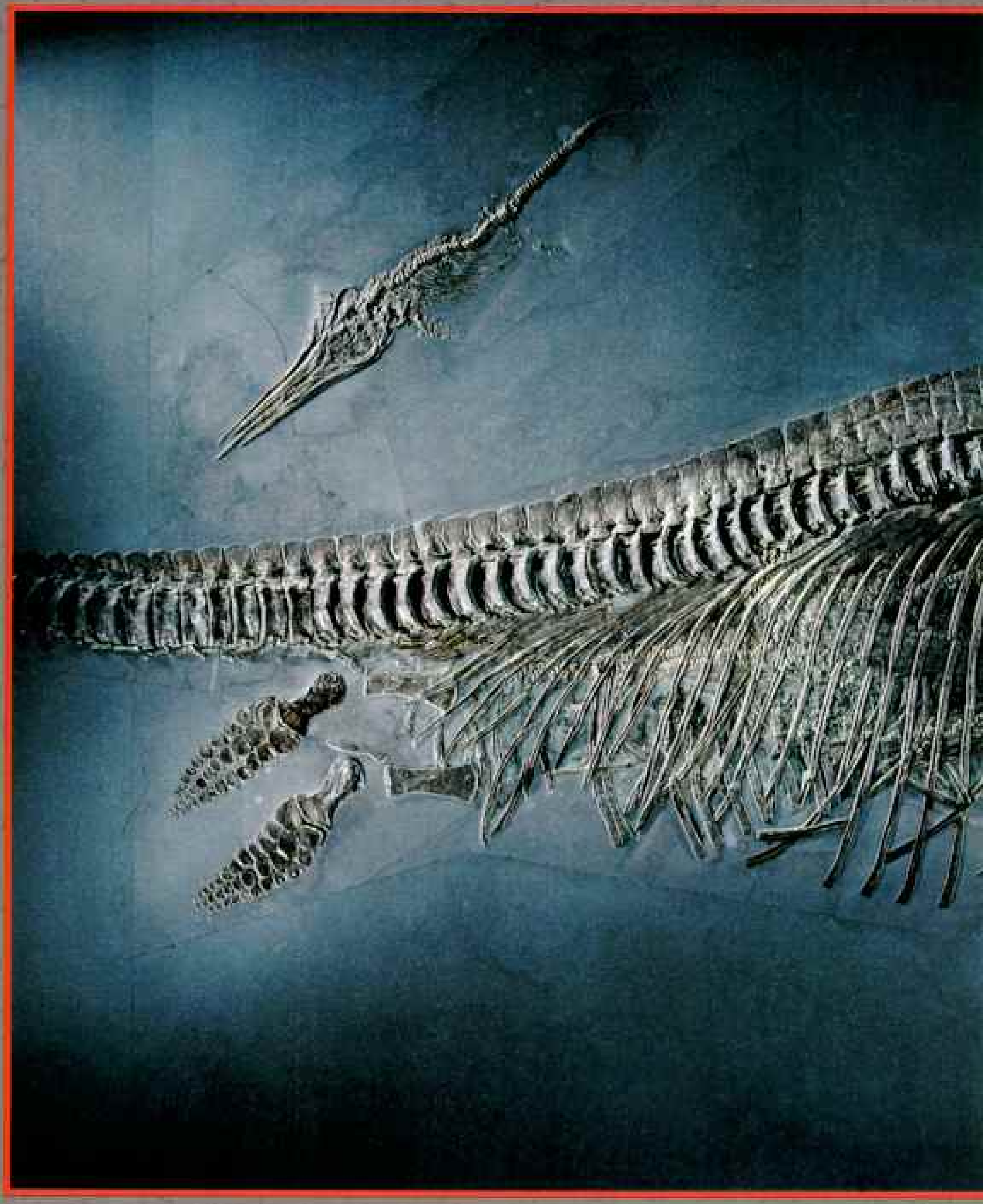
Life in a Nutshell 783

Most acorns don't grow up to be mighty oaks. The reason: A host of creatures invade the shell for food and shelter. Zoologist and photographer Mark W. Moffett takes a close look.

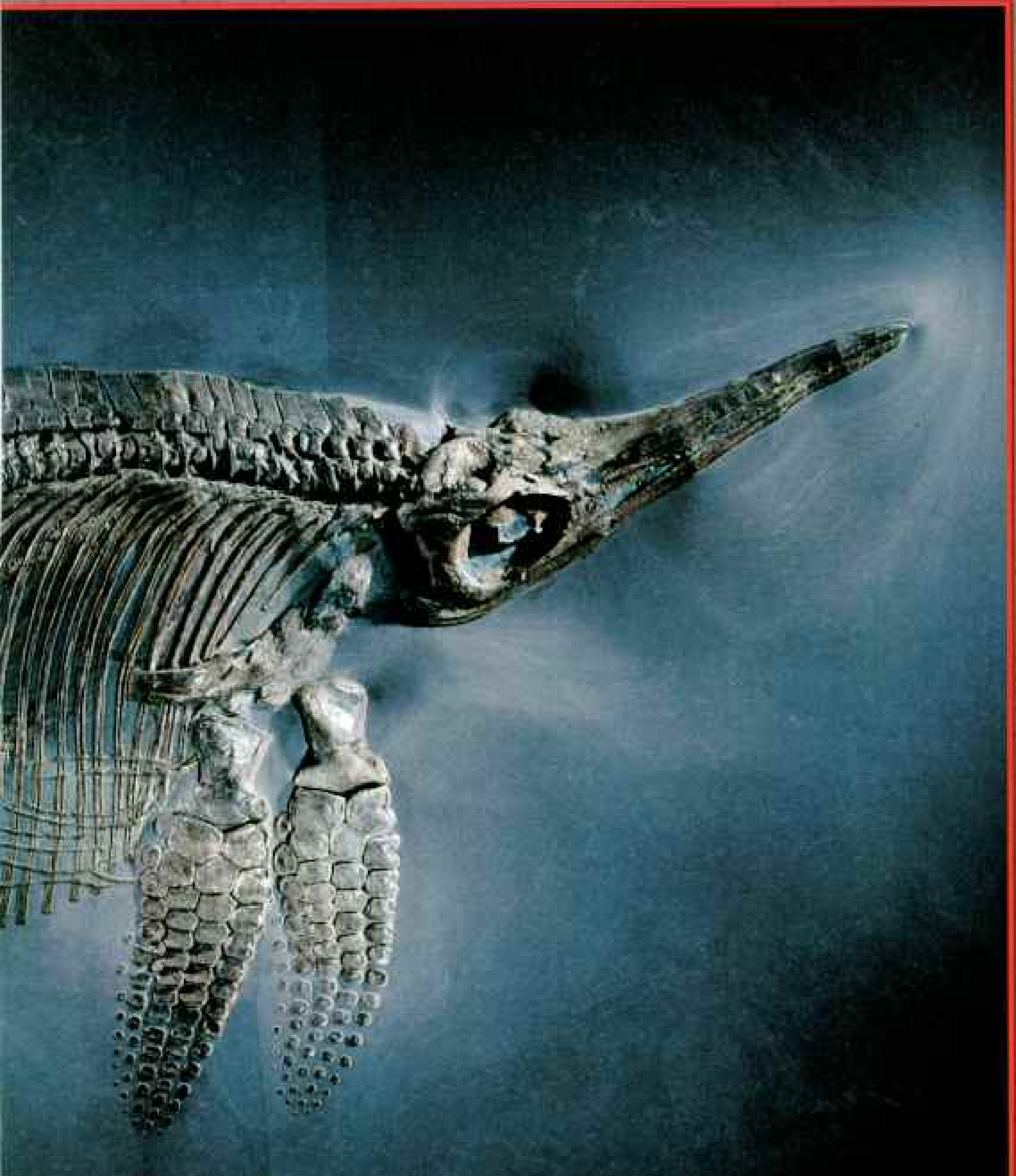
COVER: *Flanked by adult "ultrasaurs," among earth's largest land animals, a 12-foot-tall juvenile crosses a western Colorado river plain 140 million years ago. From a painting by John Gurche on this month's supplement.*

THE NATIONAL GEOGRAPHIC MAGAZINE
IS THE JOURNAL OF THE NATIONAL GEOGRAPHIC SOCIETY

FOUNDED 1888



Mining the fossil record, scientists struggle to explain mysterious episodes in which many of earth's species suddenly die out. Ichthyosaurs—such as this mother with an infant and five unborn babies—survived two great extinctions only to perish before the dinosaurs 66 million years ago.



PHOTOGRAPHED AT MUSEUM HAUFF, HOLZMADEN-TECK, WEST GERMANY

Extinctions

By RICK GORE ASSISTANT EDITOR

Photographs by JONATHAN BLAIR

HE WAS THE LAST of the free fliers, this ungainly bird his captors nicknamed Igor. His keepers now wince when they hear him called that. California condors are supposed to have local Indian names.

Chumash. Miwok. Pomo. For time beyond memory Indians throughout the West have regarded the condor as a god. His spirit, some say, inspired legends of the thunderbird, whose flight is responsible for the weather. Thunder is the flap of his wings, lightning the flash from his eyes. Today Igor's eyes, as he perches in his pen at the San Diego Wild Animal Park, are the eyes of extinction.

Igor, officially titled AC-9, for adult condor number nine, was the last wild survivor of his species. Amid great controversy he was trapped in April 1987 and brought to wait—and, zoo officials hope, to breed—along with a few comrades, until the world might once again be safe for condors.

Igor's flying prowess fires public opinion. Since the 1930s millions of dollars have been spent to save California condors and preserve their habitat. That power has bought the condors time—to sit, remote from human contact, in this large fenced enclosure. Other creatures have not fared as well. Since Igor's capture the dusky seaside sparrow disappeared from the planet. During that same time as many as a hundred acres a minute of the world's tropical forests, among the most richly populated habitats on earth, have been destroyed. Ecologists can only speculate about how many unnamed, unknown creatures have vanished with the trees. An estimated million species will be lost in the next 25 years—a rate of one every 15 minutes.

THE JAWS of extinction threaten to snap shut on the California condor, foreground, a once widespread species reduced to about 30 birds by the presence of humans. Behind it looms the skull of Tyrannosaurus rex, *a victim of the mass extinction that ended the Cretaceous period. A little T-rex lives on in the anatomy of modern birds, which evolved from dinosaurs some 150 million years ago.*

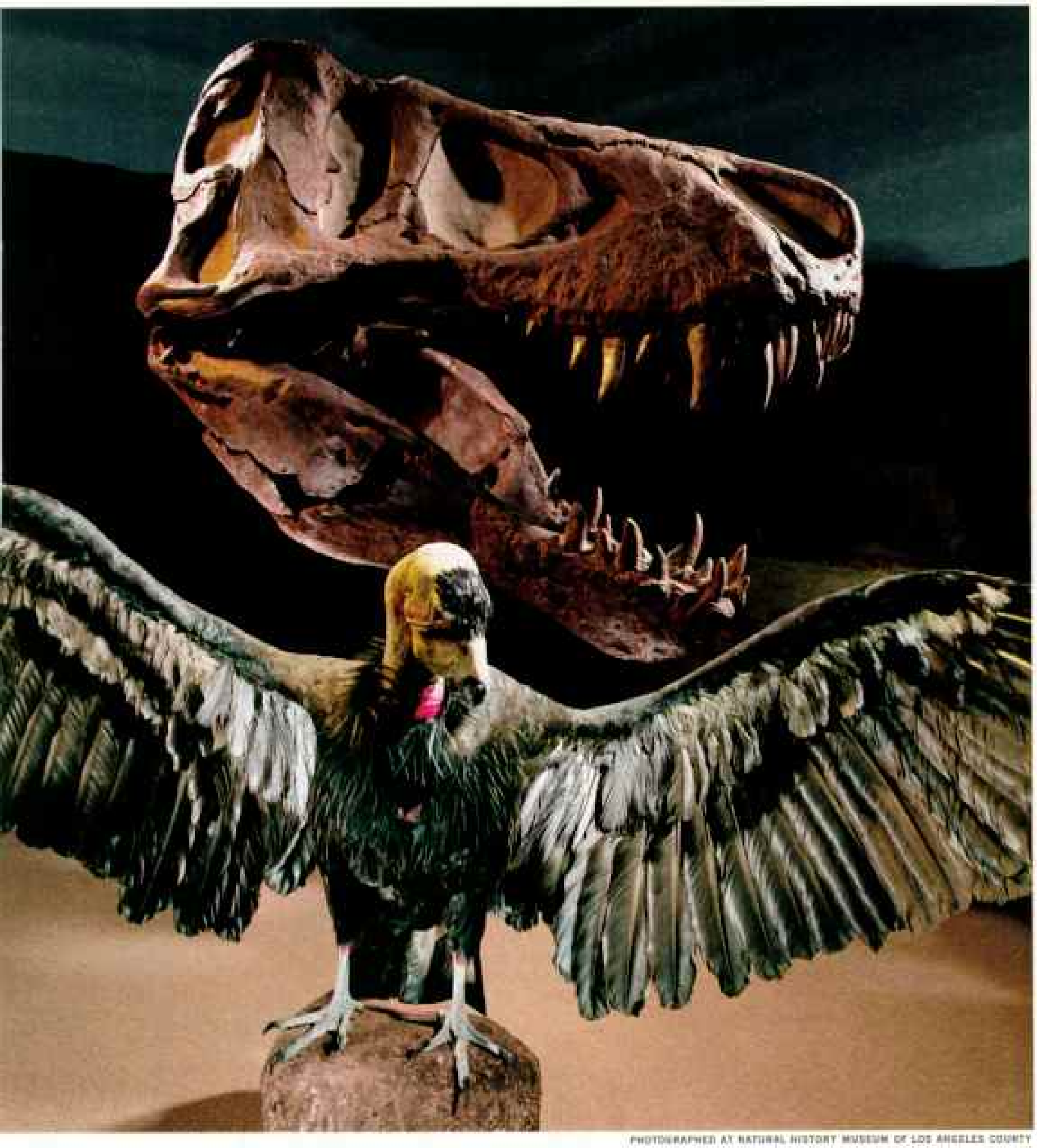
Many scientists contend that our planet is experiencing its greatest mass extinction in 66 million years. At that time the dinosaurs vanished, along with between 60 and 80 percent of other animal species. Some small dinosaurs, however, already had evolved into the first birds. They made it through that extinction. So Igor's eyes are also those of experience.

Igor and his fellow condors bring me back into the present. For months I have been keeping company with fossils. Trilobites. Ammonites. Triceratops. Titanotheres. All were victims of at least 12 mass extinctions, five of them immense, that our planet has endured since the fossil record of animals began about 800 million years ago.

Mass extinctions. The concept has hit science like a fireball during the 1980s. Paleontologists had long realized that occasionally large numbers of species disappeared simultaneously from the fossil record. Those disappearances often marked the close of geologic periods. Yet the causes behind those great dyings had remained obscure. The fossil record was too imprecise, too difficult to read, too pocked with missing pieces and contradictory clues.

All that is changing. Innovative geochemical techniques are coaxing subtle secrets from ancient rocks. Fossils are being reexamined. Computers are finding provocative patterns in the extinctions. In the process the rules of evolution are being rewritten. And so is the four-billion-year history of life on the planet.

The excitement began in 1978 when a team from the University of California and Lawrence Berkeley Laboratory found a large enrichment of the element iridium in a pencil-thin, 66-million-year-old layer of rock from Gubbio, Italy. This iridium-rich clay lay right at the boundary between the Cretaceous period, when there were dinosaurs,



PHOTOGRAPHED AT NATURAL HISTORY MUSEUM OF LOS ANGELES COUNTY

and the Tertiary, when there were none. (Scientists nickname this transition the K-T boundary.)

Because iridium is rare on earth but common in meteorites, the Berkeley scientists—Walter and Luis Alvarez, Frank Asaro, and Helen Michel—proposed that earth had been hit by an asteroid ten kilometers (six miles) across. Wildly controversial at first, the proposal has since been backed up by abundant and convincing evidence from around the globe. Most scientists now concur that at least one great extraterrestrial object struck the planet around the time the dinosaurs died out.

With Alvarez I hike an Italian mountain road to inspect the Gubbio boundary clay. He digs out a chunk and hands it to me.

"You are holding debris from the *(Continued on page 672)*

Mass extinction: the causes...

Through the study of fossil trilobites, below, and other creatures, scientists know that the story of life on earth has been punctuated by mass extinctions. But exactly how they occurred is a matter of unprecedented debate, sparked by the impact theory, lower left, and argued by scientists in fields as diverse as geophysics, astronomy, and paleontology.

"These are exciting times to be looking at extinction," says NASA geologist Bevan French, stating one of the few conclusions

The idea that large objects could strike our planet and cause mass extinctions was considered radical until just over a decade ago. Then a team of researchers at the University of California found high levels of iridium—a metal rare on earth but common in meteorites—in a thin layer of clay laid down about the time dinosaurs became extinct. Their conclusion—that an asteroid hit earth 66 million years ago, wreaking environmental havoc—shocked the scientific world.

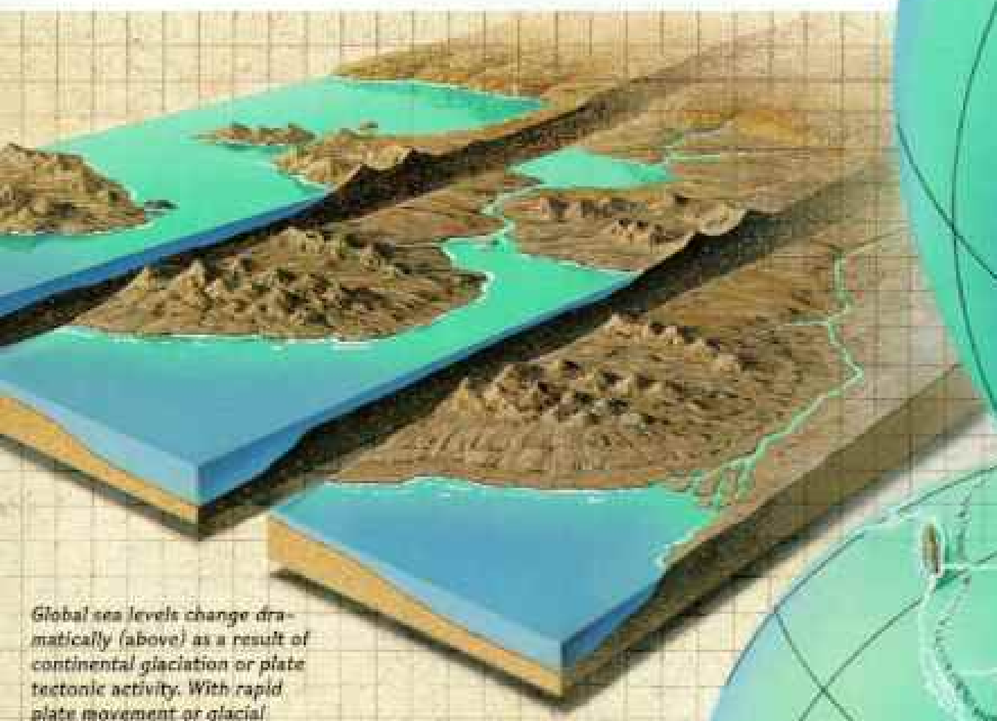
Further analysis of the iridium layer has supported the impact, although scientists are widely divided over its effects.

One theory holds that periods of intense volcanic activity (below) could disrupt the atmosphere—blocking sunlight or creating a greenhouse effect, thereby causing extinctions. Some have suggested that volcanism could have produced the iridium layer.

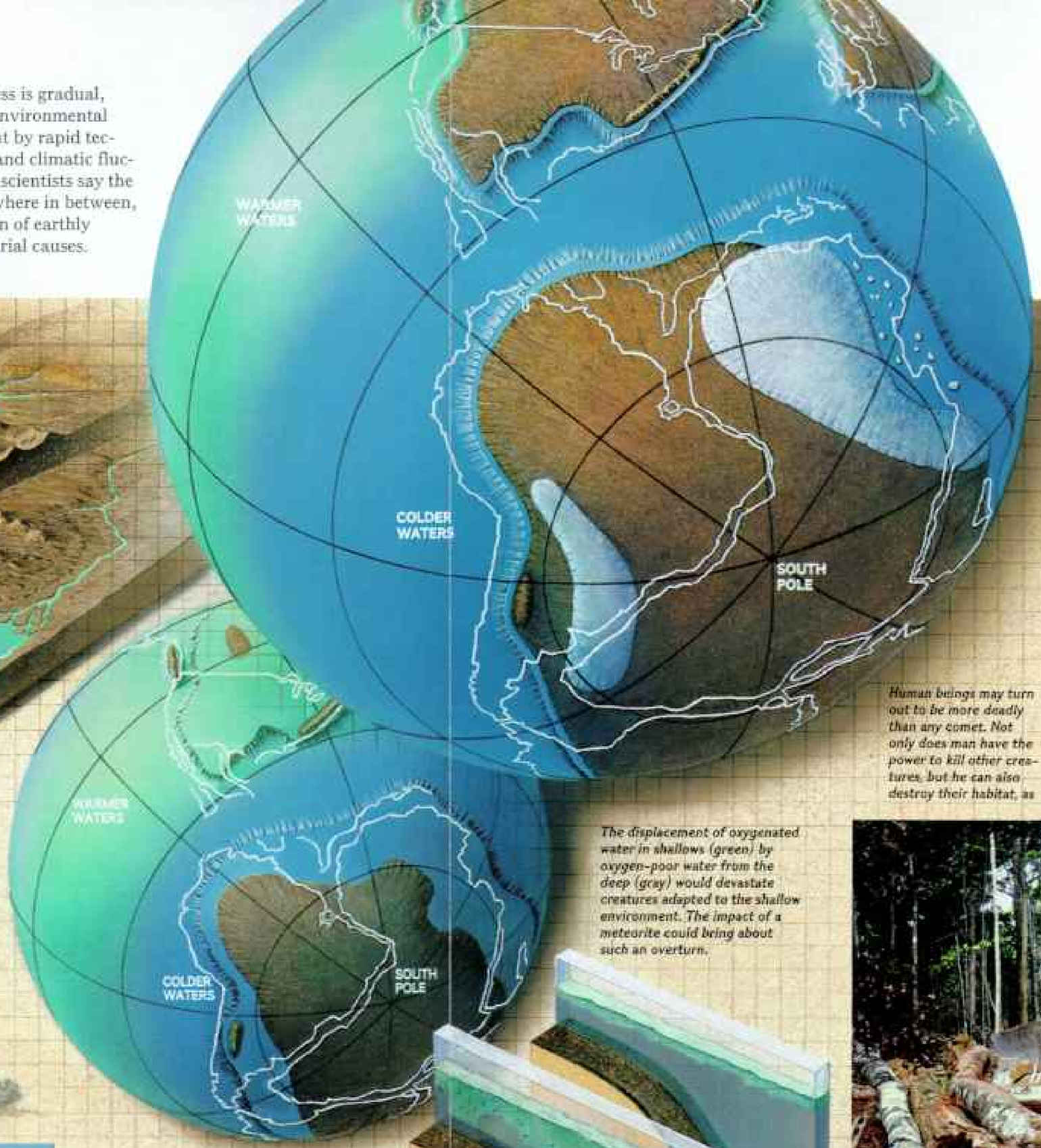
on which all scientists agree.

At one end of the spectrum are those who believe mass extinctions are triggered by brief, cataclysmic events such as the impact of a celestial body or periods of intense volcanic activity. Others argue that the extinction process is gradual, brought on by environmental changes wrought by rapid tectonic, oceanic, and climatic fluctuations. Many scientists say the truth lies somewhere in between, as a combination of earthly and extraterrestrial causes.

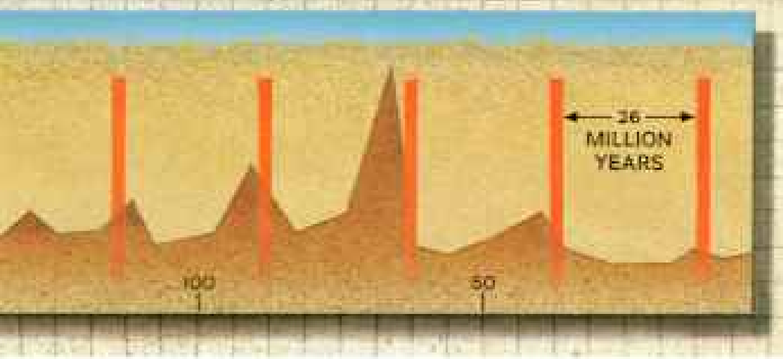
PAINTING BY LLOYD K. TOWNSEND; PRINCIPAL CONSULTANTS: STEVEN M. STANLEY, DEPARTMENT OF EARTH AND PLANETARY SCIENCES, JOHNS HOPKINS UNIVERSITY; J. J. SEPKOSKI, JR., DEPARTMENT OF GEOPHYSICAL SCIENCE, UNIVERSITY OF CHICAGO. PHOTOGRAPHS BY NATIONAL GEOGRAPHIC PHOTOGRAPHERS JAMES L. AMOS (FAR LEFT) AND JAMES P. BLAIR (BELOW); RICHARD ALEXANDER COOKE III (LEFT)



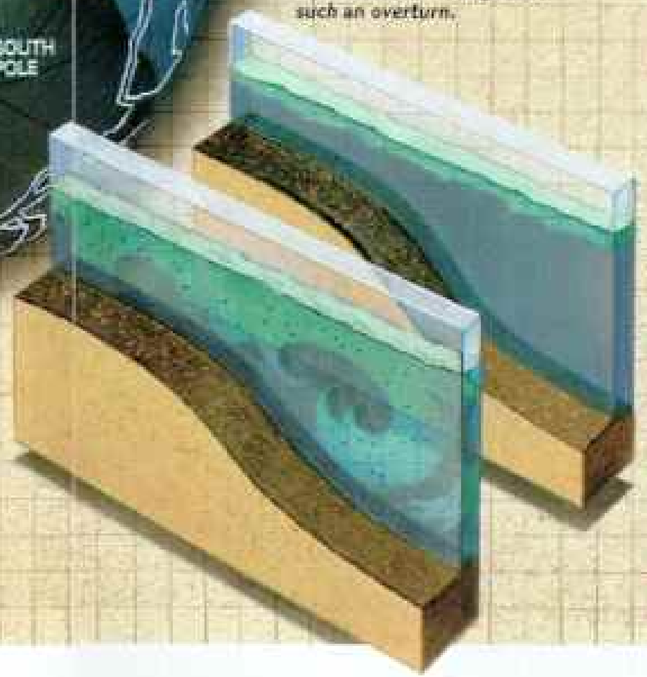
Global sea levels change dramatically (above) as a result of continental glaciation or plate tectonic activity. With rapid plate movement or glacial melting, sea levels rise. Periods of glaciation or tectonic quiet produce low sea levels. This variation can have disastrous effects on creatures living in some of our planet's prime habitats—estuaries and shallow seas.



During the late Ordovician period about 440 million years ago (small globe), warm equable seas (green) dominated the world. Most land was submerged. Five million years later (large globe) continental ice sheets had formed. Sea level had dropped, exposing vast areas of land, and cold water (blue) had expanded into the tropics. As a result, more than 20 percent of marine families perished. Such global climate changes are found throughout the fossil record.



By plotting episodes of mass extinction throughout geologic time, some scientists have detected an interval of roughly 26 million years (orange vertical bars) between extinctions. This suggests a celestial timetable for extinctions—a periodic comet shower, for example, triggered by the passing of a star or other celestial events. According to these calculations, life on earth is safe for another 12 million years.



The displacement of oxygenated water in shallows (green) by oxygen-poor water from the deep (gray) would devastate creatures adapted to the shallow environment. The impact of a meteorite could bring about such an overturn.

Human beings may turn out to be more deadly than any comet. Not only does man have the power to kill other creatures, but he can also destroy their habitat, as in the rain forests of South America (below). Many scientists warn that modern man is creating one of the greatest mass dyings of all time.

The victims and survivors

Extinction has claimed 99 percent of all species that have ever lived—many of them victims of "background" extinction, the piecemeal disappearance of species due to small-scale environmental changes. Others perished in one of earth's major mass extinctions (vertical bars) detected in the fossil record.

"During mass extinctions the rules change," says paleontologist Jack Sepkoski of the University of Chicago. "What had been advantageous may suddenly become a liability."

Tremendous size, for example, helped the dinosaurs dominate for some 140 million years. But they vanished during the great Cretaceous extinction, while many smaller animals, including mammals, survived.

In general, widespread species seem to weather mass extinctions better than those endemic to small regions. Others at high risk are those that live in tropical climates and cannot readily adapt. The ocean is no refuge—extinctions hit marine as well as land dwellers.

Scientists don't yet know why some groups (the trilobites, the ammonoids) survived several mass extinctions, then disappeared altogether—while others (the crinoids, the corals) nearly vanished, then reappeared. Or why fish and mammals have been so successful, radiating to fill vacated habitats. Says Sepkoski, "The whole thing may boil down to luck."

Horizontal color bars feature selected groups. Thickness of bar indicates the number of taxonomic families for each group. Red vertical lines denote mass extinctions.

Blue shading denotes marine family diversity. Spawned in the Precambrian, marine animals suddenly proliferate in the Cambrian seas.

Pie slices, below, represent estimated percentages of marine animal species that have survived extinctions.

TRILOBITES

CRINOIDS

CORALS

TRILOBITES SURVIVE TWO EXTINCTIONS BUT PERISH DURING THE THIRD.

GREAT PERMIAN EXTINCTION NEARLY WIPES OUT CRINOIDS.

AMMONOIDS RECOVER FROM FOUR EXTINCTIONS, THEN DISAPPEAR AT THE FIFTH.

600 MILLION YEARS AGO | 500 | 400 | 300 | 200

CAMBRIAN | ORDOVICIAN | SILURIAN | DEVONIAN | CARBONIFEROUS | PERMIAN | TRIASSIC | JURASSIC

Stromatolite-producing cyanobacteria dominate the world for two to three billion years, then fall prey to a new arrival: animals.

The ancestral supercontinent Gondwana drifts over the South Pole in the Ordovician, triggering a period of prolonged glaciation. Early fish survive, but marine invertebrates and primitive reef builders are hit hard.

Most of the world's fish and perhaps 70 percent of its invertebrate species perish in the late Devonian.

In the greatest mass extinction of all time nearly all Permian species perish.

PERCENT VICTIMS

PERCENT SURVIVORS

PAINTING BY ALLEN CARROLL, NATIONAL GEOGRAPHIC ART DIVISION; DATA FROM J. J. SEPKOSKI, JR., DEPARTMENT OF GEOPHYSICAL SCIENCES, UNIVERSITY OF CHICAGO

MAMMALS

MAMMALS PROLIFERATE AFTER EXTINCTION OF DINOSAURS.

DINOSAURS

DINOSAURS RULE FOR 140 MILLION YEARS, THEN VANISH FROM FOSSIL RECORD.

CORALS SLOWLY DIVERSIFY AFTER PERMIAN EXTINCTION.

FISH

FISH FAMILIES INCREASE DRAMATICALLY AFTER CRETACEOUS EXTINCTION.

AMMONOIDS

900
800
700
600
500
400
300
200
100
0

NUMBER OF FAMILIES

In scientific classifications, a family can include one or many dozens of species. Since families (shown in the graphs at left) can survive an extinction even if all but one of their species dies out, the species losses, estimated in the pie charts at the bottom, are actually far greater than the family data suggest.

100

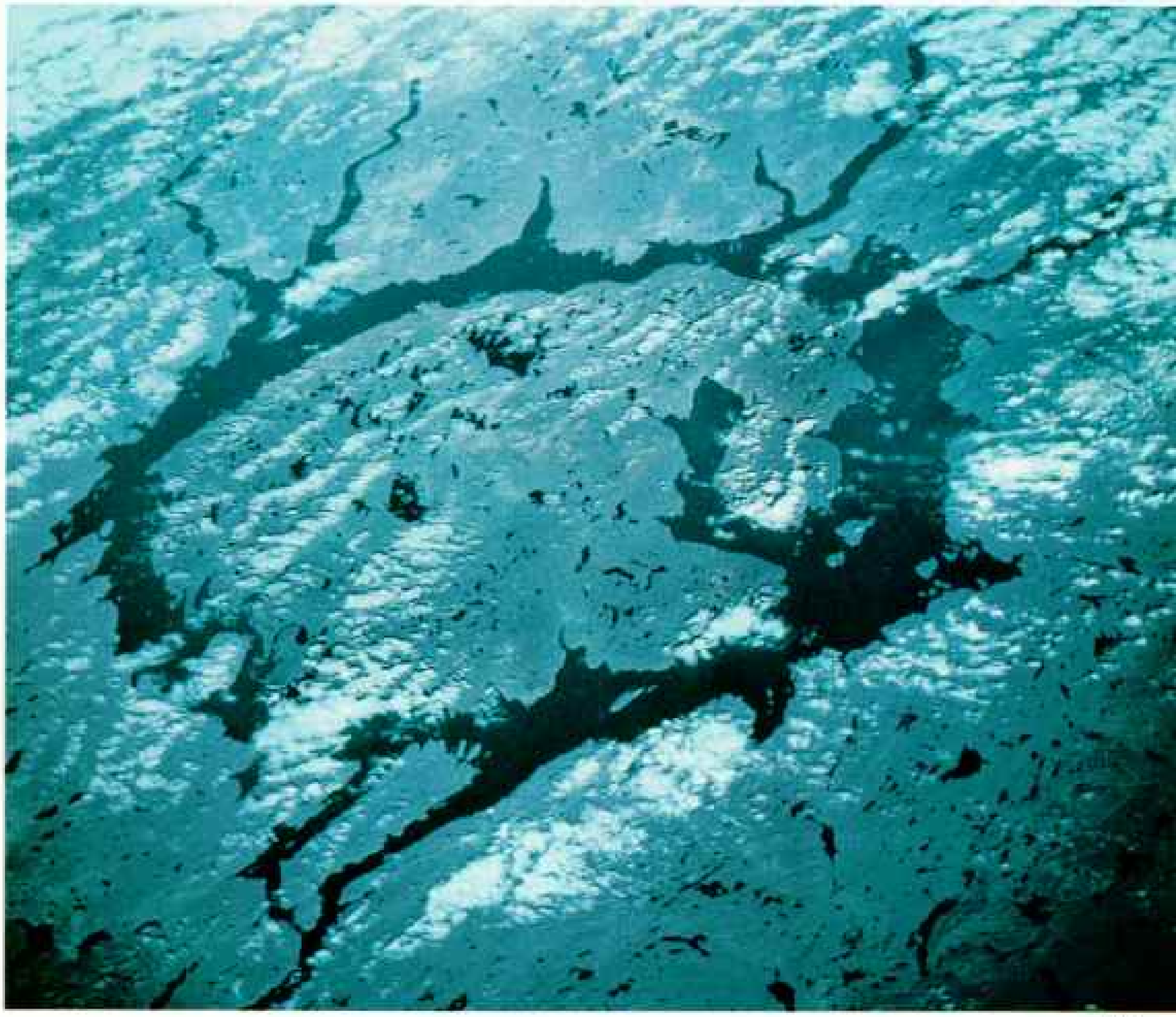
TODAY

CRETACEOUS | TERTIARY | QUATERNARY

At the end of the Triassic, up to 75 percent of marine invertebrate species and some land dwellers vanish, perhaps in an impact-related catastrophe. Two recently evolved groups, dinosaurs and mammals, make it through.

Many scientists believe the Cretaceous-Tertiary (K-T) extinction was caused by a meteorite impact. Victims include a host of marine species.

Some experts believe that earth is currently in the midst of a major mass extinction. It began with the megafauna wiped out by Ice Age hunters and continues today through habitat destruction and other human interventions.



NASA

(Continued from page 665) impact," he says. "In the first days after earth was hit, dust blanketed the entire world. It grew pitch-dark for one to three months. If the impact was on land, it probably got bitter cold. If it hit at sea, the water vapor could have created a greenhouse effect, making things hot. Hot nitric acid would have rained out of the atmosphere—a life-threatening rain that would have dissolved the shells of organisms."

That's not all. A surprising discovery by Wendy Wolbach, a graduate student at the University of Chicago, indicates that the world may have turned even nastier, as it did last summer at Yellowstone National Park.

A red sun shines like the eye of an angry god through the pall of billowing smoke at Old Faithful. A rush of heat. A swirl of suffocating, sooty air. Suddenly on the hillside behind the famous geyser the gates of hell burst open, and a fire storm races down the slope. A million acres on fire. The worst conflagration to strike the vast Yellowstone ecosystem in history. An awesome, terrifying orgy of flame. Yet this holocaust is insignificant compared with what Wolbach believes happened that day 66 million years ago when earth was hit. The entire world caught fire.

Even as Yellowstone burns, Wolbach shows me her evidence in her Chicago office—scanning electron microscope pictures of soot particles

embedded with the iridium layer from three widely separated sites—Denmark, Spain, and New Zealand.

Wolbach's discovery stemmed from the curiosity of her research adviser, cosmochemist Edward Anders, about what kind of extraterrestrial object had struck the planet at the K-T boundary. A meteorite from the asteroid belt? A comet? He suggested that Wolbach attempt to isolate carbon in the iridium layer. Carbon would have trapped certain rare gases brought in by the impacting object. The isotopes of those gases might provide chemical signatures to identify the intruder from space.

To her surprise Wolbach has found an enormous enrichment of soot.

"To get the amount of soot we find," she says, "as much as 90 percent of the world's forests must have burned."

Granted the impact of a ten-kilometer body would be equivalent to 10,000 times the power of all the world's nuclear weapons, how could fire spread so disastrously across the globe?

"Even if it hit in the ocean, the impact would have created a crater 300 kilometers across," says Anders. "A huge plume would have pushed the atmosphere aside. The fireball would have had a radius of several thousand kilometers. Winds of hundreds of kilometers an hour would have swept the planet for hours, drying trees like a giant hair dryer. Two-thousand-degree rock vapor would have spread rapidly. It would have condensed to white-hot grains that could have started additional fires."

In addition, lightning discharges like those in a volcanic eruption could have ignited windswept fires on all landmasses that marched far faster than those at Yellowstone.

CLUE to a killer's identity may remain in rugged central Quebec, where the Manicouagan crater was apparently blasted by a giant meteorite some 210 million years ago. That roughly coincides with a mass extinction of marine species at the end of the Triassic period. Sky-darkening dust from the impact may have played a role.

SUCH DOOMSDAY SCENARIOS strain our belief. And many scientists refuse to accept that such catastrophes have caused the great dyings.

"We don't need an impact," I have heard over and over from paleontologists. "We can explain mass extinctions with earthly causes."

And so they can. Falling sea levels. Ice ages. Collisions of continents. Volcanism. Climate changes. Altered ocean chemistry. The potential mechanisms for mass death are many.

No matter what causes them, mass extinctions do occur. They force a new perspective on the history of life.

"Mass extinctions change the rules of evolution," explains David Jablonski of the University of Chicago, one of the leading extinction theorists. "When one strikes, it's not necessarily the most fit that survive; often it's the most fortunate.

"When their environment is disrupted, groups that had been healthy can suddenly find themselves at a disadvantage. Other species that had been barely hanging on squeak through and inherit the earth.

"The best example is mammals. Dinosaurs and mammals originated within ten million years of each other about 220 million years ago. But for 140 million years dinosaurs ruled, while mammals stayed small and scrambled around hiding out in the underbrush. Mammals all basically looked alike—squirrelly or shrewish and no bigger than a badger—until the dinosaurs disappeared. Then they took off. Within ten million years there were mammals of all shapes and life-styles: whales and bats, carnivores and grazers. Mammals just couldn't do anything interesting until the dinosaurs were out of the way."

LIVING FOSSILS, stromatolites were recently discovered by geologists of the Caribbean Marine Research Center in shallow waters of the eastern Bahamas. The mounds are composed of sticky mats of cyanobacteria (formerly known as blue-green algae) that cement sand and sediments. Appearing in rocks 3.5 billion years old,

stromatolites are the earliest known communities of life. They declined dramatically between 500 and 700 million years ago and survive today only in environments hostile to predators, such as this area swept by swift channel currents and in hypersaline waters in Western Australia, where a community was found three decades ago.

Mass extinctions thus promote new beginnings, new eras of experimentation. If earth's slate of life were not episodically wiped clean, how far might we have evolved beyond the primordial slime?

That slime surely suffered too. The first great extinction may have been a gas attack. As one microbiologist explains, "It was the worst case of pollution in earth's history."

What was this toxic waste, this obnoxious gas? Paradoxically, it was what today sustains all animal life: oxygen.

DESCENDANTS of the stromatolite builders, mats of modern cyanobacteria survive in environments too harsh for most life—such as in this 42°C (108°F) hot spring rivulet in Yellowstone National Park. No threat to the cyanobacteria, the wolf spider is a relative latecomer; his ancestors appeared about 400 million years ago.

At one time earth's oceans and atmosphere were virtually oxygen-free, or anaerobic. Carbon dioxide dominated the planet. Then, about three billion years ago, certain bacterial members of the primordial slime invented the kind of photosynthesis that releases oxygen as a waste product.

Oxygen is a reactive, aggressive gas. It shuts down or burns out organisms adapted to anaerobic life. So with oxygen the new aerobic bacteria could coerce their way into a place in the sunlight and drive their competitors underground or into extinction.

The waste built up. The oceans were oxygenated, then the skies.

No organism has so dominated the world as did those filamentous oxygen-producing microbes. Wherever seas were warm and not too deep, they built diverse bacterial communities—mound-shaped mats of microorganisms. The fossils of those mats, called stromatolites, resemble great reefs of cabbage-shaped mounds. Beds of layered stromatolites, often several kilometers thick, swirl through rocks that were formed in shallow seas between 2.5 billion and 600 million years ago.

Then stromatolite populations crashed. Like the anaerobic life they displaced, stromatolites still exist but can be found only in isolated areas. What happened?

In a word, animals. Life began to feed on itself.

THE APPEARANCE of animals heralded the adoption of a new survival strategy. Photosynthesis had enabled organisms to make their own food from carbon dioxide and water. The new strategy bypassed that step. Why make your own food? Why not eat some organism that has already done the work? Eating someone else takes energy, however. You have to graze or hunt. That requires a high-powered aerobic, or oxygen-burning, metabolism. As the advent of oxygen made grazing animals possible, it made sitting ducks of the stromatolite builders.

Animal life exploded across the planet at the start of the Cambrian period, around 570 million years ago. Perhaps oxygen levels crossed a threshold that enabled animals to make shells and experiment with increasingly complex tissue.

"For 25 million years life was unconstrained," says University of Chicago paleontologist Jack Sepkoski. "If evolution had continued at the rate we see at the Cambrian-Precambrian boundary, we'd have shrimp Newburg from New York to London."

By the time Cambrian seas filled, about 545 million years ago, life had evolved nearly all the phyla, or basic body plans, that it uses today. But one body plan dominates the fossils of that great epoch: that of trilobites.

PHANTOMS OF TRILOBITE DAYS haunt central Utah's House Range as geologist Pete Palmer drives me to the site of the first mass extinction of animals clearly documented by the fossil record. At least three times toward the end of the Cambrian, trilobites, distant cousins of horseshoe crabs, were nearly extinguished by mysterious, perhaps global, disasters. Their bodies litter this former seafloor with what Palmer calls "trilobite trash"—a head here, a tail there.

"Trilobites were innocuous creatures," says Palmer, who works for the Geological Society of America. "Most were somewhere between one and six inches long. They couldn't bite. They weren't vicious. Some were floaters, some swam. Mostly they were mud grubbers. Their mouths faced backward. They had multiple legs that brought food to their mouth. They may have scavenged soft fleshy stuff or eaten marine algae."

ILLUMINATING earth's dark ages, David Ward of Montana State University bathes cyanobacteria in ultraviolet light, causing chlorophyll to fluoresce. Its presence indicates photosynthesis, a process that literally changed the world 2.5 billion years ago. Such photosynthetic microbes released oxygen into the biosphere, allowing oxygen-based life to develop.

Trilobites lived in a flooded world. Sea levels were high. Minneapolis would have been coastal. The rocks of Utah's House Range were part of a limestone platform offshore, like today's Bahamas.

We drive dirt tracks into Little Horse Canyon, then climb up through what had been Cambrian muds to a gray limestone shelf. A line about as thick as my fingernail runs across the rock. Below the line all the trilobite trash is made up of "roundheads," Palmer's name for the roundheaded family that dominated the mud.

"This line coincides with a crisis," says Palmer. "We suddenly lose the roundheads. In the rocks just above us there's nothing but very primitive trilobites with square heads. They came in like the Mongol hordes. They had to be hiding out in some special local environment, maybe in the deeper, colder waters farther offshore. Once the world was theirs, they diversified rapidly.

"Then one day, bang. . . ."

Palmer points to a ledge high above our heads. "Up there the same thing happens to the squareheads. Then another group of trilobites appears by the millions. At the end of the Cambrian period, their descendants too are decimated and never come back strongly."

What happened?

FORMED in the shallow sea that covered western North America 370 million years ago, limestone exposed in the Ancient Wall —a range in Canada's Jasper National Park— may hold fossilized answers to what caused a mass dying of reef-building invertebrates during the late Devonian period.

"Maybe an extraterrestrial object splashed into the ocean," says Palmer. "Perhaps, like today, the seas were strongly stratified—warm, oxygen-rich upper strata on top of cold, oxygen-poor deep water. If you threw that deep water onto these shallow shelves, you could have devastated the trilobites living there. Those organisms couldn't stand even a few weeks of that."

That scenario could explain the squarehead survival. Being primitive, they had been pushed to the cold, deep margins where no other creatures could make a living. They had adapted to just those conditions that exterminated their more advanced competitors.

AFTER THE CAMBRIAN, trilobites never bounced back. Sophisticated new predators, suggests University of Washington biologist Peter Ward, made their life-style obsolete. Nautiloids, distant relatives of today's chambered nautilus, combined massive jaws with the ability to swim swiftly across the seafloor. "As the airplane revolutionized warfare, the nautiloids created havoc for mudbound creatures," says

Ward. "The early trilobites only looked ahead. The ones that survived also looked up."

Reef life—aborted early in the Cambrian—evolved anew in the Ordovician. Clams, starfish, and crinoids, lily-shaped animals that made gardens out of sea bottoms, also emerged. Then around 440 million years ago this increasingly diverse global ecosystem collapsed.

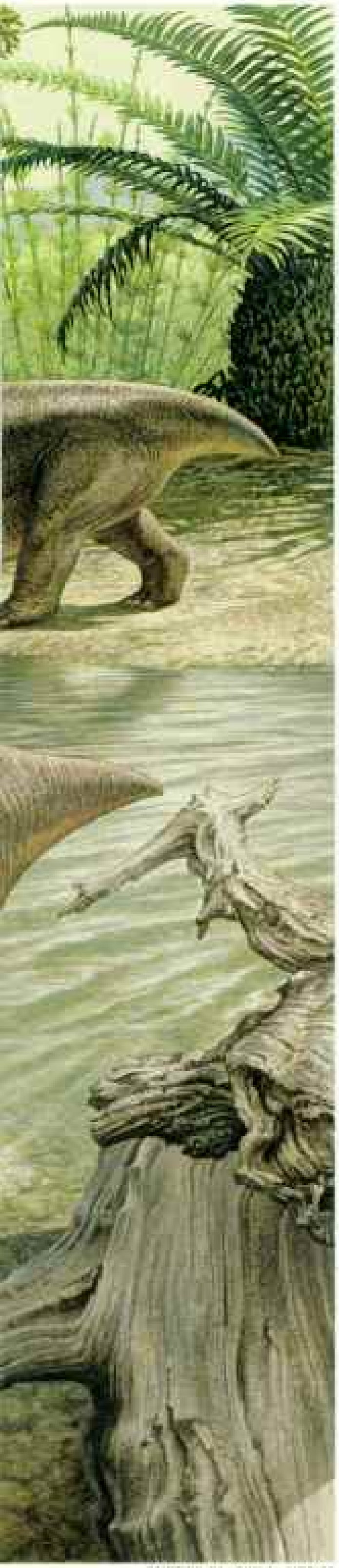
The most obvious villain in the massive Ordovician extinction was the planet's own restlessness, the inner turmoil forever moving earth's continents about. In the late Ordovician that turmoil drove a huge, ancient continent, Gondwana, over the South Pole. Immense glaciers developed, drawing their water from the oceans and chilling even the tropics. "The ice age literally drained the shallow seas," says paleontologist Peter Sheehan of the Milwaukee Public Museum.

Reef life was especially hard hit during the Ordovician extinction.

"Reefs are attractive but dangerous places to live," says David Jablonski. "The web of interactions is so complicated that the entire community can crash if just a few of its members go. Reefs are always getting clobbered."

EYE TO EYE with the Devonian disaster, Helmut Geldsetzer of the Canadian Geological Survey examines fossils exposed on an outcrop near the Lyell Icefield in British Columbia. He believes a sudden flooding of shallow seas by oxygen-poor water from the deep may have killed the reef builders. The cause, he suggests, "might be an asteroid impact."

SQUAT LYSTROSAURUS, *a mammal-like reptile, represents a lineage that survived the greatest mass dying of all time, at the end of the Permian. Like his cow-size relative* Placerias *(right), the cast of whose skeleton was photographed in Petrified Forest National Park,* Lystrosaurus *was herbivorous.*



PAINTING BY JOHN A. SIBBICK

With the drifting of Gondwana beyond the polar region and the decline of the ice ages, the reefs rebounded with altered life-forms. For the next 70 million years they flourished, laying limestone bedrock across much of earth's crust, including the Great Lakes region. Today those fossil reefs give the ground beneath Chicago the strength it needs to support some of the world's tallest skyscrapers.

As the reefs were recovering, the seas saw an explosion of huge predatory fish. Land plants evolved, as did the first amphibians. The biological stage was being cast with players for the next tragedy.

The late Frasnian, scientists call the great extermination toward the end of the Devonian period 370 million years ago. It exposes itself most strikingly in the Canadian Rockies, where massive Devonian reefs have been sheared and tilted by earth movements. Jutting skyward like great shards in remote alpine splendor, the mountains are pocked

with mementos of their birth—shells and the skeletons of corals and similar creatures.

With Helmut Geldsetzer of Canada's Geological Survey I climb into the Rockies. We reach a thin yellow band, a sulfur mineral, which Geldsetzer believes precipitated as oxygen suddenly vanished from the upper layers of the oceans. As that band was deposited, most of the world's fish and 70 percent of its invertebrates perished.

"The seas would have looked like the aftermath of a global red tide —dead animals floating everywhere," says Geldsetzer.

He hammers out a piece of the yellow rock. Once again I can put my fingers on a mass extinction. I ask what did the killing, what sapped the seas of oxygen. He invokes the same killer that Palmer suggests ravaged the trilobites: the splash of an extraterrestrial impact flooding the continental shelves with anoxic water from depth. He notes that iridium has been found in Devonian rocks in Australia.

Other scientists reject this idea. They argue that the Australian iridium was concentrated by mats of organisms and that the extinction resulted from a cooling of the oceans as Gondwana headed back over the South Pole and new glaciation approached. These experts maintain that the extinctions were spread out over several million years. But the

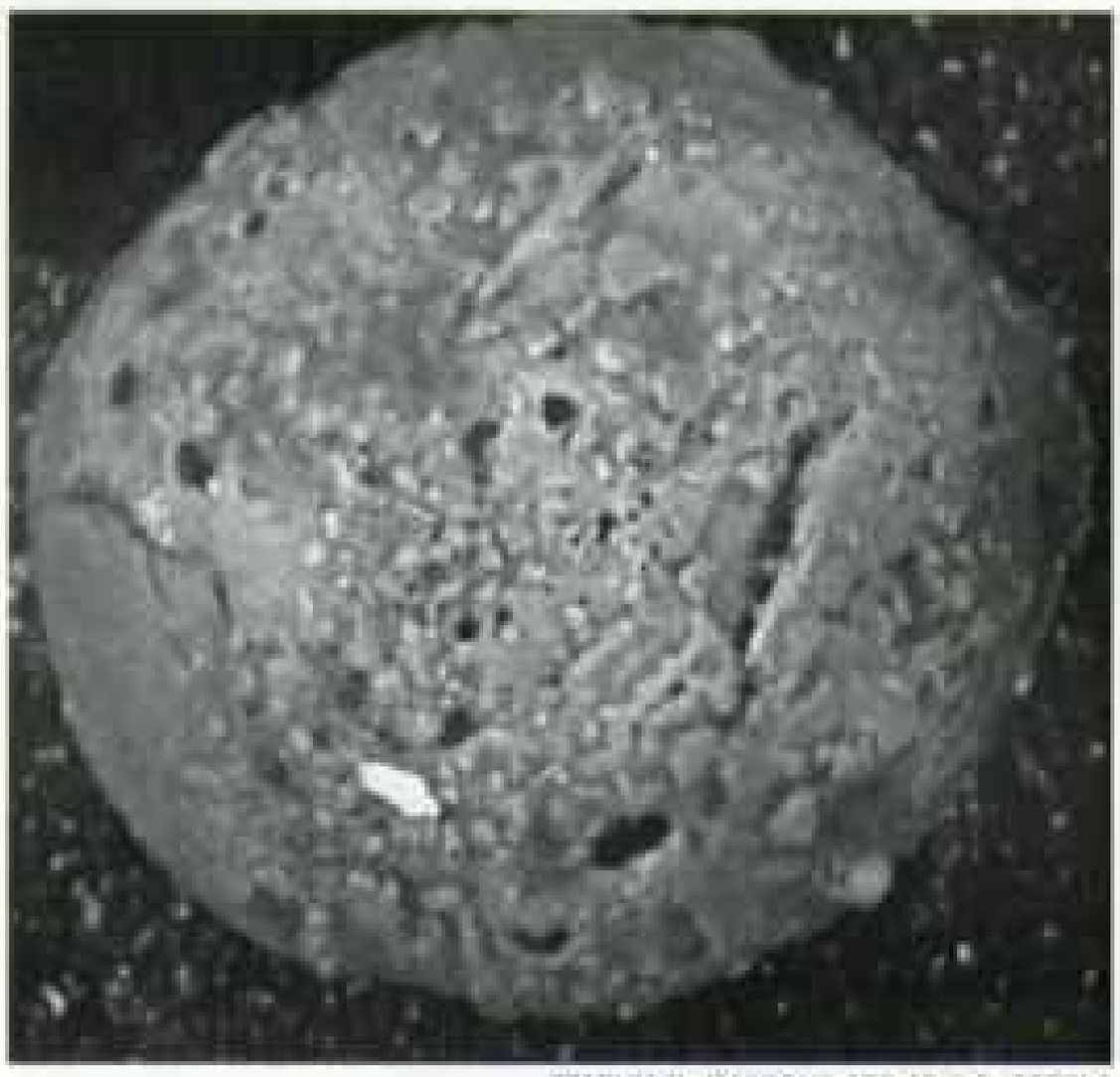
LAYERS OF CONTROVERSY surround a thin band of gray clay scrutinized by scientists on this seaside cliff in Zumaya, Spain. Found worldwide, the layer marks the boundary between the Cretaceous and Tertiary periods. Experts studying the clay see clear

evidence of an impact—including high levels of iridium. Debate rages over the connection between the impact and the death of dinosaurs. But few scientists deny that extraordinary events are recorded in that narrow layer of sediment.

catastrophists heatedly disagree, arguing that the event was abrupt, worldwide, and occurred in the midst of a long warm spell.

"At most we are dealing with 20,000 years—and maybe just one stormy night," says Willi Ziegler, director of the Senckenberg Museum in Frankfurt.

With Charles Sandberg of the U. S. Geological Survey, Ziegler has studied fossils of abundant small eel-like animals known as conodonts. The shapes of conodonts changed often and distinctively enough during the Devonian that scientists can date rocks precisely with them. Particular conodonts in a rock indicate whether the rock formed in deep or shallow seas.



STANLEY V. MARGOLIS AND ERIC F. OSBORN

EVIDENCE of impact, this tiny spherule collected from the K-T boundary layer at Zumaya is thought to be a melted fragment of the object that struck the earth 66 million years ago. The spherule, here magnified 5,000 times, contains platinum in the high concentration present in meteorites but not normally found on earth.

Ziegler and Sandberg's conodont analysis indicates great swings of sea level around the time of the extinction. They see shallow-water conodonts suddenly appearing in deep-sea rocks. They argue that storms, and perhaps tsunamis, ravaged the planet, washing nearshore life out to sea. In Nevada, which was then deepwater terrain, Sandberg has found huge boulders of coastal rocks that were apparently ripped seaward.

"We suspect this was caused by a comet shower or increasingly closer passes by an asteroid or field of asteroids," says Sandberg. "An asteroid's gravity could raise great tides. Imagine the stress on marine life if sea levels went up 30 meters, then dropped 60."

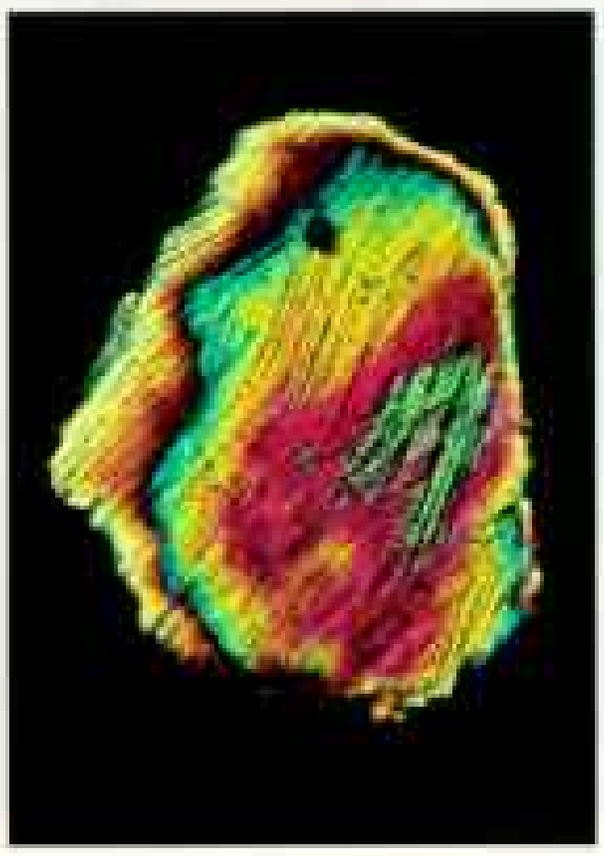
Wild thoughts? There are data from the Devonian to support endless speculation. The confusion grows worse with the next extinction, which terminated the Permian period about 240 million years ago.

THE PERMIAN was easily the greatest extinction of all time. Perhaps 96 percent of all species disappeared. No one yet claims strong evidence for an extraterrestrial extinguisher. The best guess today is that the planet itself did the killing.

The Permian extinction was the first to affect terrestrial life significantly. During previous extinctions most life was confined to the water. But by the end of the Permian, coal swamps had proliferated, insects swarmed, and pig-size amphibians were roaming across earth's warm surfaces. Creatures known as mammal-like reptiles dominated the land.

Mammal-like reptiles varied enormously. Early versions resembled lizards, but reconstructions of later species make me think of a dog-faced tank with a short tail. They may have had fur, and to specialists their bone and teeth structure looks more mammalian than their simultaneously evolving reptilian cousins. For example, their limbs extended directly beneath their bodies, rather than to the sides, as is the case with reptiles.

Even as the mammal-like reptiles were evolving during the Permian, the forces of plate tectonics were forging the supercontinent Pangaea, joining all the planet's continents into a single colossal landmass. With but one continent the amount of shallow offshore water—among the richest habitats on the planet—shrank drastically. Also, Pangaea encroached on both poles, probably triggering a series of crippling ice



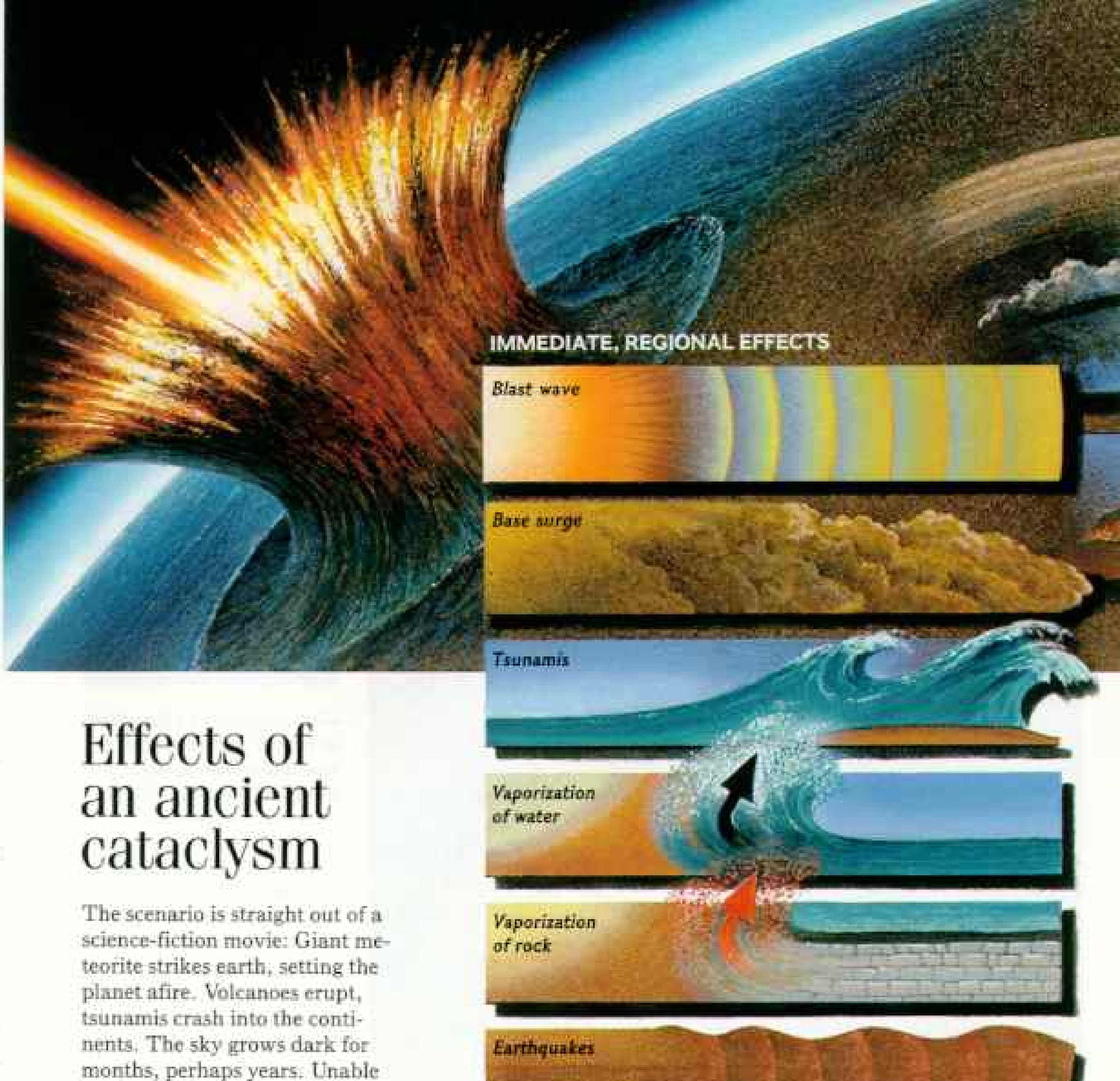
GEO-DETECTIVE Glen Izett of USGS was skeptical about the impact theory. Then his light-polarizing microscope revealed quartz grains in samples of the K-T layer (above) with the type of fractures caused by nuclear explosions or meteorite impacts. Judging from the size and abundance of "shocked" quartz grains he has found in the western U. S., Izett believes the impact occurred there.

ages in both hemispheres. According to paleontologist Bob Sloan of the University of Minnesota, sea levels bobbed up and down by 200 meters; coastlines advanced and retreated 1,900 kilometers (1,200 miles). Even tropical seas would have been chilled. On land climate grew progressively drier, the winters Siberian.

The mammal-like reptiles suffered at least six distinct mass extinctions during the last eight million years of the Permian, says Sloan, indicating that the great die-offs may occur in pulses. Those pulses reflect the Permian's strong climatic swings. The die-offs illustrate that, paradoxically, extinctions can benefit life.

"Look at what survived each pulse," says Sloan. "The survivors were always those that appear to be more warm-blooded and thus dealt better with cold climates. They also tended to have more complicated jaws and teeth, as well as more efficient respiratory systems."

Moreover, the survivors were small, establishing a pattern for subsequent terrestrial extinctions. As Sloan says, "The surest route to



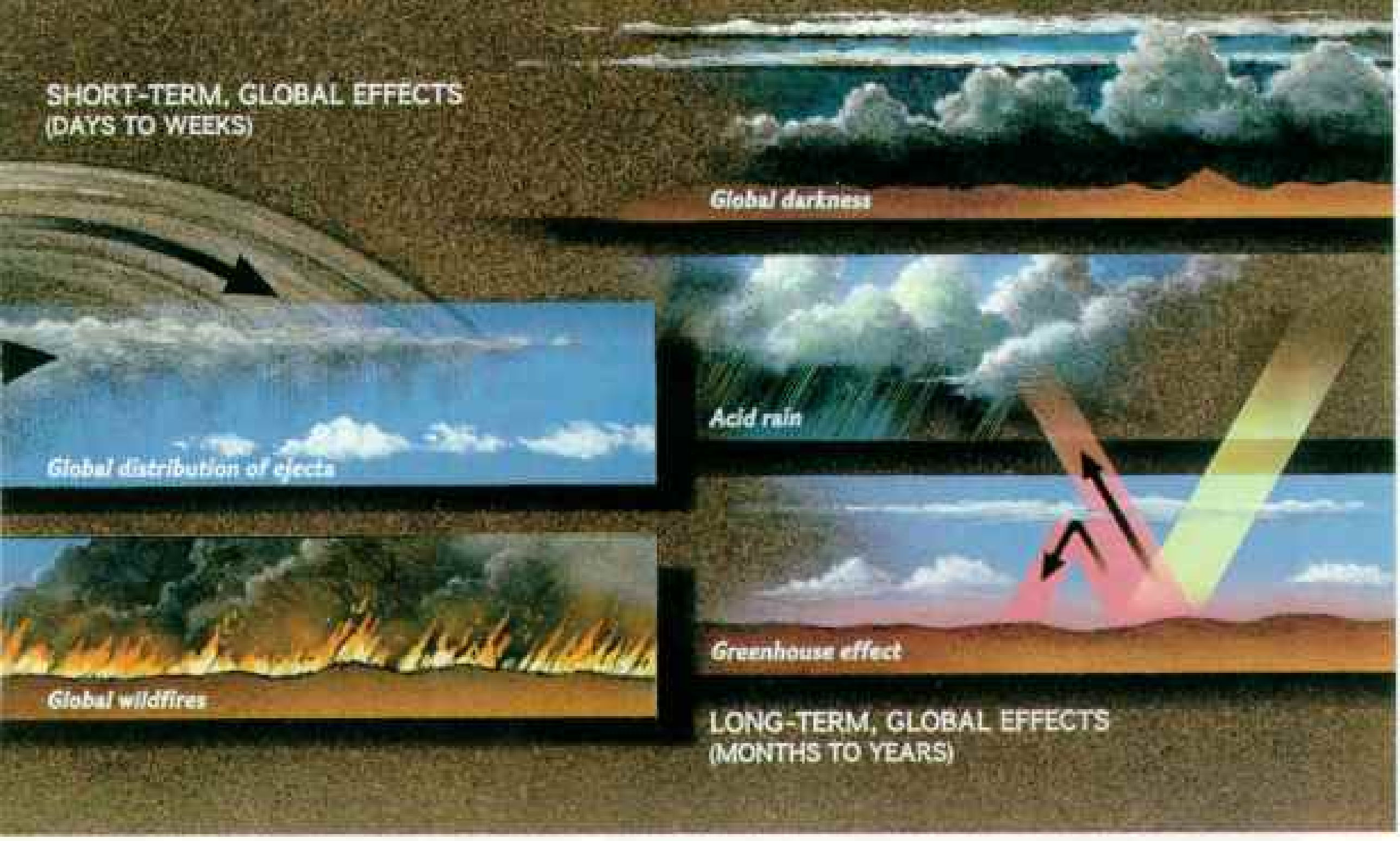
Effects of an ancient cataclysm

The scenario is straight out of a science-fiction movie: Giant meteorite strikes earth, setting the planet afire. Volcanoes erupt, tsunamis crash into the continents. The sky grows dark for months, perhaps years. Unable to cope with the catastrophic changes in climate, countless species are wiped off the face of the planet.

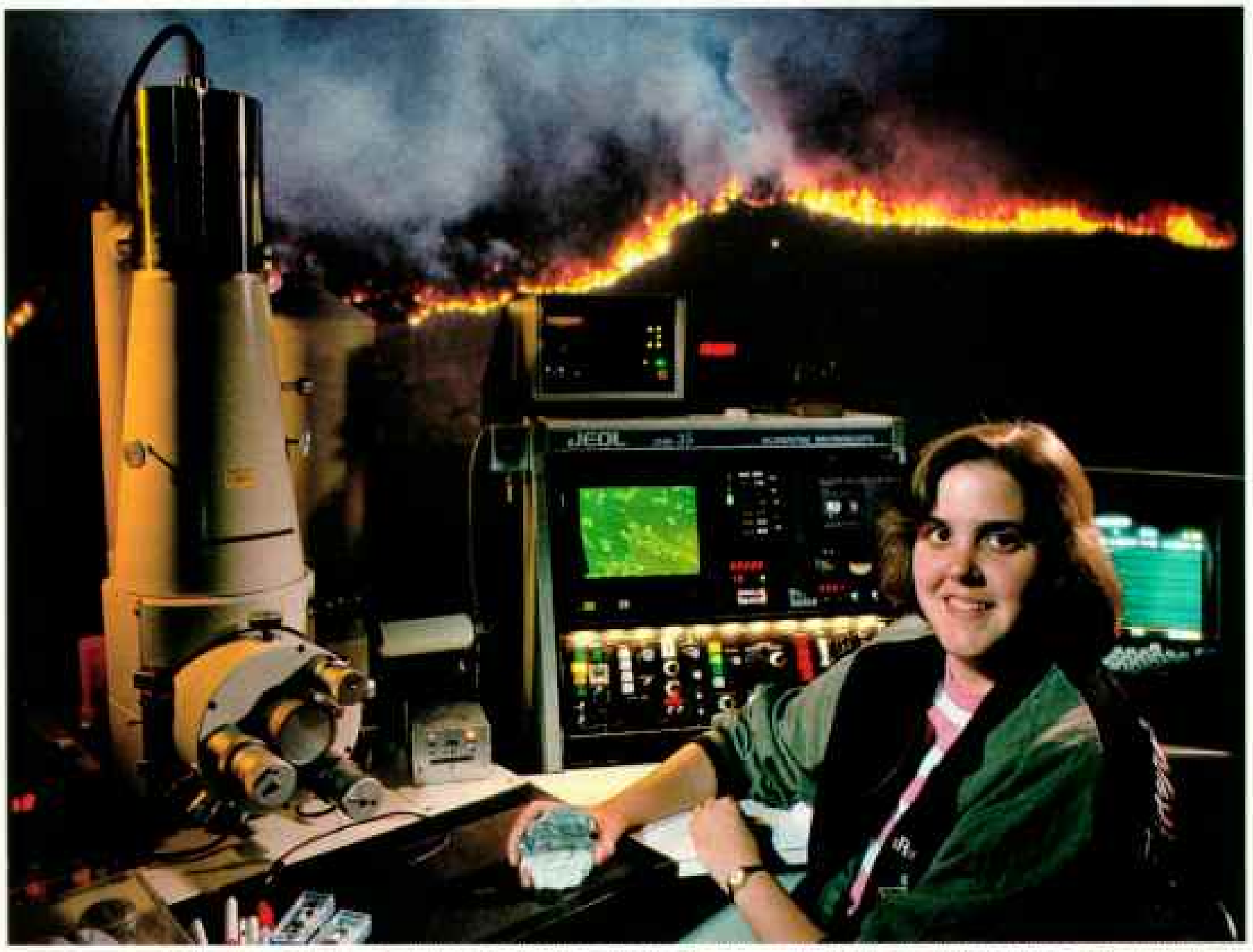
Yet that is the apocalyptic scene scientists suggest, as evidence grows that comets or meteorites may indeed be agents of mass destruction on earth.

In the moments following the impact of an object ten kilometers in diameter, experts believe, a blast wave similar to that of a nuclear explosion would destroy everything within several hundred kilometers, its intense heat and winds combining to set wildfires, perhaps even a global inferno. If the impact occurred on land, earthquakes would rock the continent for days. If at sea, huge tsunamis could destroy coastal habitats across the globe. Other immediate effects would include a horizontal "base surge" of melted and pulverized material and a plume of vaporized water and/or rock ejected into the stratosphere above the impact crater—the fine particles eventually darkening skies around the world.

Scientists are debating the long-term effects of such an impact. Most agree that an era of strong acid rain would ensue. Some believe a global dust cloud would trigger an age of darkness and cold. Others see a sharp greenhouse effect—particularly if the object struck and vaporized limestone in the ocean basins, filling the atmosphere with massive quantities of carbon dioxide. This CO_2 layer would trap heat, raising temperatures worldwide.



THE FIRES OF YELLOWSTONE were nothing compared to a fire storm that raged 66 million years ago, according to Wendy Wolbach, below, of the University of Chicago. Testing samples of the K-T layer from around the world, Wolbach found high levels of soot, suggesting a global wildfire started by an impact. Magnified on her screen is soot found in strata similar to those she holds from New Zealand. The light-colored rock at bottom is from the Cretaceous. A dark layer marks the K-T boundary, when 75 percent of animal species became extinct.

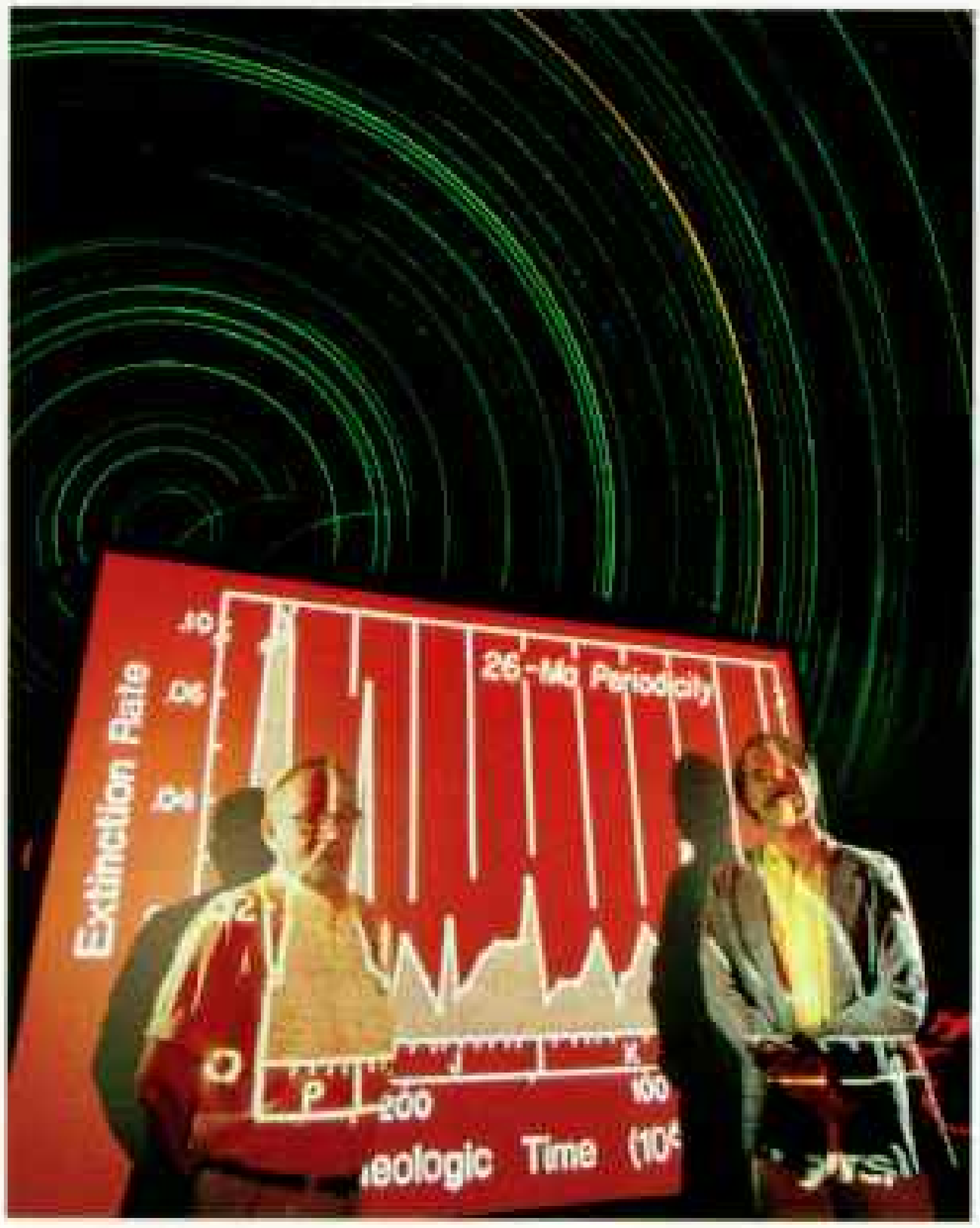


PAINTING BY LLOYD K. TOWNSEND. PRIMARY CONSULTANTS: EDWARD ANDERS, ENRICO FERMI INSTITUTE, UNIVERSITY OF CHICAGO; BEVAN M. FRENCH, NASA

extinction is to be large." Big creatures need more food and have more trouble finding hideouts.

One squat creature whose ancestors made it through the end of the Permian was a tusked herbivore called *Lystrosaurus*. About as cute as E. T., *Lystrosaurus* exploded across Pangaea after the Permian—largely because there wasn't much left big enough to eat it.

In the ensuing Triassic period evolution soon produced not only large new mammal-like reptiles but also waves of new experiments. Marine monsters called ichthyosaurs began to prowl the seas, crocodiles the swamps. Flying pterosaurs took off.



The first dinosaurs also appeared. Extremely fast and small, they often were two-legged, probably resembling big pheasants on the run. Their upright posture freed their forelegs to be used like hands for grasping.

If not warm-blooded, most dinosaurs had evolved high metabolic rates. Some perhaps were covered with down, and later, feathers. Nevertheless, for a while dinosaurs waited in evolution's wings. Although they were superior players, the dinosaurs could not, by themselves, displace the mammal-like reptiles.

AT THE CLOSE of the Triassic period, about 200 million years ago, the dinosaurs may have gotten a little help from the cosmos. In the wilds of central Quebec sits the Manicouagan crater, half the size of Connecticut. The only radiometric dating of remote Manicouagan puts that impact several million years before the end of the Triassic. However, paleontologist Paul Olsen of Columbia University's Lamont-Doherty Geological Observatory suspects that the dates are wrong and that the Manicouagan impact is the fingerprint of a global mass extinguisher from space.

"The fireball alone from an impact that size would have scorched everything down to New Jersey," he says. It thus could have created the kind of global havoc suspected at the K-T boundary.

Whether or not they had cosmic good fortune, the dinosaurs took charge of the land with the advent of the next period, the Jurassic. During the Jurassic's 60 million years, the great reptiles developed sovereign size. The gargantuan *Brontosaurus* and related creatures roamed river plains, browsing tall conifer trees. So did the armored, tractor-size *Stegosaurus*, although it might have had to stand on its two hind legs to nibble the branches. It had to stay ever alert for the huge meat-eating *Allosaurus*.

These monsters vanished, along with many smaller dinosaurs and marine creatures, when a profound but mysterious crisis struck at the end of the Jurassic. A new generation of low-browsing, beaked dinosaurs emerged. What made them the evolutionary victors? Was there a

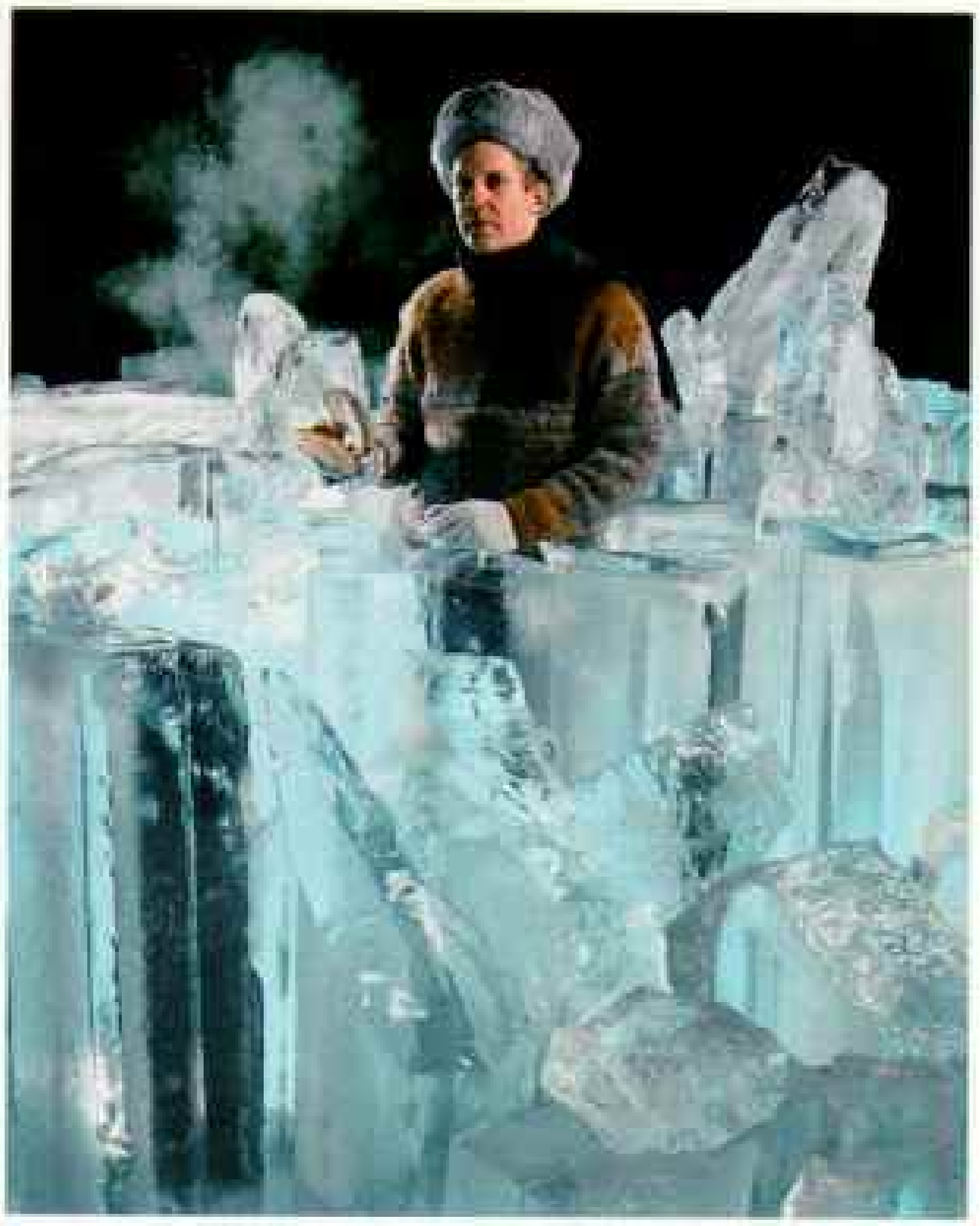
global habitat change? Why was life in the oceans also hard hit? The Jurassic mass killer left almost no clues.

Dinosaurian life rebounded vigorously during the long warm eons of the ensuing Cretaceous period. Then, about 90 million years ago, another poorly understood pulse of extinctions struck both land and sea. One modest spike of iridium has recently been reported for this mid-Cretaceous extinction, implying impacts from space. Because other spikes have not been uncovered for this boundary, the significance of the lone spike is being challenged. But there may be a more surprising suspect for agents of extinction—flowers.

About this time blooming and fruit-bearing plants, known as angiosperms, began to explode across the land. By attracting animals to spread their pollen and seeds, the angiosperms colonize quickly. They also reproduce rapidly. Controversial dinosaur expert Robert Bakker of the University of Colorado argues that the new generation of low-browsing Cretaceous dinosaurs began turning the world over to flowers. Dinosaurian overgrazing threatened many low-growing plants with extinction—except for the angiosperms. Their reproductive superiority helped flowering plants compete with the munching jaws of oblivion.

In turn, this contagion of angiosperms must have had an enormous impact on the dinosaurs' diets. Could it be linked to their mid-Cretaceous extinction?

Certainly new dinosaurs evolved in the aftermath. The late Cretaceous saw duckbill dinosaurs prowling the swamps and forests. On the more open plains, especially in western North America, great herds of rhino-like *Triceratops* and their relatives fed on the new vegetation. Back then a vista across the Dakotas would have resembled a saurian version of today's Serengeti Plain. The lion of that world was the infamous *Tyrannosaurus rex*.



Fire or ice? ***Based on his studies of the fossil record, paleobiologist Steven Stanley of Johns Hopkins University (above) believes that global cooling explains most mass extinctions. He holds a Spondylus, a tropical bivalve that died out some 3 million years ago. At the other end of the spectrum, David Raup and Jack Sepkoski of the University of Chicago share the limelight with their theory that mass extinctions occur every 26 million years, perhaps as a result of periodic bombardment by comets.***

In all, at least 30 genera of dinosaurs—perhaps a hundred species—inhabited the planet during the final ten million years of the Cretaceous. Some specialists argue that most persisted right up to the K-T boundary. Others brandish data indicating that all but 13 genera had perished well before the Cretaceous ended. Recent, hotly contested evidence suggests nine genera of dinosaurs may have straggled on into the following Paleocene epoch. Part of the answer to this debate lies buried in the badlands of the Great Plains.

Ten thousand years ago in the badlands, runoff from the last glaciers cut through the purplish gray and green soils of the Hell Creek formation near the North Dakota-Montana border. As those eroding streams carved buttes out of the vast flatlands, they cut through and exposed for future geologists the last two million years of the Cretaceous period. Hell Creek is the only place on earth that preserves in

detail—with iridium and an abundance of fossils—the dying days of the dinosaurs.

On this July morning the bleak buttes are speckled by the colorful T-shirts of scientists and volunteers sent by the Milwaukee Public Museum. Hammering and chiseling under a blazing badlands sun, Claudia Berghaus, Joan Mathys, and Carol Moertl extricate fragments of a *Triceratops* front leg bone. Doug Stephenson is perched higher up the butte, near the K-T boundary, working on scraps of a scapula.

"I can't get over it," says Jay Warner, who is usually an engineer. "Back in Milwaukee I was worried I wouldn't find a single bone. I found a piece of a turtle in my first five minutes, a dinosaur in ten."

"We want to know what the pattern of diversity was," explains the museum project's coordinator, Peter Sheehan. "It has not been adequately shown that dinosaurs already were dying out before the impact. We're trying to eliminate one of the two possibilities—the whimper or the bang. A gradual pattern of decline is not what you'd expect if an asteroid killed them."

Sheehan contends that past estimates of dinosaur diversity are

biased: The better-known North American fossil sites have been mined more thoroughly than other spots. Dale Russell of the National Museums of Canada says dinosaur diversity in North America did not change significantly before the boundary. In central Asia, another dinosaur-rich area, it increased, while much of the world remains poorly sampled.

In the past, fossil hunters usually collected only museum-quality specimens. They ignored the scraps, which may be the most valid indicators of the real abundance of late Cretaceous life.

The scrap that creates the most excitement on this day is not dinosaurian, nor even reptilian.

"We've got a mammal," announces museum paleontologist Diane Gabriel, bending over her sliver of a discovery, a jawbone from a marsupial. "It was probably slightly larger than a chihuahua. That means it was a giant for its time."

MAMMALS are rare in these late Cretaceous rocks, but in the eyes of the Minnesota paleontologist Bob Sloan they are far from insignificant. Sloan believes that 200,000 years before the K-T boundary a receding sea level had created a land bridge between North America and the long-isolated Asian continent. A plague of little Asian mammals invaded North America and began eating the same flowering plants that most dinosaurs ate.

"The mammals ate much less food per animal," says Sloan. "But there were so many of them. They ate the last of the dinosaurs out of house and home." Others suggest the dinosaurs' nemesis was a climate-induced change in vegetation.

In fact, the dinosaurs and their huge flying cousins, the pterosaurs, were among the few land-based animals to go extinct at the end of the Cretaceous. Turtles, crocodiles, many lizards, and most mammals made it through, perhaps because they did not eat much and were small enough to find refuges.

The cruelest K-T extinctions struck the seas. Most plankton, the primary food source, died out—understandable if months of darkness or global acid rain followed an impact. All large marine reptiles also vanished, as did most denizens of the seafloor. Rudists, huge coral-like clams whose shells built Cretaceous reefs, were obliterated. Ammonoids—lovely, coiled survivors of many past extinctions—died out completely.

Not all these creatures disappear from the fossil record right at the

A SPIKED COLLAR and a rhino-like horn helped Styracosaurus (left) fend off his number one enemy—Albertosaurus, a scaled down version of T-rex who stalked the late Cretaceous coastal swamps in what is now Dinosaur Provincial Park in Alberta, Canada. The Tyrrell Museum's lifelike replica is modeled on fossils found in the park.

Whatever caused the extinction at the end of the Cretaceous, this vegetarian cousin of Triceratops *wasn't around to see it.* Styracosaurus *disappeared from the fossil record some 12 million years before the K-T boundary.*

K-T boundary. Some vanish earlier in steps. Thus other scientists argue that the K-T impact was not the cause of the dyings. "Ecosystems were decaying for at least two million years before the impact," explains paleobiologist Steven Stanley of Johns Hopkins University.

Stanley, a prominent theorist, sees long-term cooling as the culprit. Yet there is no obvious reason for such cooling. The next ice age was tens of millions of years away. Massive volcanic eruptions may have dropped global temperatures temporarily by injecting particles into the

atmosphere that blocked sunlight. Indeed, one of the greatest outpourings of lava the world has known occurred at the K-T boundary. This basalt flow buried the Deccan region of India. However, many volcanologists doubt that the relatively calm nature of lava eruptions would propel much debris into the upper atmosphere.

Whatever cooled the planet, Stanley contends that the impact at the boundary probably was but a final insult to an already overstressed global ecosystem.

As I was told by another paleontologist: "Things got bad, then they got worse."

Impact enthusiasts have recently come up with a way to explain the multiple stages of K-T extinctions. Earth, they argue, was hit not by one great object but rather by a shower of comets that bombarded the planet over several million years.

Erle Kauffman of the University of Colorado finds evidence for wild disarray in ocean chemistry beginning two million years before the

boundary. Those disruptions, he argues, were created when comets struck the seas, generating tsunamis and overturns of deep anoxic or toxic water like those suggested for earlier extinctions. Those oceanic events also could have created global climate crises far worse than El Niños we experience today. The final terminating impact, says Kauffman, probably occurred on land, where it produced fire storms, soot, and a pall of dust.

One major question surrounds the final impact. Where's the crater? Craters are not always obvious.

"The largest impact and the largest extinction in the past hundred million years occurred at the same time as the largest extrusion of lava," observes geologist Michael Rampino of New York University. "That's quite a coincidence." He and others suspect that the object struck India, thereby causing the great Deccan basaltic lava flows.

If Rampino is right, the K-T crater would be buried beneath the basalt.

Or consider the quiet farm town of Manson, Iowa. It sits over the center of a 32-kilometer-wide crater that glaciers filled with debris during the last ice age. Thus today the only striking feature of Manson is its tall grain elevators. Geologists, however, have recently dated the crater below Manson at 66 million years—perfect timing to make it the K-T killer.

Most scientists agree that 32 kilometers is much too small to create the havoc envisioned by impact enthusiasts. But some suspect Manson's crater may be larger. The 32-kilometer hole may be just an inner pit.

Of course, the impact may have struck the ocean. If so, the scarred seafloor could have been buried by sediments or been recycled into the planet's innards by plate tectonics.

TERROR of the trilobites, Anomalocaris (above, at center) did not last long, but many a trilobite shows wounds attributed to the predator. It was extinct by the end of the Cambrian, whereas trilobites hung on until the Permian mass extinction. The fossil of a Jurassic fish covered with armor-like scales is removed from a West German quarry (facing page).

JONATHAN BLAIR, D. L. BRUTER, A. JENSEN; PHOTOGRAPHED AT PALEONTOLOGISK MUSEUM, OSLO, NORWAY (ABOVE)

PERHAPS more controversial than the impact hypothesis itself is the notion that such showers occur regularly. Jack Sepkoski and David Raup of the University of Chicago have combed a century and a half of fossil record keeping and found a pattern. They see peaks of extinction about every 26 million years. Such regularity implies a cosmic driver to the extinctions. No known earthly mechanism keeps such good time.

Many scientists dispute Raup and Sepkoski's statistical methods; many concur, seeking astrophysical explanations.

The most obvious source for the calamities would be the dense cloud of comets that astronomers believe surrounds the outer solar system. Something could periodically unsettle that cloud, flinging a battalion of comets toward the inner planets over several million years.

Three mechanisms have been proposed. A dense, dark companion

star orbiting our sun would toss out comets as it passed through the cloud. So might an unknown, tenth planet. Thirdly, our solar system moves periodically up and down through the star-dense spiral of our Milky Way galaxy. Perhaps our comet envelope is perturbed each time we pass through that spiral arm.

Astrophysicists find dynamical problems with all three mechanisms. Many argue that the showers strike randomly, not regularly. Others see a frequency not of 26 but of about 30 million years.

Both spacings fit the next era of extinctions, which hit between 35 and 40 million years ago. Those dyings eliminated herds of rhino-like mammals and many sea creatures. Although iridium spikes correlate to some of these die-offs, gradualists argue that a well-documented chilling of the seas did the killing.

Advocates of the 26-million-year period point to a mild extinction around 14 million years ago as evidence for the most recent bombardment. That places us today safely between showers. Those favoring 30-million-year or random spacing are less sanguine.

Michael Rampino points to three large craters—Bosumtwi in Ghana

(10.5 kilometers in diameter) and two in the Soviet Union, Elgygytgyn (23 kilometers) and Zhamanshin (13 kilometers)—that were created in the past 3.5 million years.

"We could still be in a shower," says Rampino. "Halley's comet could be part of it. We aren't out of the woods yet."

Intriguing debris from the impact of a large celestial object 2.3 million years ago has recently been found strewn across some 600 kilometers of the Pacific seafloor off Cape Horn.

"About 2.3 million years ago there was an abrupt shift in climate," notes geologist Frank Kyte, leader of the University of California at Los Angeles team that discovered evidence of the impact. "Huge continental ice sheets developed in the Northern Hemisphere."

Kyte notes that the climate had been deteriorating before this, our most recent ice age, set in. But he speculates that the injection of water vapor into the stratosphere could have formed a global cloud cover that reflected heat off the top of the atmosphere.

"No one would argue that impacts alone cause ice ages," adds Mike Rampino. "But might they push the climate into a new state?"

LAID LOW by the hand of man, the woolly mammoth appears to live again in a diorama presented at the Royal British Columbia Museum in Victoria. Museum technician Wally Bishop checks the musk-ox hair that covers this 11-foot replica, modeled after the beast that ranged over North America, Axia, and Europe during the Pleistocene. Many scientists believe the mammoth, like most of the epoch's megafauna, was hunted to oblivion in Europe and Asia, then became extinct as Ice Age hunters invaded North America across the Bering land bridge.

WHETHER OR NOT we fit a cosmic timetable for an extinction, we surely are in one today.

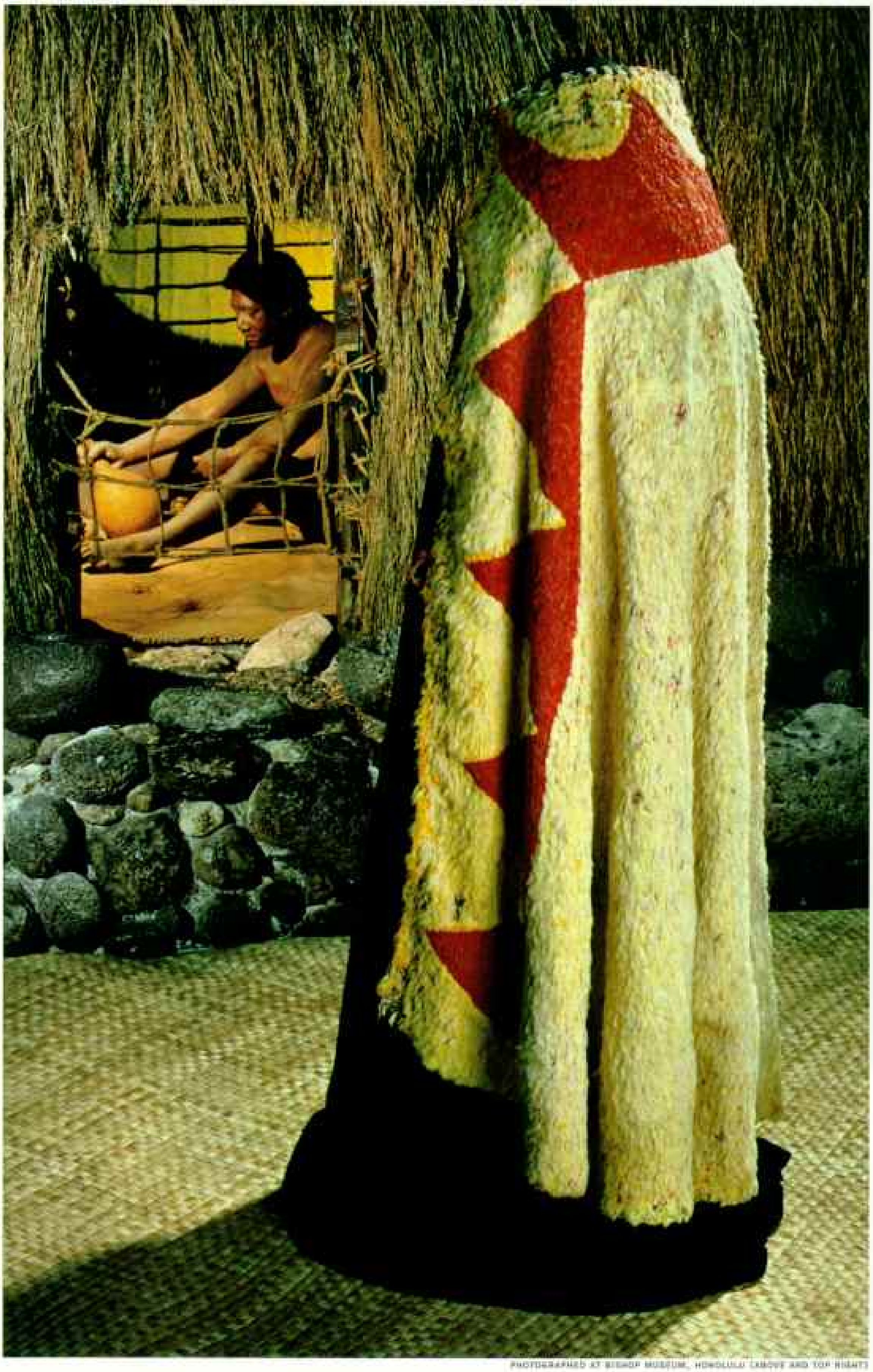
It began in North America about 11,000 years ago. Most large mammals were wiped out. Saber-toothed cats, mastodons, mammoths, huge ground sloths, short-faced bears, and dire wolves. All perished abruptly. What happened?

Some scientists argue that the climate grew drier. In western North America arid conditions dried up the food supply of large herbivores. As the herbivores disappeared, so did the carnivores that preyed on them.

The extinctions, however, were so rapid—within five hundred to a thousand years—that many scientists suspect an alternate—or at least assistant—villain in this extinction: *Homo sapiens*. Man the hunter emerged from the Ice Age with lethal new hunting technologies—snares, traps, and sharp-pointed weapons.

Today the impact of human technology on the biosphere worsens. It exterminates not just the big creatures but the tiny. Man has become an asteroid. A very big one.

It is easy to blame today's frightful extinctions on habitat destruction in developing countries. To be sure, the crisis is acute in Brazil and Madagascar and the Philippines, where rapidly expanding populations



PHOTOGRAPHED AT BISHOP MUSEUM, HONOLULU (ABOVE AND TOP RIGHT)

and the need for economic development can erase a forest in weeks.

"They are losing their inheritance," says botanist S. H. Sohmer of the Bishop Museum in Honolulu. Just back from the Philippines, where he is helping local biologists bolster national awareness of the problem, Sohmer paints a dismal picture.

"In the plant group I study, 42 percent of the species reported in 1930 have not been collected since," he says. "The leveled forests are often replaced by an aggressive plant called cogongrass. If the logging and slash-and-burn agriculture don't stop soon, we'll wind up with entire islands covered by it. Conceivably this archipelago, which once had one of the world's richest biotas, will end up with only a handful of species."

It is easy for the wealthier countries to decry and then ignore these habitat losses. But we have only to ask who buys the timber or beef these felled forests produce. Or who generates the acid rain that is wiping out New England's sugar maples or West Germany's Black Forest.

The United States can look at Hawaii, which most of us regard as paradise but which biologists consider the endangered-species capital of the world. Though occupying less than 0.2 percent of the nation's landmass, Hawaii contains 27 percent of its endangered birds and plants. Seventy-two percent of those U. S. species that have already become extinct did so on these islands.

IN THE ALAKAI SWAMP on the island of Kauai a male *'o'o-'a'a* sings his melancholy song alone.

"He's the best songster in the islands," says state aviculturist Fern Duvall. "His call is unforgettable, like the flutes of the old Hawaiians."

For the past three years the mating calls of the 'o'o have gone unheeded. For he is the last of his species, the end of the line.

"We've lost not only a species," says Duvall, "but its entire family—all the honey eaters will be gone."

Meanwhile, in Honolulu's Bishop Museum schoolchildren file past the celebrated yellow feather cape of King Kamehameha I. The cape was assembled from the plumage of the lost honey eaters in the late 18th century.

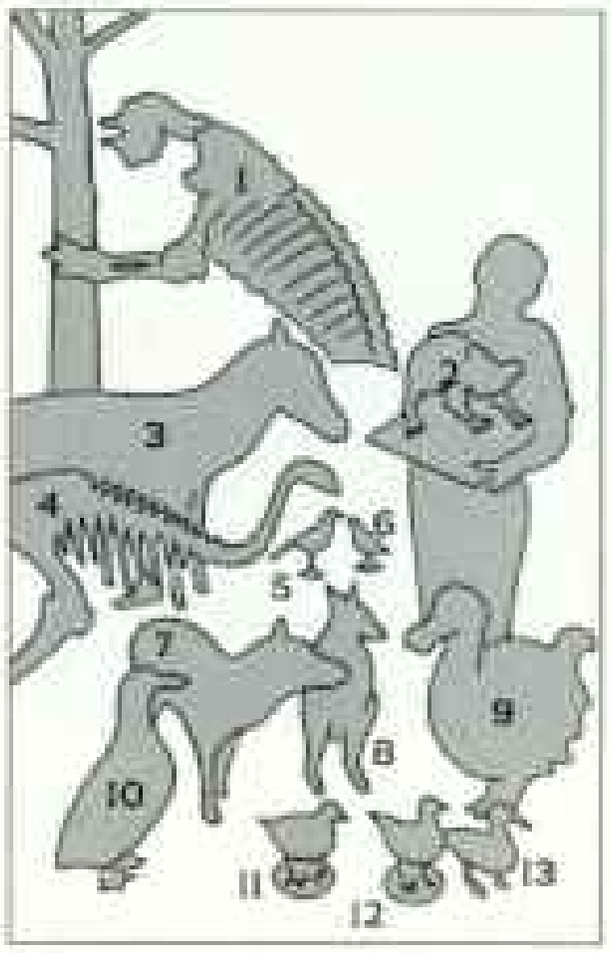
"It took the feathers from 80,000 birds to make this cloak," says their guide.

Many Hawaiian birds were flightless. Before humans the islands knew no mammalian predators, and wings grew less useful. Thus when humans brought rats and dogs, native birds and eggs were easy prey. Imported goats, pigs, and cattle ravaged avian habitats. Humans felled their forests.

In a dark lava tube on the island of Maui ornithologists Storrs Olson and Helen James of the Smithsonian Institution excavate soils deposited during the past 8,000 years. A dark layer high in the soil strata

PRIZED for its plumage, the Hawaiian 'o'o-'a'a (top) was overhunted to adorn cloaks like one worn by chief Kiwala'o (facing page). After studying the fossil record in Maui's lava tubes, Helen James of the Smithsonian Institution (above) rates predators introduced by Polynesians—pigs, dogs, and rats—as more deadly agents of extinction.

A WHO'S WHO of extinction surrounds curator Iain Bishop at England's Tring Zoological Museum. He holds the one species still living—an endangered aye-aye from Madagascar. The Carolina parakeets (above) were collected in 1870, decades before they disappeared. Experts believe that species are presently dying at the rate of 100 a day.



1 Giant ground sloth
2 Aye-aye
3 Quagga
4 Moa
5 Passenger pigeon
6 Carolina parakeet
7 Tasmanian wolf
8 Toolach wallaby
9 Dodo
10 Great auk
11 Male heath hen
12 Female heath hen
13 Labrador duck

contains charcoal, which has been dated as being 825 years old. "We think the charcoal correlates to the burning of the forests for agriculture," says James. "We see bird bones below the charcoal and Polynesian rat bones above. Later we get black rats and house mice, announcing the arrival of the Europeans."

New diseases arrived too. An avian pox, imported in 1964 with a pheasant from Nepal, most likely brought one of Hawaii's most unusual birds, the *'alala,* or Hawaiian crow, to the twilight of extinction.

At the Olinda Endangered Species Captive Breeding Facility on Maui nine of the last fifteen known Hawaiian crows await the breeding season in their pens. Overnight someone has placed an offering—a volcanic stone wrapped in a large leaf—beneath a statue of a Hawaiian salamander god that stands on the lawn of the station.

"The offerings began when the crows were brought here in 1987," says Fern Duvall, who is in charge of the facility. "We must assume that someone is trying to help the crows reproduce.

"Actually, the Hawaiians did not think the 'alala was a bird at all," he continues. "It behaves in remarkable ways. It feeds with its feet, like a parrot. It shrieks, growls, and moans. It makes noises more like a tiger. When the feather hunters heard it in the fog-bound forests, they thought it was a spirit. If you killed an 'alala, you paid with your life."

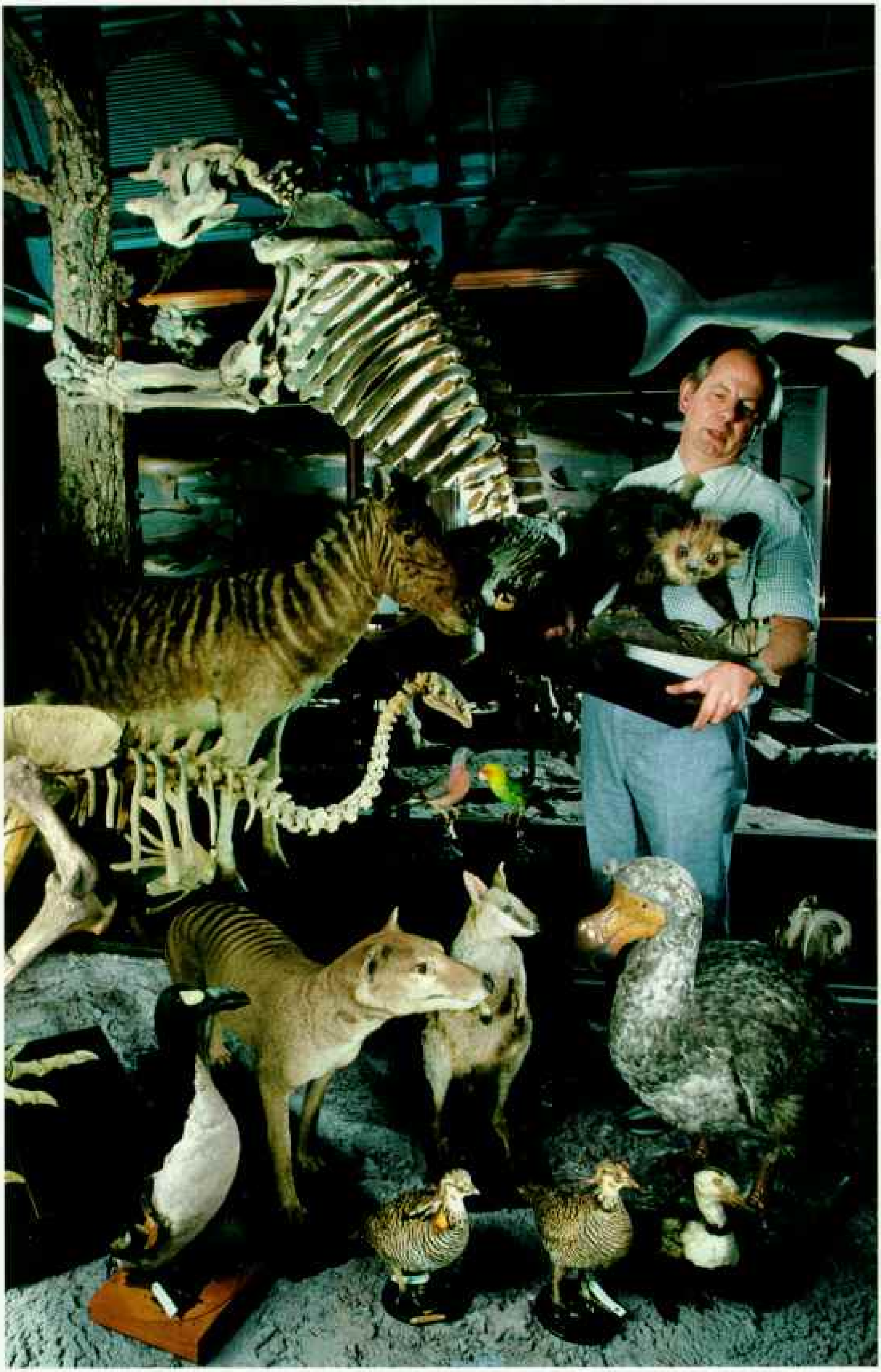
This season's courtship is beginning. In one pen a male, named Keawe, and a female, Mana, are performing nest-building calls and displays. Their efforts are doomed: Disease has left Mana sterile. However, the mating ritual stimulates useful behaviors. Keawe's semen could later fertilize other females. Mana could sit on a nest abandoned by another female.

The three other pairs of crows offer varying degrees of hope for building a captive population. Even so, the outlook for the 'alala is bleak. There is simply no safe place for them in the wild at this time.

I AM ANGRY as I rest from a hike on the slopes of the volcano Haleakala. In Hawaiian prehistory I would have been sitting in a diverse forest rather than this overgrazed scrubland dominated by prickly plants that cattle won't eat. Almost nothing, from the peacock that preened minutes earlier in my path to the cabbage butterfly that just now alighted on my arm, is native. Is this island slope, where only the rats and the pigs and the cactuses thrive, a microcosm of our future?

Other questions, fed by my fieldwork, arise. Hasn't this happened before—diversity suddenly becoming paucity—and each time didn't life recover to reach new heights of evolutionary creativity? In the big picture is it really so terrible, what's happening today? Life will go on. No matter how bad we make things, some organisms will cope, survive, then flourish. Isn't that the lesson of mass extinctions? What's different about this one?

We are the difference. For the first time since life on earth began four billion years ago, a living organism can begin to understand what is happening to this planet. We can see that the health of species is interconnected, that if we let too many disappear, we will go too. For the first time, a living organism can consciously do something to halt a mass extinction. Perhaps most important, for the first time a living creature can gaze out across the species of the earth and say: This is beautiful. I care. I will not let it go. □



Obdurate as stone, the cities of Senglea, Vittoriosa, and Cospicua, which cluster on Grand Harbour, weathered Turkish siege in the 16th century and Axis bombing in the 20th. Despite a litany of invasion that spans centuries, Malta survives on its own terms.

MALTA

The Passion of Freedom

By WILLIAM S. ELLIS ASSISTANT EDITOR Photographs by BOB KRIST

THERE ARE TIMES when the whole of Malta is struck by the morning sunlight in such a way that the three inhabited islands of the archipelago seem to rise out of the sea to vanish along a sky trail of tawny dust.

It can be seen best from the sea. Even on days without the light-crafted illusion, the approach should be made by boat. Sail south from Sicily for 60 miles or so, and there will be Malta along with the other two islands, Gozo and Comino, positioned in the Mediterranean with the squatty, menacing presence of gloomy brood hens. There will be towers and forts and the splendid architecture of the capital, Valletta, rising above the ramparts.

There is a sense here of nobility and resolve, an implicit assurance of unsinkability. Down through the centuries Malta has been put to the survival test time and time again. Neither Süleyman the Magnificent and his Ottoman Empire in 1565 nor the combined airborne military might of Italy and Germany in World War II succeeded in visiting defeat on this battle-scarred nation. Even at times of imminent collapse Malta rallied with grand gestures of heroics.

Cloaked in history, three Knights of Malta stand in the Palace of the Grand Masters in Valletta. Squeezed out of Rhodes in 1523 by Ottoman Turks, the knights, a military and hospital order, were given Malta in fief by Spain's Charles V in 1530 for the yearly tribute of a falcon. In tribute to Roman Catholicism, a crowd fills a Valletta street (opposite) during the Procession of Our Lady of Sorrows.

Malta wears well its many cloaks of history, as, for example, the militant keeper of the Christian faith, with the cross raised in one hand, a sword in the other. But looking beyond the battlements, there is another Malta to behold, a nation gorging itself on the bittersweets of new independence; a nation, too, striving to gain a financial and ideological footing in the family of Western nations.

Just two years ago Malta was in the throes of an election campaign marked by violence—death, even—on the streets of the cities and towns of the island nation. When it was over, the Nationalists were in power, having ended 16 years of socialist rule by the Malta Labour Party. Today the polarization continues to the extent that last year a group of Labourites blockaded Malta's Grand Harbour in an attempt to prevent British naval vessels from entering on a courtesy call. Among those aboard one ship was Prince Andrew.

But there is a growing sense of confidence in the stability of Malta as the government in Valletta reaches out in an effort to repair Labour Party-wrought damages to relations with the West. At the same time, the reach is


Kinlochs
Quality Street
ANASTASI
PANINI

A Crossroads for Empires

GEORGE CROSS

UNITED KINGDOM

1 British in control, 1800-1964
With British help the Maltese force a French surrender; the British retain control until 1964.

ST. PAUL

2 Roman rule begins in 218 B.C.
Malta prospers. St. Paul, shipwrecked here in A.D. 60, introduces Christianity.

FRANCE

FRENCH FLAG

3 French take Malta, 1798
Napoleon stays six days before spiriting off art treasures and church artifacts.

SPAIN

ITALY

Rome

Sicily

TURKISH BATTLE FLAG

4 Turks lay siege to Malta, 1565
Despite a four-month battle that leaves nearly half the knights dead, Turks try—and fail—to capture Malta. The defeat humbles the Ottoman Empire.

Istanbul

MALTESE CROSS

5 Norman conquest, 1090
Western influence grows; Knights of St. John, also known today as the Knights of Malta, arrive in 1530 after being driven from Rhodes by the Ottoman Turks.

MALTA

Rhodes

Carthage

6 Phoenician and Carthaginian colonies, from the eighth century B.C.
Human habitation dates from 5000 B.C.; the first literate culture arrives with Phoenicians, legendary founders of Carthage.

CARTHAGINIAN COIN

LIBYA

Mediterranean Sea

ARABIC TABLET

7 Arabs invade Malta in A.D. 870
Ousting of the Byzantines paves the way for 220 years of Arab rule. Arabic influence imprinted on Maltese language.

LAMBERT AZIMUTHAL EQUAL-AREA PROJECTION
INFORMATION PROVIDED IN PART BY THE NATIONAL MUSEUM, MALTA

Mediterranean Sea

Marsalforn
Xaghra
GOZO
Victoria
Xlendi
Ggantija
Xewkija
Mgarr
COMINO

Marfa Ridge
Mellieha Bay
Mellieha
Mellieha Ridge
St. Paul's Bay
Sugibba
Wardija Ridge
240 m
206 ft
Victoria Lines
Mosta
Naxxar
Rabat
Mdina
Birkirkara
Sliema
Marsamxett Harbour
Grand Harbour
Valletta
Dingli Cliffs
Dingli
Qormi
Zebbug
Senglea
Vittoriosa
Cospicua
MALTA DRYDOCKS
TARXIEN
LUQA AIRPORT
Zejtun
Ghar Lapsi
MNAJDRA
HAGAR QIM
Zurrieq
Marsaxlokk
Birzebbuga
Marsaxlokk Bay

FARMLAND
BUILT-UP AREA

∴ Selected prehistoric temple site

SCALE VARIES IN THIS PERSPECTIVE.
DISTANCE FROM VALLETTA TO RABAT,
11 KILOMETERS (7 MILES).

NGE CARTOGRAPHIC DIVISION
DESIGN: JOHN LOTHERS
RESEARCH: DAVID MILLER
PRODUCTION: MEGHAN KIEFFER
MAP EDITOR: SUE PLATIS
PAINTING BY CHRISTOPHER KLEIN

MALTA

A COMPACT REALM, the republic's inhabited islands, Malta, Gozo, and Comino, cover 122 square miles. Once a haven for NATO warships, Malta now maintains a policy of steadfast neutrality and prohibits foreign military bases.

AREA: 316 sq km (122 sq mi). **POPULATION:** 348,910. **CITIES:** Valletta, capital, 9,239; Birkirkara, 20,490. **LANGUAGE:** Maltese, English. **RELIGION:** Roman Catholic. **LITERACY:** 83%. **ECONOMY:** Industries: tourism, textiles, ship repair. Export crops: potatoes, flowers. Per capita income: $4,205.

also meant to bring in foreign investments.

Only a nation freshly cast into the brotherhood of the self-ruled could have expended so much national energy on politics as Malta has. It gained independence from Great Britain in 1964. The last of the British fleet based here sailed out of Grand Harbour 15 years later, and for the first time since before the birth of Christ, Malta was master of its own house. The British were gone, as were, before them, the Phoenicians, Carthaginians, Romans, Byzantines, Arabs, Normans, Knights of St. John, and French.

Confirming allegiance to church and country, Edward Fenech-Adami is sworn in as prime minister on May 12, 1987. The Nationalist Party candidate beat his rival, Labour Party incumbent Karmenu Mifsud Bonnici, by less than 5,000 votes. Though pro-Western, Adami won't break Libyan ties nurtured by his predecessor.

"WE WERE deprived of our rights for many centuries," said Raymond Mahoney, a Maltese author. "That is one of the reasons for our obsession with politics. Another is our temperament, the full-blooded passion of the Mediterranean."

Sometimes that passion is like a crackling in the air. It brings a deep intensity to Maltese life, even to the simplest of acts. I once watched a Maltese man peel an apple, but he didn't just *peel*. He challenged himself to remove the skin completely in one piece with a single, nonstop twirl of the knife. And that is what he did, explaining that success or failure is a standard by which to judge the peeler's attractiveness to the opposite sex.

The passion is no less intense when an elderly man having coffee in a Valletta café says, "Look, I remember going to church and having the priest ask me if I voted Labour. When I told him I did, he refused to hear my confession."

In their 16 years of government control, the socialists made an icon of the lunch pail, a saint of the "worker." Ah, that word, worker! Maltese Labourites caress it with their voice until it becomes an aria unto itself.

The former government turned against the Roman Catholic Church in the face of the reality that Malta subscribes to Catholicism more heavily, on a population percentage basis, than almost any other nation on earth.

As an entrenched power base in the country, the church drew the wrath of Labour, and at one point an angry group of party supporters attacked the church's headquarters outside Valletta. Using a statue of the Virgin Mary as a battering ram, they entered a chapel and caused extensive damage. The inner agony of the island, Winston Churchill's "tiny rock of history and romance," had come to that.

Church-state relations have now improved to where there are lyrics of joy as well as lamentations to be heard in the land. On Good Friday, a day observed in Malta with the muting of church bells and the lowering of flags to half-staff, thousands of persons line the streets of the town of Mosta to observe a procession of hooded figures (page 710) dragging heavy chains on their feet and of men bearing statues depicting such scenes as Jesus being hugged by Judas.

There are similar Good Friday processions elsewhere in Malta, but the parish church in Mosta, from where the participants set out, carries the credentials of a miracle having been at work there. It happened in April 1942. A large German bomb came tearing through the dome of the church, a dome almost as large as that of St. Peter's in Rome, bounced off an interior wall, and then slid across the marble floor. The bomb failed to explode, and there were no injuries among

the 300 worshipers who were in the church.

That was the month, April 1942, that would break the back of this seagirt land if it was to be broken. The number of air-raid alerts averaged close to ten a day, the highest for any single month during the three years of World War II that Malta lay under siege. The Royal Opera House in Valletta took a German bomb and was destroyed. But the ruins would remain there, just inside the old gates to the city, as a symbol of the terrible ordeal of that month.

The outside world took notice of Malta's suffering, and on April 15, 1942, King George VI of Great Britain awarded the island the George Cross: "To honour her brave people . . . to bear witness to a heroism and devotion that will long be famous in history." A representation of the cross now appears on the Maltese flag.

SINCE THE DAY the war ended, the bombs stopped falling, and the Maltese emerged from the underground shelters, there has hardly been a time here, it seems, when the streets were not given over to processions or parades or just the throbbing swell of heavy population density. The three islands cover about 122 square miles (nearly twice the area of Washington, D. C.) on which close to 350,000 persons live. Whether on the promenades that skirt the handsome bays at Sliema, one of Malta's largest cities, or along Valletta's Republic Street, there is the unrelenting press of crowds. Malta strains against the embrace of the sea, but there is no relief; shadows here run together.

As Malta lies at midpoint between Europe and Africa, there is a cultural ambivalence at work in the country. Under Labour, the nation allied itself with Libya's Muammar Qaddafi and allowed the construction of a mosque on a site not far from the fort where the Knights of St. John used the heads of their Turkish captives as cannonballs. The relationship has cooled with the Nationalists in power, but Libyans continue to come to Valletta to shop and escape, if even for a few days, the austerity of their homeland.

The images here are often strongly Arabic: festive street life and conspiratorial huddlings, open-air flea markets on Sunday mornings, and everyday sales on the streets of pies made of phyllo dough wrapped around gobs of warm ricotta cheese (at least one vendor, with a stand just outside Valletta's city gates, keeps his pies in wooden drawers, filed away like ingots in a vault). In contrast, there are whispers of British gentility here, along with poses of stiff upper lipmanship.

It was for their language that the Maltese borrowed most heavily from others. "About 75 percent of the Maltese language is of Semitic origin, including old Arabic," Francis Ebejer said. "Another part of our language is of romance origin. And, of course, we have a lot of neologisms left over from the British occupation."

Thus, when Ebejer, a novelist and playwright of wide renown in Malta, would like milk for his coffee, he asks for *halib*, as an

Witness to the entrance and exit of British rule, Palazzo D'Aurel, home of Baron and Baroness Trapani-Galea-Feriol and their children (left), housed the British command in 1800. The British met here to close the military base in 1979.

"In Malta, it's politics for breakfast, lunch, and dinner," says Charles Flores, program director for Radio Malta, here at home with his two daughters (right). Flores and his wife seldom vote the same way. Division is a unifying theme. Villages split over competing saints, sports fans over football, and everyone over politics.

Arabic-speaking person would do. When he wants to offer a casual departure sentiment, he says, as would an Italian, *ciao*.

Even with the Nationalists controlling the government, canonization of the worker continues. And nothing becomes that more than the festivities held throughout the country on the first day of May. The buzz of prayers fills St. John's Co-Cathedral in Valletta on this feast day of St. Joseph the Worker as the archbishop's procession, trailing clouds of incense, nears the high altar in the centuries-old church. One highlight of the Mass will be the blessing of the tools and products of laborers and craftsmen and professionals.

It is not likely that the builders of the church, the Knights of St. John, would have approved of such classless benediction.

Although the order began as a hospital service for Christians stricken while on pilgrimage to the Holy Sepulchre in Jerusalem, it later became a military one as well, and to be a knight, one had to be of noble birth.

The knights were not at first impressed by the Maltese islands, on which there are no rivers or mountains, where the sun burns into the soft, yellowish limestone that underlies everything, and where the winds of winter hurl the sea against the shores. But, then, the price to be paid for Malta, as stipulated by Charles V, Holy Roman Emperor and King of Spain, was minimal: on All Saints' Day of each year, one falcon.

The knights ruled Malta for more than 250 years, or until Napoleon took it away from them and held it just long enough to strip away many of the treasures. They fashioned the island into an imposing fortress that even 30,000 elite soldiers in the service of the Ottoman Empire of Süleyman the Magnificent could not overrun. When they were not fighting, the knights were building—Valletta, for example. They quickly graced that tasteful city with structures of great beauty, including the *auberges* (inns) representing areas of Europe from which most of the knights in Malta came: Aragon, France, Germany, Provence, Castile, Auvergne, Italy.

Being in Valletta now, or in the southern port town of Marsaxlokk, or up on the north shore near the bay where, it is written in the Bible, St. Paul was shipwrecked, it is possible to sense the presence of the knights even after the passage of all the centuries. For Joseph Galea, the past is more than a feeling; it is the lengthy chronicle of a time when Malta was helping in no small measure to thwart the designs of Islam on Christian Europe.

Galea, a knight himself, was detailed in 1938 by the government of Malta to collect the records of the order. "I brought all of them to the library, as a repository, and have been working devotedly ever since," he said. "They go back to 1107, and, in all, we now have more than 5,000 volumes. It's my life."

Mdina, the ancient Maltese city and former capital where Galea lives (part of his house dates back to Norman times), figures prominently in the extraordinary historical pedigree of the country. Like Valletta, it is a fortified city with gates and of a character drawn from reaches to East and West. There are small signs on some of the doors of the houses in Mdina cautioning proselytizing Jehovah's Witnesses not to bother to knock, but otherwise there is a feeling in the city suggesting that little has changed since St. Paul was here, making a believer out of Publius, the chief Roman citizen of Malta.

The knights continue to maintain a medical facility—a blood bank—in the country. "More than half the blood needed in Malta comes from this bank," the director, Dr. Paul Farrugia, who is a knight, told me.

In Malta membership in the order has increased in recent years to where there are now about three dozen, most of them elderly.

IT IS JUST AS WELL that Dr. Farrugia and the other knights in Malta are not at battle ready, for invading forces no longer come to these shores. With the recent application of nuclear power to the tools of war, Malta has lost much of its strategic military value. Its natural harbors are still among the finest in the world—indeed, Valletta's Grand Harbour may be *the* finest—but the days when naval vessels steamed into these waters are gone.

"I would agree that Malta has lost its positive strategic value, but it still retains a negative strategic value. It is in the interest of other nations that Malta should not lean to one side," said Edward Fenech-Adami, the nation's prime minister. "I mean, NATO no longer needs Malta for its defense purposes. On the other hand, NATO would not like Malta to go to the Warsaw Pact, nor do the Maltese want to. This is the negative strategic value I speak about."

From a crane cabin, an operator assists construction of a Soviet timber carrier at Malta Shipbuilding Co. Ltd. Shipbuilding and dry dock repairs, one of Malta's major industries, generated nearly 70 million dollars in income last year. Libya owns a 30 percent share in the company, but Malta retains the largest interest.

Under the Labour Party's longtime rule, Malta tilted away from the West. In April 1986, for example, Malta gave advance notice to Libya: Planes, later identified as U. S. bombers, were headed toward North Africa. Such actions cause Western countries in general to regard Malta with distrust.

If the Labour Party brought about an imbalance in Malta's foreign policy, Prime Minister Fenech-Adami, in line with the ideology of his Nationalist Party, hopes to correct it.

"I see no reason why our good relationship with Libya should not stand," he told me. "But Malta must steer its own course. Malta needs closer links with the European Community, but that should not exclude a neighborly relationship with Libya."

THERE HAVE BEEN no whirlwinds of change during the two years of Nationalist stewardship. Nearly 50 percent of the economy remains under government control, and there has been no meaningful move toward privatization. Rather, the Nationalists have advanced slowly, loosening the controls, increasing subsidies to church schools, chipping away at the high number of workers in the public sector, and moving ahead to establish Malta's first stock exchange.

No commercial venture in the country is larger than Malta Drydocks. The facility is located on the site where the British maintained their major naval facility. Ship repair and construction are traditional trades in Malta, but now the vessels are commercial rather than naval. With passenger liners in need of repairs calling here, Malta has retooled. Workers who once wove cocoons of armored plate around deck guns on ships with such thunderbolt names as *Valiant* or *Illustrious* are now laying teak dance floors on the *Princess* this or the *Countess* that.

Like the Drydocks and its sister operation, Malta Shipbuilding Co. Ltd., most of Malta's lifelines are plugged into the sea, and none are more important than the plant that sits below the high cliffs on the south shore at Ghar Lapsi. It is there that salt water is taken from the Mediterranean and made potable. Without this process, Malta, which receives less than 15 inches of rain some years, would

Pearls of light drape Mosta's parish church during a summer festival. In 1942, as 300 worshiped, a German bomb crashed through the dome and clattered to the floor, unexploded. Malta endured prolonged heavy battering in World War II—suffering some 6,700 tons of bombs in April 1942 alone. Said U. S. President Franklin D. Roosevelt: "Malta stood alone but unafraid . . . one tiny bright flame in the darkness." Today the fire of faith burns in devotees who drag chains down a Mosta street on Good Friday.

be a nation in the grip of desperate thirst.

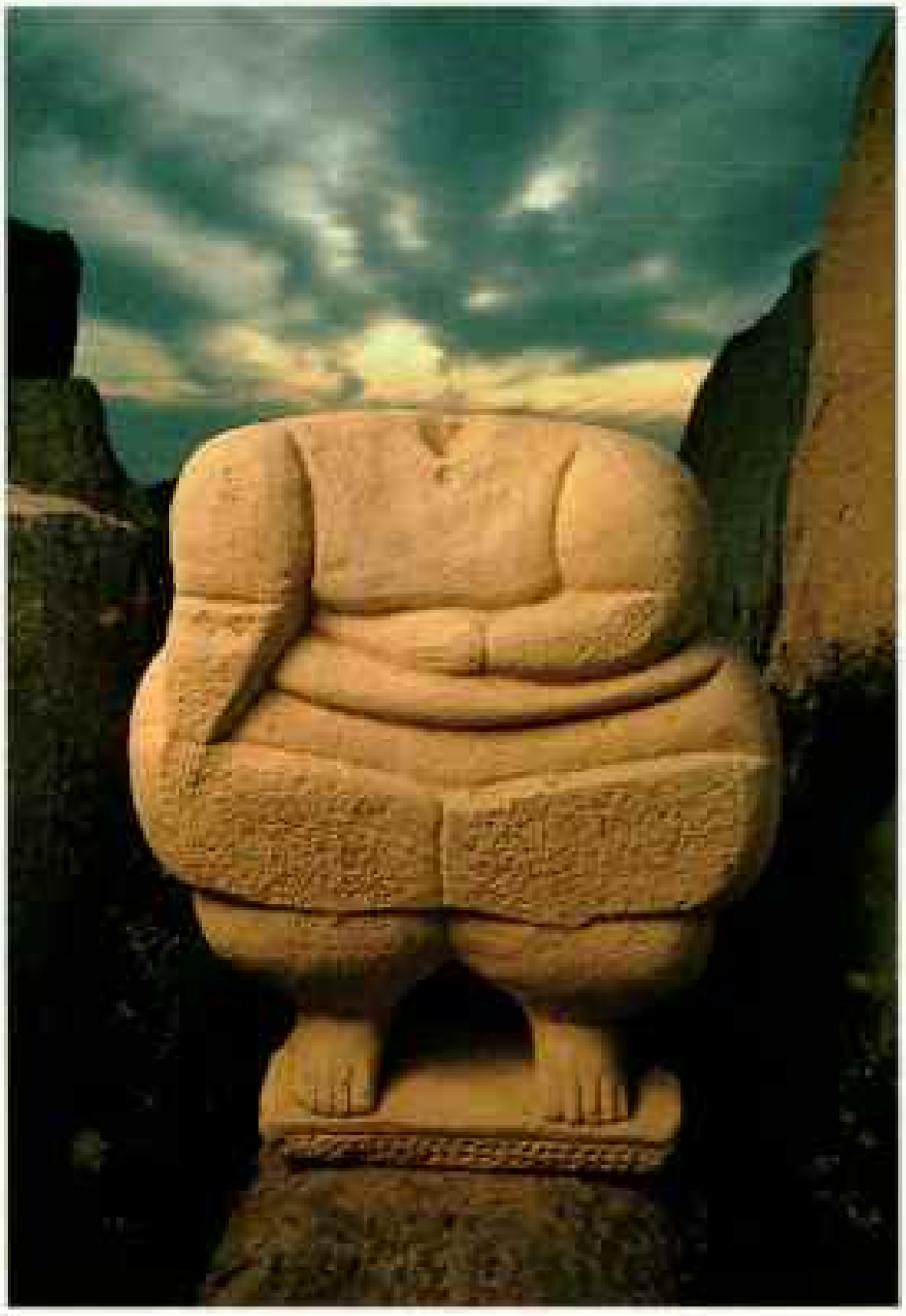
"This is one of the largest seawater reverse osmosis plants in the world," said Tim Clark, an American who is director of operations. "The production here is about six million gallons of water a day." This and three other plants produce about 16 million gallons a day against a nationwide need of 23 million gallons. The rest comes from wells.

ON MANY mornings the cliffs of Malta are alive with gunfire as hunters, or, as they call themselves, "sportsmen," shoot or trap as many of the birds as possible. Most of the birds are migrants, setting down on the islands while en route to Africa or Europe.

The Maltese have long had an obsession with birds. Old men are frequently seen on the streets carrying small finches in cages, taking the bird for an outing as a dog is taken for a walk. Still, there are men who position themselves on the cliffs, before dawn on spring mornings, with their backs to the wind, and they shoot and shoot until, at the end of the spring season, nearly 100,000 turtledoves have been killed.

"Migratory birds were, for a long time, a food source for Mediterranean people," Joe Sultana, former president of the Malta Ornithological Society, said. "The Maltese no longer shoot them for food. They do it for fun.

The bedrock of civilization in Malta is, quite literally, limestone taken from quarries. Soft when cut (left), the stone hardens with exposure. Limestone blocks form the walls of Malta's temples, like one at Mnajdra (above), among the world's oldest stone monuments. Boulders were shaped with stone hammers and moved on round stones like ball bearings. Obsidian or flint blades completed the fine carving. This temple and some 30 others were built in the third and fourth millennia B.C. by a culture that migrated from Sicily. The temple at Hagar Qim yielded the statue of a "fat lady," probably a fertility goddess, shown here in a replica (right). The temples suggest an intricately organized society with a priestly cult involved in ancestor worship. After about a thousand years, the temple-builder civilization seems to have disappeared abruptly, inexplicably.



Those 100,000 doves shot—that's a poor season; they kill twice as many in a good one."

Perhaps the greatest tragedy is that of the falcons. Speak of Malta in San Francisco or, for that matter, in Nouakchott, Mauritania, and the reaction is likely to be one of instant recognition: the Maltese falcon of Humphrey Bogart film fame. Until two years ago, there were one or two pairs of peregrine falcons nesting on the cliffs, but now there are none. Sultana says they were shot.

On the other side of the main island the shore is more gentle, given over at places to pleasant beaches. Many resort hotels are here, filling up each summer with tourists from the United Kingdom and other parts of Europe, but mostly Britain. The British servicemen who were stationed in Malta during the Second World War come back. They bring their families, and they sit in the fierce heat of July and August, and they remember.

As an independent Malta gropes to find its place in the world of nations, more and more attention is being directed toward tourism.

It would be wrong to draw visions of Malta as a Mediterranean island rimmed in white sand and splashed with the brilliance of blooming oleander. The recreational beaches

Stone walls near the village of Zurrieq on Malta's southern coast overlie slopes like open-worked lace. Topsoil is thin; the latticework of barriers slows erosion from winter rains. The land is only modestly giving: A third is arable, and crops include potatoes, citrus, tomatoes, and fodder.

here are few, and, in season, they are in heavy, crowded use. Then too Maltese summers are cursed with a breath-snapping heat. Nevertheless Germans and Scandinavians, as well as the British, come to the island in strong numbers. By 1990 nearly a million tourists are expected to visit Malta each year.

THE FIRST SETTLERS on Malta are believed to have arrived around 5000 B.C. They came from Sicily, probably after having looked out on a clear day from the southernmost point there and seen the islands. As farmers, they came with animals and seeds, and here, at a time before the pyramids were built in Egypt, their descendants constructed megalithic temples of ingenious design. Though in ruins, they are still here, at Hagar Qim and Tarxien and the ones called Ggantija on Gozo.

Tony Dingli is not an expert on the Ggantija ruins, and, indeed, there are not many of those who live on Gozo who can explain the purpose of the niches, altars, or libation holes. But Tony Dingli knows Gozo and its people as well as anyone.

He knows, for example, of a place at the lovely seaside village of Xlendi where there are steps leading down a cliff to a small secluded beach. Once there was a gate with a padlock at the top of the stairs, and the only keys were in the possession of a group of nuns. Now the access is open to all, but for many years, Dingli likes to recall, figures in white could be seen going up and down the stairs, while the muffled sounds from the hidden beach were no different from those of young girls and their squeals when testing the temperature of the surf.

Many people on Gozo have a relative living in the United States or Australia. "Myself, I had four brothers living in New York City at one time," Dingli said. "I went there too, but I stayed only four months. It was too noisy. My brothers could sleep all right, but I had trouble. I had headaches, and I was awake, it seems, the whole time I was there."

There are signs on some houses in Gozo that read God Bless America, and there are men like Rando Zammit who wear New York Yankees baseball caps. He lived in New York for 14 years before returning to attend the death of his father and assume ownership of the family business. They always come home to Gozo then—when the father dies and there is tradition to be maintained.

For Rando Zammit it was the business of quarrying the limestone that is used for virtually all housing construction in Malta. It lies in the ground on Gozo in seemingly endless quantities. I asked Zammit how long he

The crush of grandmotherly love enfolds three-year-old Marita Saliba on Gozo. Here life slows to the unhurried pace of a game of brilli. *But there is nothing casual about how Malta plays the hand dealt by geography. Guided by an instinct for survival, it insists on neutrality. "I don't want to lose friends," says its prime minister. "I want to make new ones."*

could take the soft limestone from the site. "Forever," he replied. Once the stone had to be cut by hand, but electric saws are used now. "We can do 20 times more work with four people than they could in the old days with 80 workers," Zammit said.

The island is still strongly devoted to the church and its teachings. In almost every village the first Mass of the day is celebrated at 4:45 a.m., and it is well attended. "Up until the time I was ten years old, whenever I came across a priest, I'd kneel down and kiss his hand," Tony Dingli said.

THE YOUNG MEN of Gozo still go off to foreign lands in search of work and to escape from the confines of tradition on the island. Toni Mizzi has seen nine of his sons go away to Australia, and he understands. "They have a better future there," he said. "Anyway, now they can phone me direct from Australia."

Elsewhere in Gozo there are aged men tending to their fishing nets, and women with hands like the burls on ancient trees tatting and carrying on the tradition of fine lace being made in Gozo. If it isn't the feast day of a saint, the island bridges dawn and sunset with sunstruck inertia.

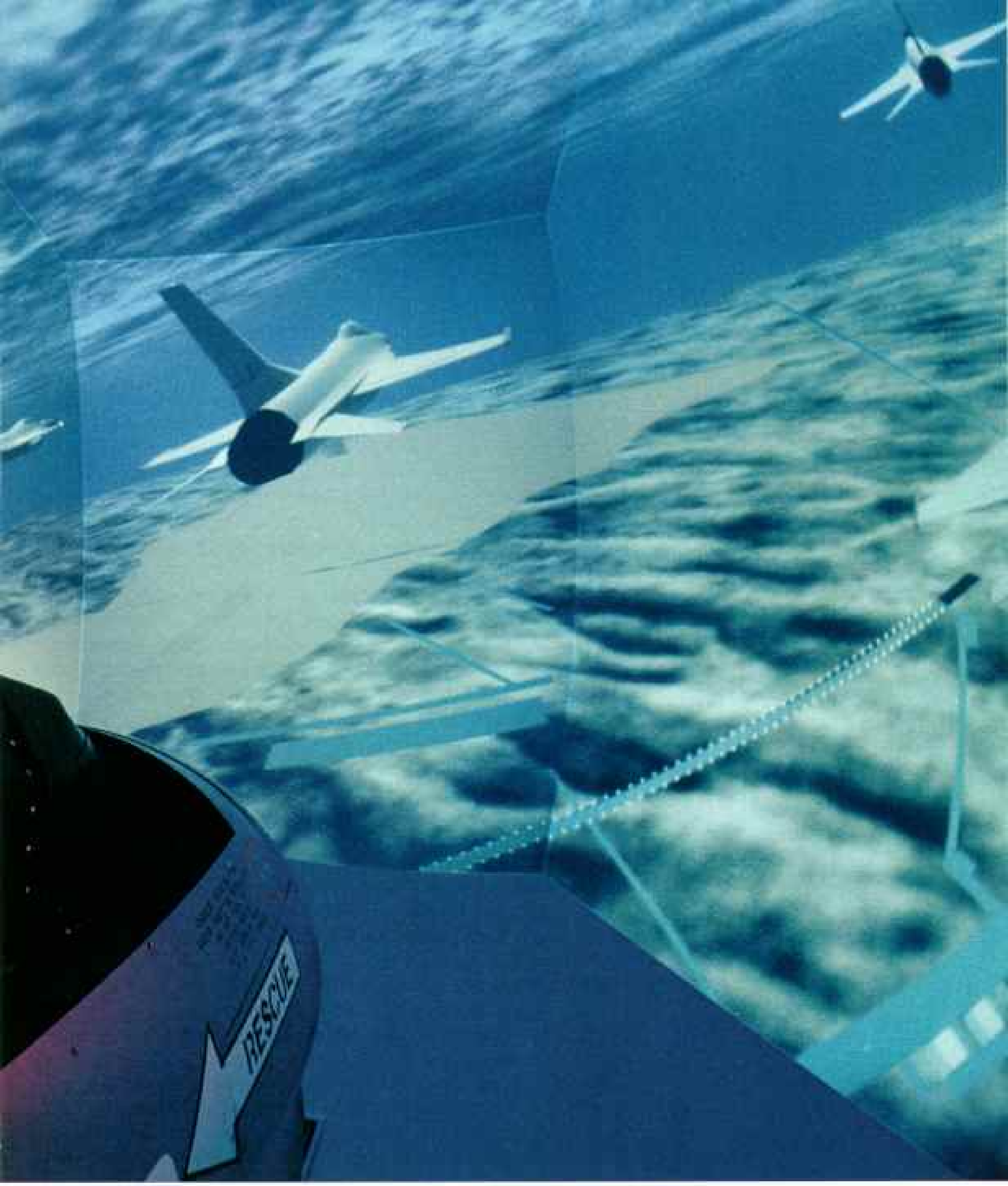
Charles Flores lives in Malta in a house with a plaque reading Poetics on the front door. He is a poet, and, in the manner of many Maltese, he has given a name to his house rather than a number. "It is a charming custom," Flores said, "but I suspect it must cause the postman some problems."

Flores lives with his wife and two daughters on the outskirts of Valletta in a place called Birkirkara. He is a man of strong intellect, a man whose emotions have been singed by the fires of nationalism. He has been attending political rallies for much of his life, and when he is at one, standing in a crushing crowd of thousands on a narrow street in a village, lending his voice to the drone of approval for a party (Labour) speaker, Charles Flores does not really care very much about the quaintness of Gozo with its lacemakers and net-mending fishermen.

I went with Flores to a Labour rally at the town of Mellieha, and there was violence—the hurling of bottles and the destruction of property.

But if Flores was embarrassed, it was because of the manners of his countrymen, not their zeal. He knows that the Maltese, having expended as much gallantry down through the centuries as any people on earth, have earned the right to the exuberance of new freedom. □

Images for the Computer Age



In the snug safety of a flight simulator's stationary cockpit, a pilot experiences an astonishingly real sense of combat. Images on the surrounding dome represent the ultimate in computer graphics, a fast-evolving phenomenon of the information age.

ARTICLE AND PHOTOGRAPHS BY FRED WARD BLACK STAR

IN THE DARKENED ROOM at the University of Illinois, a distinguished professor of mathematics named George Francis hunched over a computer keyboard. Above his head, on a row of oversize screens, I watched the computer graphic he had created take shape—a dreamlike female form, all curves and sensuous undulations.

This was not what I had expected from a mathematician. "What am I looking at?" I asked.

"A revolution," he replied, "a genuine revolution."

"Pardon me—but it looks more like the goddess of love."

"I think so too," said Professor Francis, mightily pleased. "But beautiful as she is, she's pure mathematics, a visual representation of equations."

Francis is but one of scores of artists and scientists I met over the past year whose lives have been transformed by their involvement with one of the world's newest high-tech tools, computer graphics.

Computer images are everywhere: on television as station identification, in commercials as dancing fruit and singing toothpaste, on computer screens in practically every scientific and manufacturing lab in the world, and in space-age magazine illustrations when an ultramodern look is needed.

Computer graphics are pictures generated by a computer programmed and operated by human beings. Only the imagination of the user limits the form they can take: animation, simulation, graphs, re-creations, portraits, architecture, drawings, paintings, or just simple lines. Because computer graphics are a way of making thoughts and ideas visible, these revolutionary images are becoming the universal language of our time.

George Francis says that the insights revealed to him by this new technique have changed the way he thinks about mathematics. "I've been reborn," he told me. "I've taught college math for more than three decades. And until I saw my work visualized by computer graphics, I never truly understood differential geometry."

So, how do computer graphics work? In concept, rather simply. A computer screen is composed of tiny dots that act in the same way as signboard light bulbs. Each minuscule dot, or pixel, can be switched on and off like a bulb—but dozens of times a second.

With the screen as canvas and light as paint, a computer user creates an image on the glowing surface of a picture tube. A decade ago a programmer had to write an elaborate script to switch each pixel on or off. Now, thanks to ever speedier equipment, an artist can turn a series of red pixels into a red line as fast as he can draw with a light pen, stylus, or mouse. The industry is literally bursting with energy. Almost daily one volatile innovation sparks another, such as Intel's recent introduction of the world's first million-transistor microprocessor. A chip a quarter of the size of a postage stamp, it will help generate even faster images. A society without computer graphics will soon seem as quaint as the world before plastics.

Millions of products made in the U.S.A. are designed, drawn, and prototyped on a computer before manufacture. Thanks to computer graphics, scientists "look" inside molecules too small actually to be seen. It is also perfectly possible nowadays to visualize the interior of a dying star or a nuclear explosion. The mind can go places where no physical being will ever be likely to go.

Anything that can be imagined can be imaged, in exquisite detail

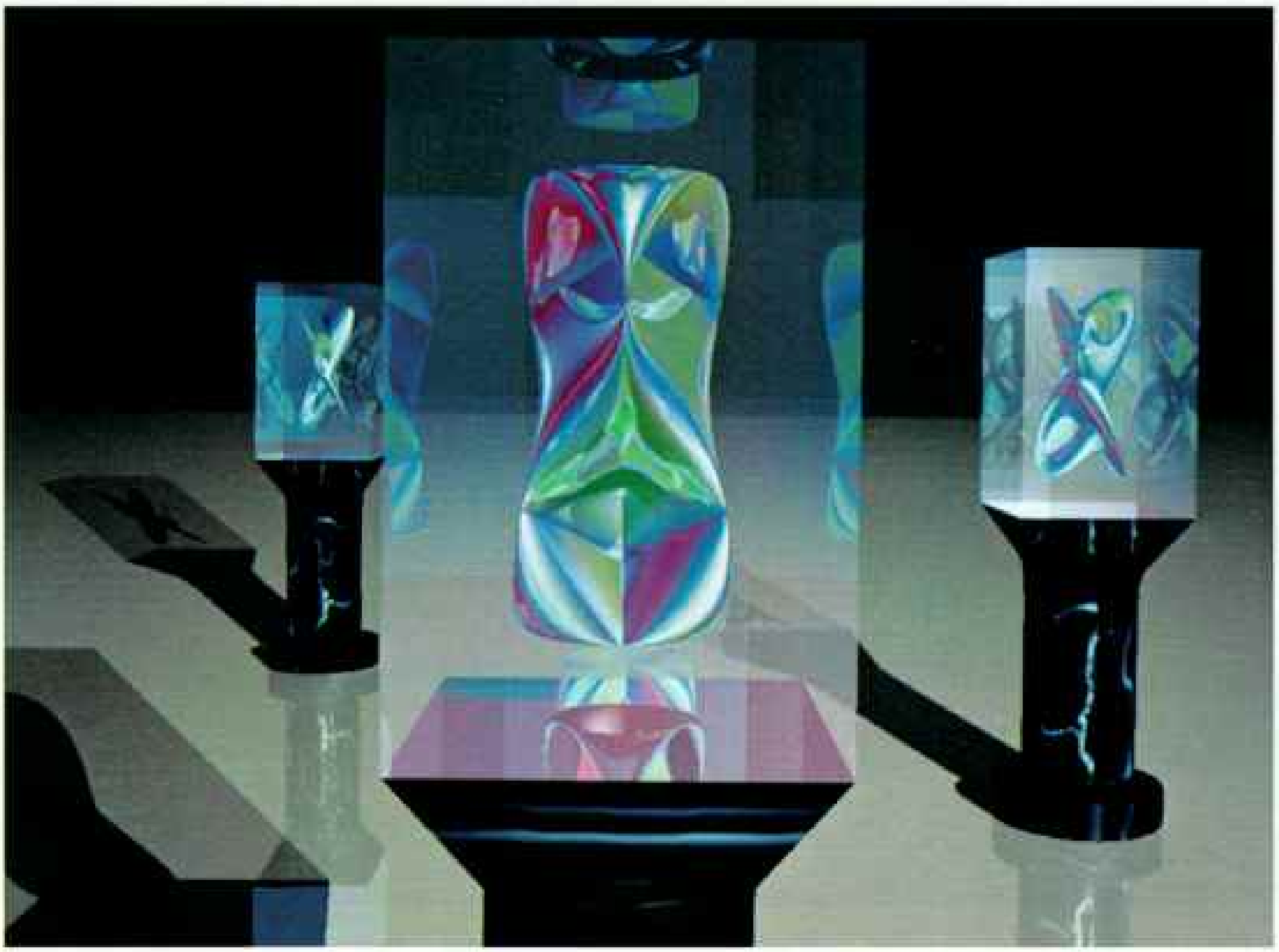
For eyes only, the Etruscan Venus (opposite, foreground), along with most of the "things" pictured in this article, exists only in the untouchable world of computer graphics. At the University of Illinois National Center for Supercomputing Applications, the Venus and her companions are actually visualizations of complex equations created by a mathematician, an artist, and a programmer working together. A technological prodigy fueled by society's expanding supply of computing power, computer graphics can reduce millions of numbers to a form readily accessible to human comprehension.

DONNA J. COX, GEORGE FRANCIS, AND RAY IDABURO, NATIONAL CENTER FOR SUPERCOMPUTING APPLICATIONS, UNIVERSITY OF ILLINOIS. THE COMPUTER SCREEN SYMBOL USED THROUGHOUT THIS ARTICLE IDENTIFIES IMAGES THAT WERE CREATED PURELY BY COMPUTER.

and in forms that can be examined, dissected, studied, and enjoyed from any angle, in any color, with any magnification.

Some original works, such as entertainment or television commercials, spring from artists' creativity. Sometimes objects need careful study with computations, like the faulty case joints that caused the tragic explosion of the space shuttle *Challenger*. The joints were redesigned after their mathematically expressed characteristics were turned into vivid computer graphics. Examining these images of the joints under stress, engineers could clearly see how fuel-tank O-rings failed in cold weather and caused the greatest American tragedy of the space age.

Computer graphics are an indispensable tool in training the crews of spacecraft and commercial airliners. Events that cannot be staged because of their danger, cost, or inaccessibility are everyday computer simulator subjects. These ultimate computer games



let pilots train in absolute safety while tossing them challenges for instant problem solving. No pilot could be ordered to land a jetliner in a thunderstorm with two engines on fire and the wheels locked up, but a flight simulator equipped with computer graphics realistically produces this frightening sequence and more, without endangering passengers or plane.

The source of much of the world's high-quality simulation is the Salt Lake City headquarters of the pioneering computer firm of

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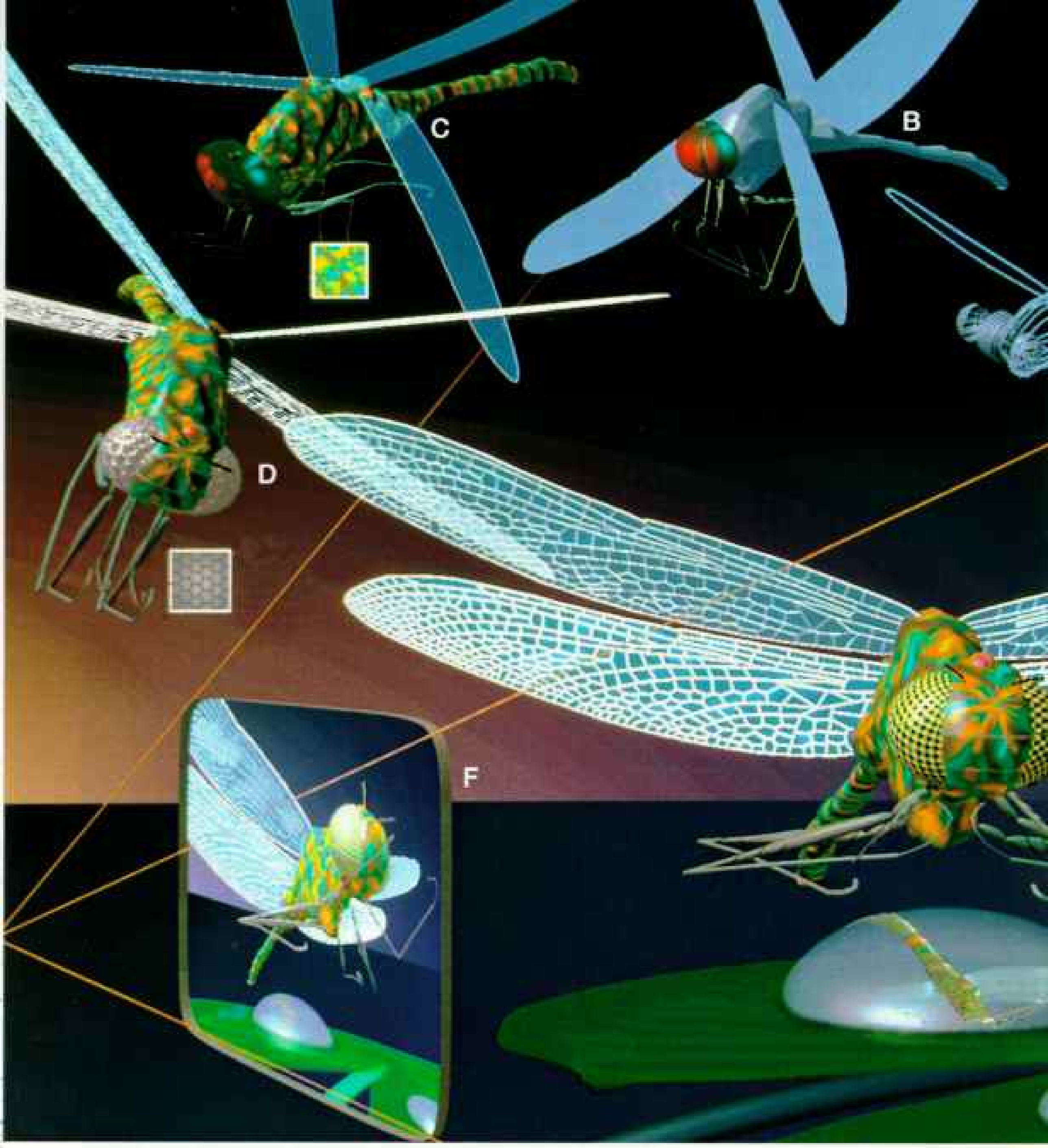
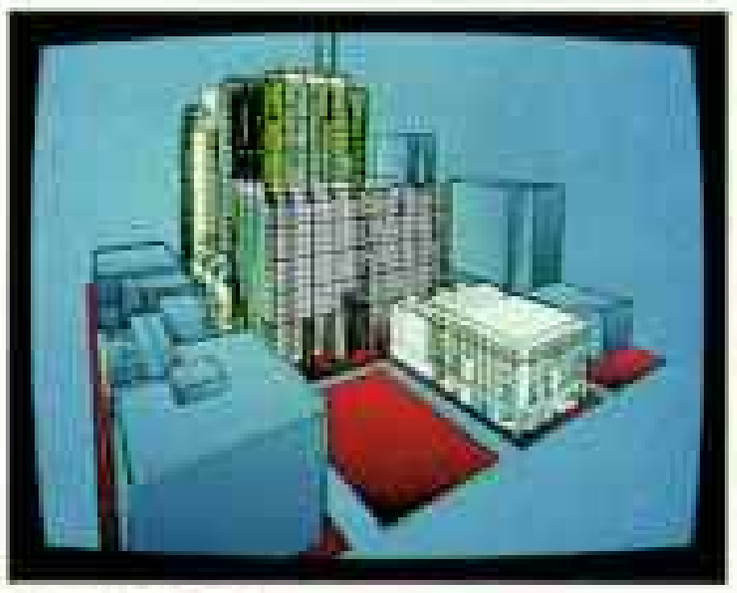
Author-photographer FRED WARD carries a portable computer wherever he goes. He has contributed GEOGRAPHIC articles on such varied topics as jade, Tibet, diamonds, Cuba, Cree Indians, and the Everglades.



Simulation

Valuable tool for defense and countless other industries, simulation provides safe tests for human-machine interaction.

☐ EVANS & SUTHERLAND COMPUTER CORPORATION, SIMULATION DIVISION



CAD/CAM

For computer-aided design and manufacturing, graphics affords unlimited freedom to explore alternatives.

☐ MAC ARCHITRON, GIRDIR

Medicine

Safer surgery is one big payoff as digitized image processing brings doctors 3-D views inside the human body.

☐ HANS-PETER MEINZER, GERMAN CANCER RESEARCH CENTER, HEIDELBERG, WEST GERMANY

Seeing the Unseeable

Conceived in an imaginary, three-dimensional void by Dallas-based artist Doug Struthers, a dragonfly emerges step by step—each stage the result of complicated computations. First Struthers constructs in the computer a "wireframe" (A), by plotting along three axes—height, width, and depth. To compose a three-dimensional thorax, thousands of tiny polygons are joined to the framework like a skin of playing cards. Filling in these facets with hues of a selected opacity and shadings for light gives the illusion of curved surfaces (B). In the third stage (C) a process known as texture mapping lends the insect its mottled coloring (box). Then the wings are assigned a degree of transparency and the eyes a specularity, or mirror-like quality.

In the fourth stage (D) the insect's wings are veined using digitized data from scientific drawings. For the eyes the artist selects another pattern (box) and experiments with a technique called bump mapping. It employs complex equations to modulate light in such a way as to create the illusion of bas-relief. The computer's amazing "what-if" ability enabled Struthers to illustrate and discard this technique and other options along the way. For his finished image (E), he chose colored hexagons to create a more interesting eye pattern.

The most demanding step for Struthers's computer, which handles almost a million instructions per second, was the rendering of the dragonfly's reflection in a water drop. Using a process known as ray tracing, the computer took two days to accomplish the task, which could have been handled in minutes, or even seconds, by some of today's supercomputers.

Throughout the process Struthers could view his creation on a computer screen (F), etched with hundreds of thousands of picture elements, or pixels. Each visible polygon in the insect's body might occupy several pixels, or just a portion of one, depending on its computed distance from the screen's plane. To inspect his work from any perspective, he used keyboard commands to change his "eye point." Other commands enabled him to zoom in and back away from the image, as with a camera lens.

☐ DOUGLAS L. STRUTHERS

Scientific Visualization

Complex mathematical equations translate into images that reveal new meaning to scientists.

☐ STEFAN C. MÜLLER, THEO PLESSER, AND BERND HESS, MAX-PLANCK-INSTITUT, DORTMUND, WEST GERMANY

Animation

Computer fantasies, spiked with startling realism, are winning honors in the motion-picture and television industries.

☐ ROBERT ABEL, RANDY ROBERTS, AND TIM McGOVERN

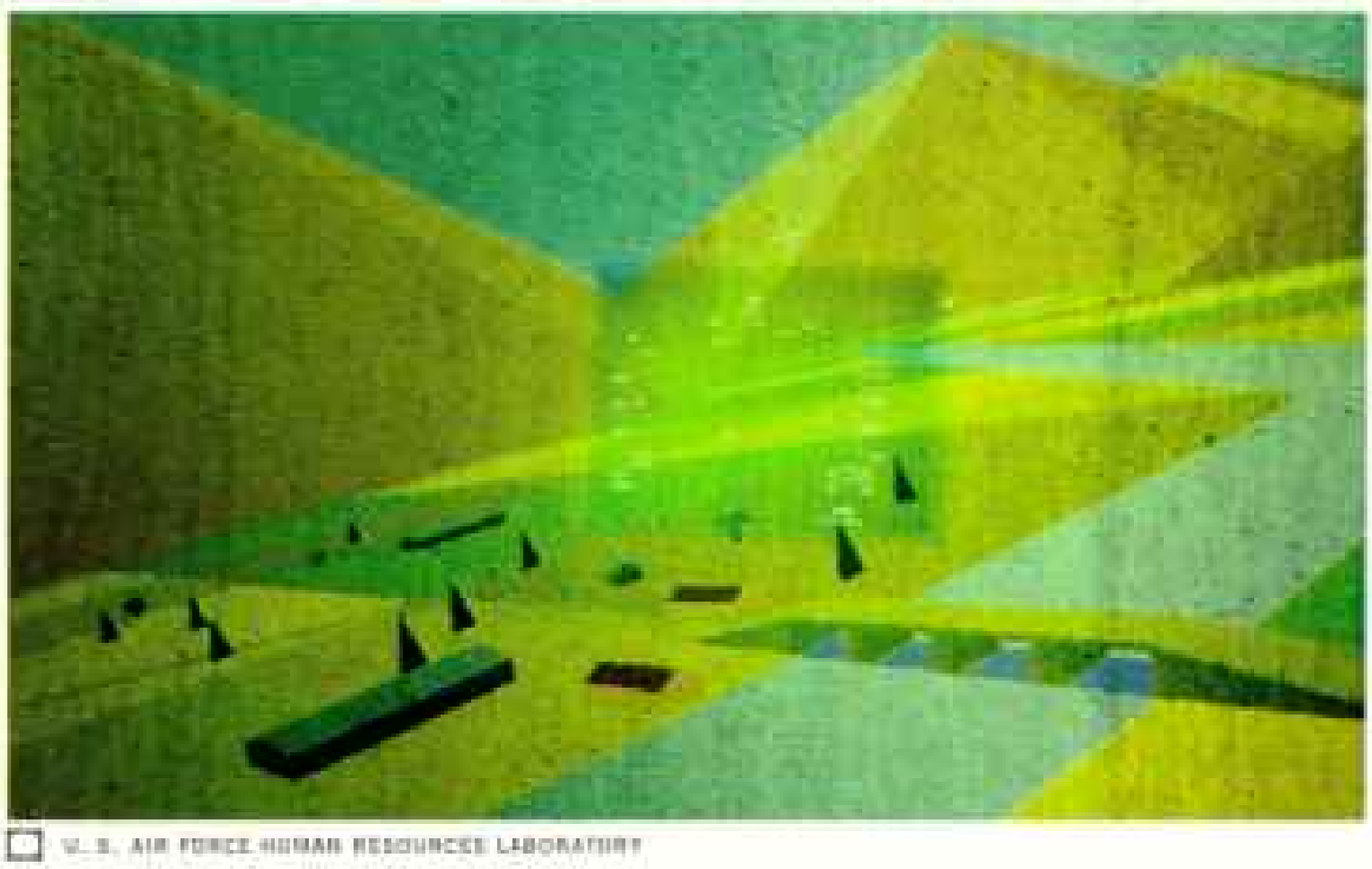
Art

Discovering new links between geometry and nature, graphics artists create beauty through mathematics.

☐ MICHAEL BARNSLEY, ITERATED SYSTEMS

Simulation

Up, down, and all around: Just the slightest head movement triggers a change of scene in the helmet-mounted display being tested at Williams Air Force Base, Arizona. Unlike dome simulators, this device provides the pilot with a total field of view, enabling him to "check six," or the six o'clock position behind his head. Images, like this scene with triangular trees and mountains (below), are projected through fiber-optic bundles onto the outer lenses, where they are beamed directly into the pilot's eyes. Flight and target data in the greenish square in the middle of the image emanate from the head-up display, or HUD. Still in the experimental stage, the helmet simulator is jointly funded by the U. S. Air Force and the Canadian government. It may lead to the development of even more compact systems.



U. S. AIR FORCE HUMAN RESOURCES LABORATORY

Evans & Sutherland. A pilot about to train on one of the E&S simulators at airline centers around the world sits in a real cockpit looking out at a surprisingly realistic picture of a computer-generated airport. His view is vividly focused by details that programmers have included or omitted—forcing him to concentrate on the essential elements.

As the plane's throttle is pushed forward for "takeoff," the scene begins to shift. Approaching objects grow larger, creating the illusion of movement, and then race by the side windows. The runway seems to speed beneath. Then the plane "lifts" as ground details get smaller. The illusion is complete. Neither pilot nor cockpit has moved a bit, but there is an overwhelming sensation of flying.

E&S president Dave Evans, a wiry computer-graphics pioneer responsible for many simulation innovations, explains: "For the ultimate in lifelike training, we let pilots fly through computer images that look just like places they may someday go. Of course what

they're really doing is flying through a computer data base. It looks real because we use actual earth mapping and terrain data as the basis for our scenes."

The images are also precisely synchronized so that the outside scene is being calculated and drawn in real time to respond in an eerily lifelike manner to the actions of the plane and pilot. In other words, the whole picture changes in response to the ways in which the pilot manipulates the controls. If, say, he makes a hard left turn, he flies into a different scene, which is instantaneously drawn to show his current position. The effect is not just lifelike—it is super lifelike. Systems are so good now that the FAA certifies experienced airline co-pilots to move up to passenger-carrying pilot status based on simulation training and testing.

To see how good the best computer flight simulation is, I traveled to Fort Worth, Texas, where General Dynamics builds the F-16, a plane considered by many the world's state-of-the-art fighter. Jack

Drewett, the manager in charge, walked me through room after room of simulators before introducing me to his baby, a 24-foot-wide white dome surrounding a fully equipped F-16 cockpit. "This is the most realistic flight simulator in the world," Jack told me. "In it, we can 'fly' you to any point on earth, in any weather, at any time, and let you dogfight, bomb, or shoot missiles."

I climbed a ladder to the pilot's seat. Although I have piloted helicopters and small planes for years, I was amazed at the concentration and dexterity needed to cope with the F-16's bewildering array of switches, dials, displays, and buttons. I wondered aloud how anyone ever fights and flies a modern warplane at the same time.

Jack nodded sympathetically. "Aircraft and weapon designs are currently limited by human capabilities," he said. "That's why these computer-graphics simulations are vital. By testing concepts and designs that engineers have only dreamed about, we see how far pilots can be pushed, and we test weapon systems before we commit to building them."

Now it was time for me to fly my mission. Jack gave a signal. Instantaneously the curved dome was alight with a giant projected mosaic of earth and sky drawn by a ten-million-dollar E&S CT-6

Cruising through a data base at Daimler-Benz in Berlin, a driver puts a Mercedes test model through its paces in a simulator similar to those used for aircraft. Computer-generated images of an imaginary road are linked to the car's controls so as to create a realistic driving experience. Such devices measure mechanical and human responses to conditions like icy roads that would be dangerous in actual circumstances.

image generator. Though the picture was moving and I was sitting still, my senses—and my queasy stomach—told me that I was off and flying in the world's hottest aircraft.

Sky and water merged in a dizzying blur as my imaginary F-16 raced a hundred feet above imaginary waves at an imaginary 500-plus miles an hour. My hands were wet with the sweat of tension and concentration. I knew that the merest forward pressure of my right wrist would plunge me into the ocean and any climb would reveal me to the enemy's radar net.

Now I was less than two minutes from my "target," a guarded power station inside the Arctic Circle. I monitored my displays for signs of hostile activity. Would enemy planes be waiting? A quick glance at my head-up display (HUD) verified I was on course for Steerpoint 12. My two HARM missiles were now tuned to look for deadly surface-to-air missiles that might shoot me down.

Less than a minute to target, my radar warning receiver (RWR) indicated I'd been acquired by enemy radar and a SAM was locking on to me. Hurry, hurry, I thought . . . no time, no time. With only a second to react I checked the multifunction display to confirm that my HARMs were armed. The HUD's green symbols

The ultimate in cruise control, technology being developed in West Germany not only brakes and accelerates but also steers a vehicle. From a TV camera on the dash, digitized images of the road (bottom) are fed into a computer system that is able to read and evaluate the road's midline and curb curvature. Developers envision the system serving as an autopilot for drivers on Germany's autobahns.

INSTITUTE FOR SYSTEMS DYNAMICS, UNIVERSITY OF THE ARMED FORCES, MUNICH

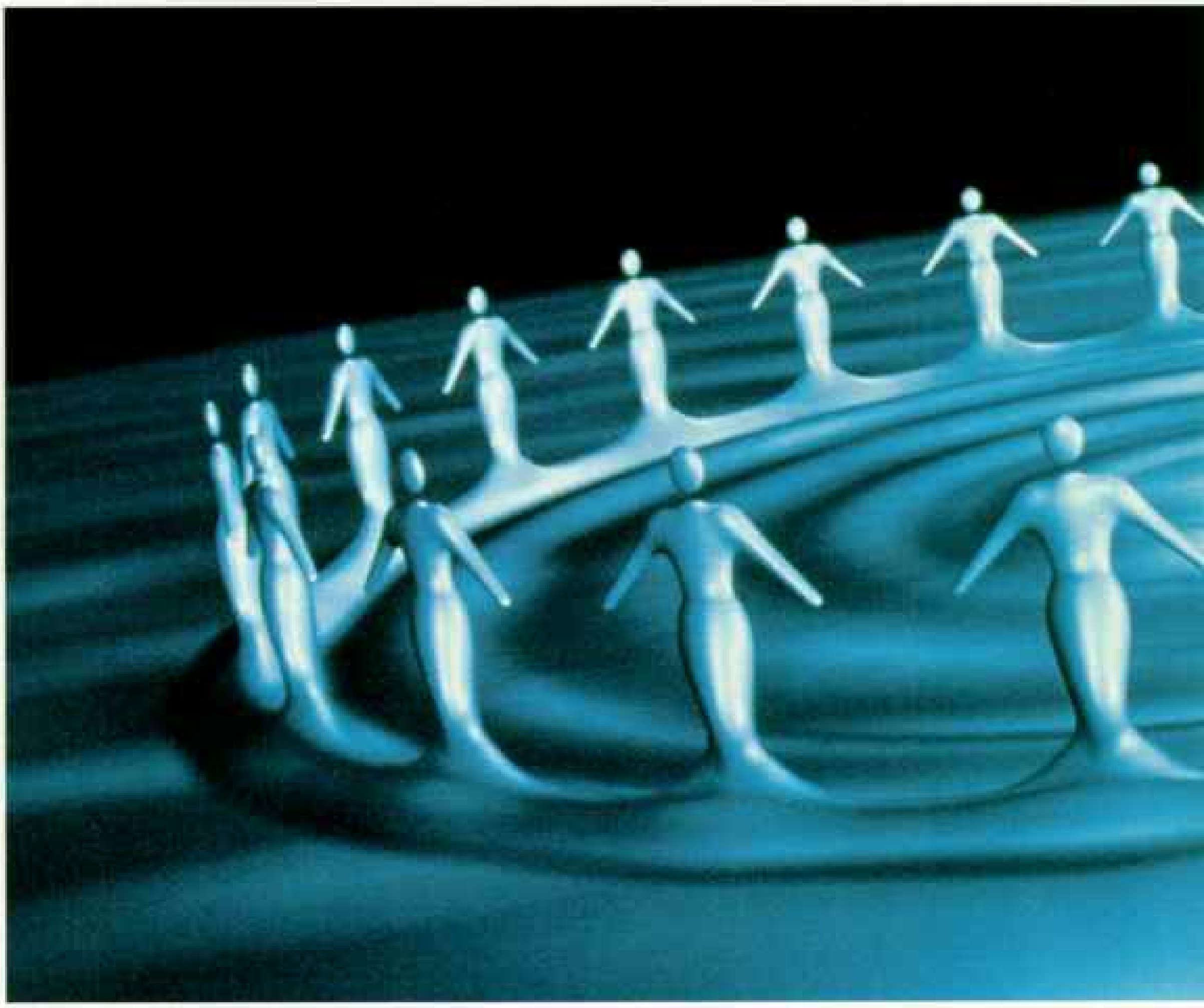
Animation

Showcase for state-of-the-art computer graphics, a four-minute film called "Red's Dream" proves that the natural quality of old hand-animated films like Pinocchio *and* Snow White *can be achieved with the new technology. Produced by Pixar—a spin-off of the Lucasfilm research group, which created breathtaking animations for* Star Trek II*—the film tells the story of a unicycle named Red, who dreams of joining a circus.*

Jam-packed with diverse shapes and forms, the complex images have won wide praise for the film's producers, who had to calculate the light-reflecting qualities of the thousands of polygons that make up each surface. Consisting of as many as 4.5 million polygons, scenes in the bicycle shop required up to nine hours of minicomputer time per frame. Averaging only 500,000 polygons, frames in the dream sequence in the middle of the film, where Red joins forces with a clown, required eight to ten minutes to render on a more advanced image computer.


SALE
Clearance


SALE



Variation on a theme from the real world, a sequence in a Japanese commercial seems an animated fantasy of a 1957 picture of a splashing milk drop by Harold E. (Doc) Edgerton, father of high-speed photography.

Though still too expensive for entire feature-length films and Saturday morning cartoons, computer animation is fast becoming a major medium for television advertising, including the "flying" logos that identify many TV stations.

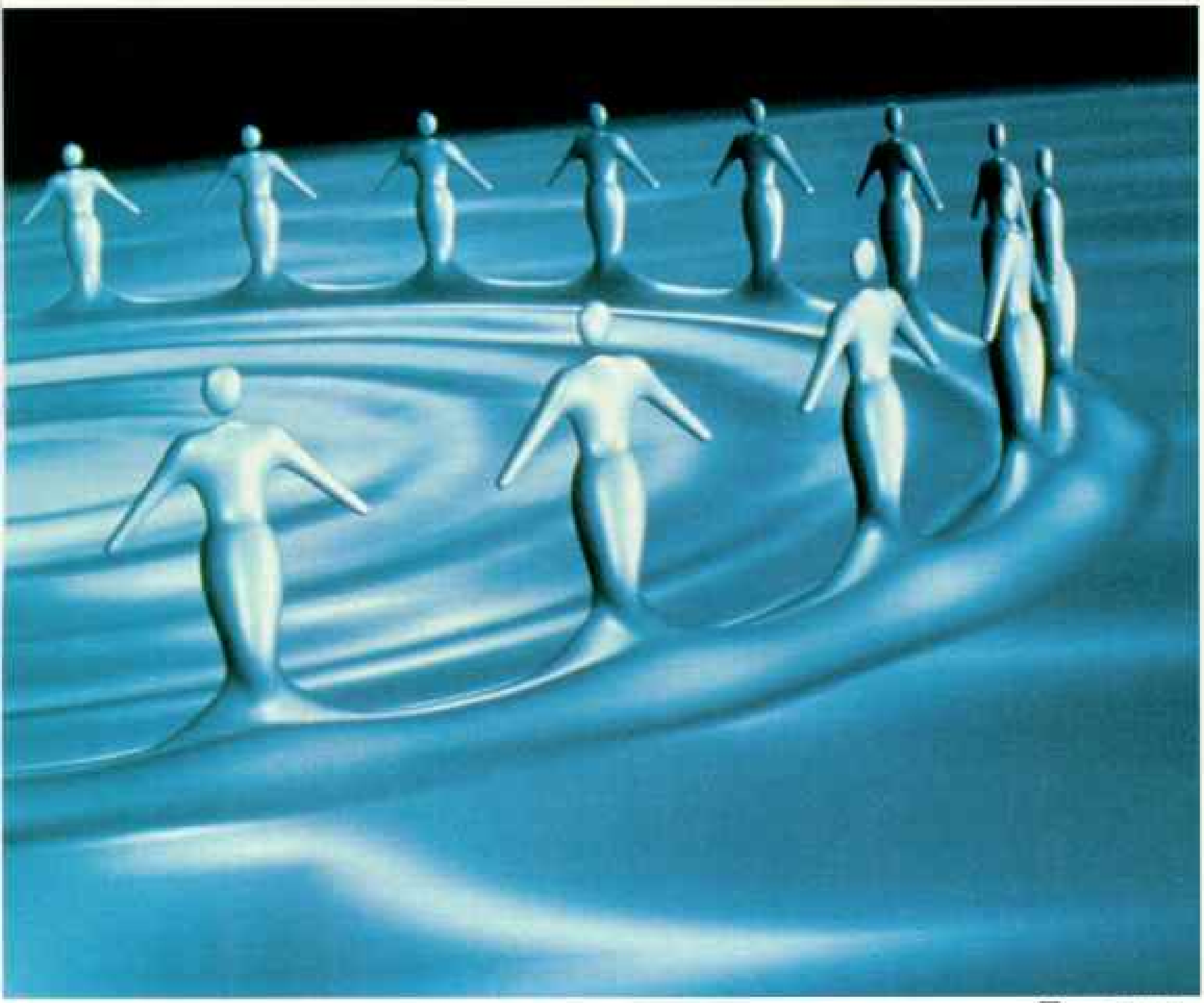
showed that I had a "hot pickle"—a system ready to launch—and gave me cues to fire. My right thumb pressed the red weapon-release button, and in a flash of smoke and flames one missile was away. The RWR updated to show the SAM was no longer a threat.

There, just ahead, the target materialized out of the mist with every detail almost as clear as a movie. A slight maneuvering correction lined up the F-16 to deliver a 500-pound MK-82 bomb on the power station. Instantly, as it fell away, I pulled the plane to a near vertical climb. My instruments indicated I had a hit!

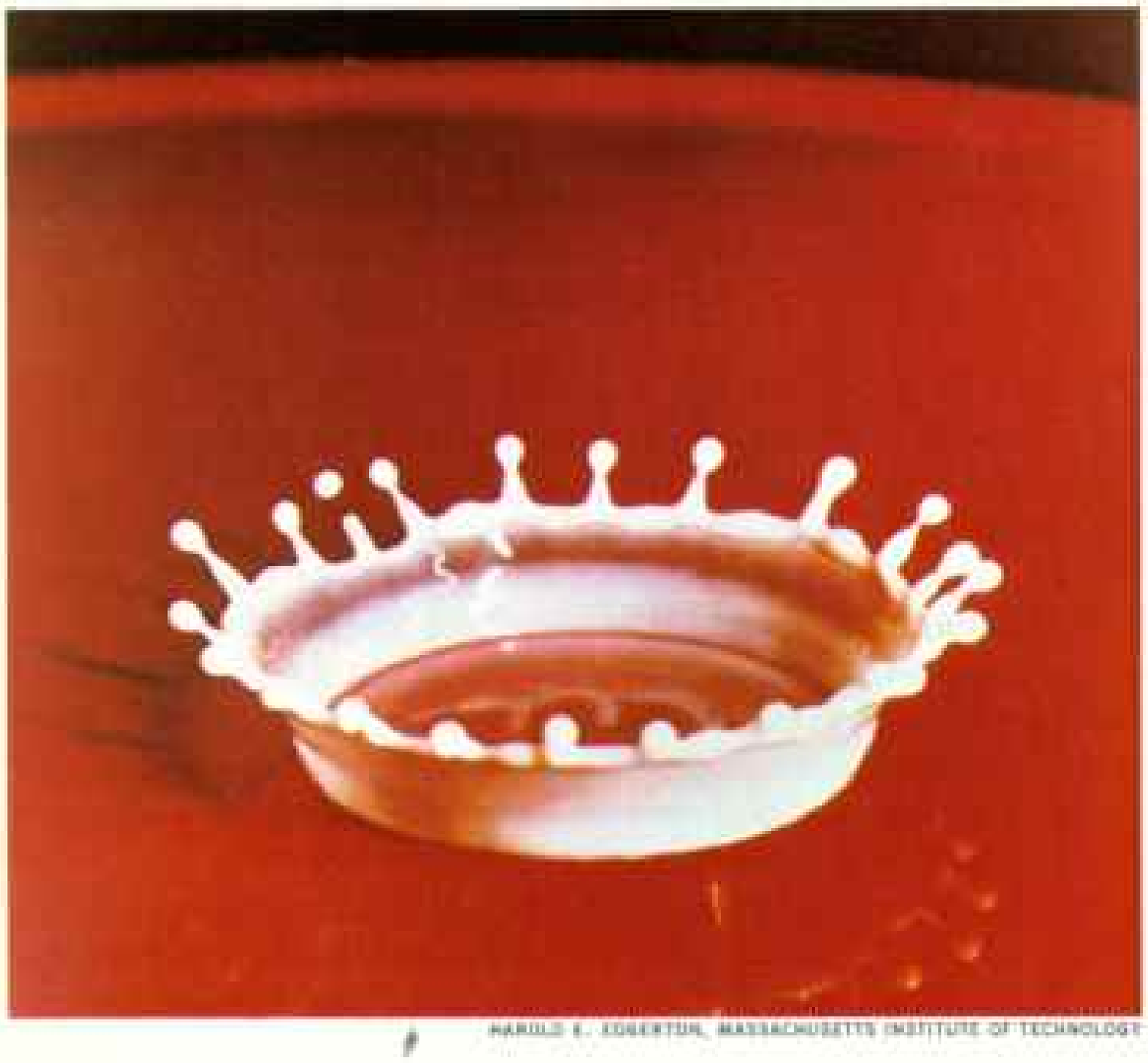
Whew! What a ride!

SIMULATOR training and testing are also available for slower and more peaceable machines than the F-16. In Berlin, buckled up behind the dashboard of a new Mercedes-Benz sedan, I sat looking at what appeared to be a normal entry ramp onto one of Germany's autobahns. Pressing the accelerator gave me both the sound and movement of my car speeding up and entering 90-mile-an-hour traffic. The entire dome with its car, screen, and projectors can rapidly swing and tilt to add real-life sensations to starting, stopping, and cornering.

"Go a little faster and I'll show you," said my "passenger," Daimler-Benz's Wilfried Käding. "We'd like a computer system



LINKS CORPORATION



HAROLD E. EDGERTON, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Order and chaos are depicted with equal ease by the computer animators at Pixar, who rendered images of an exploding globe. They are similar to the hologram representing the environmental destruction of earth that was featured on the cover of the December 1988 GEOGRAPHIC. Programmed with elevation data from earth satellite surveys, the modeling software served in effect as an engraving tool for the continents of the crystal globe.

Producing a 20-frame explosion sequence proved a special challenge, since glass, especially broken glass, is extremely difficult to simulate. After studying shards of real glass, the artists were able to write a software program that produced convincing highlights and reflections.

☐ PIXAR (BOTH)

that can look ahead in bad weather and alert the driver to danger or when it's safe to pass." I accelerated toward a hill and curve at 70 miles an hour. Suddenly murky fog obscured my view.

Wilfried shouted, "Be careful!" I swerved to dodge ice slicks now too close to miss. My braking speed, duration, and intensity were being recorded, as was the rapid beating of my heart as the car skidded sideways into a field, complete with the sights and sounds of a bad crash. The sensation of disaster was all too believable.

According to Joel Orr, president of the Virginia-based National Computer Graphics Association (NCGA), the auto industry was among the first to fully embrace computer design. Now the use of computers in this way is so common that the function has a commonly accepted name. "When a computer is used to help design a new product, that's computer-aided design, or CAD," Orr explained. "If a computer actually assists in making the product, that's computer-aided manufacturing, or CAM. CAD/CAM accounts for more than half the nine billion dollars spent worldwide in 1988 on graphics hardware and software."

At 3D Systems, Inc., near Los Angeles I watched CAD technology in action as a computer guided a blue laser beam over liquid polymer, tracing the image of a turbine at the top edge of the fluid. The laser light hardened the polymer, producing an intricate solid working model of a turbine in less than an hour without human intervention or the clamor and grime of workshop or factory.

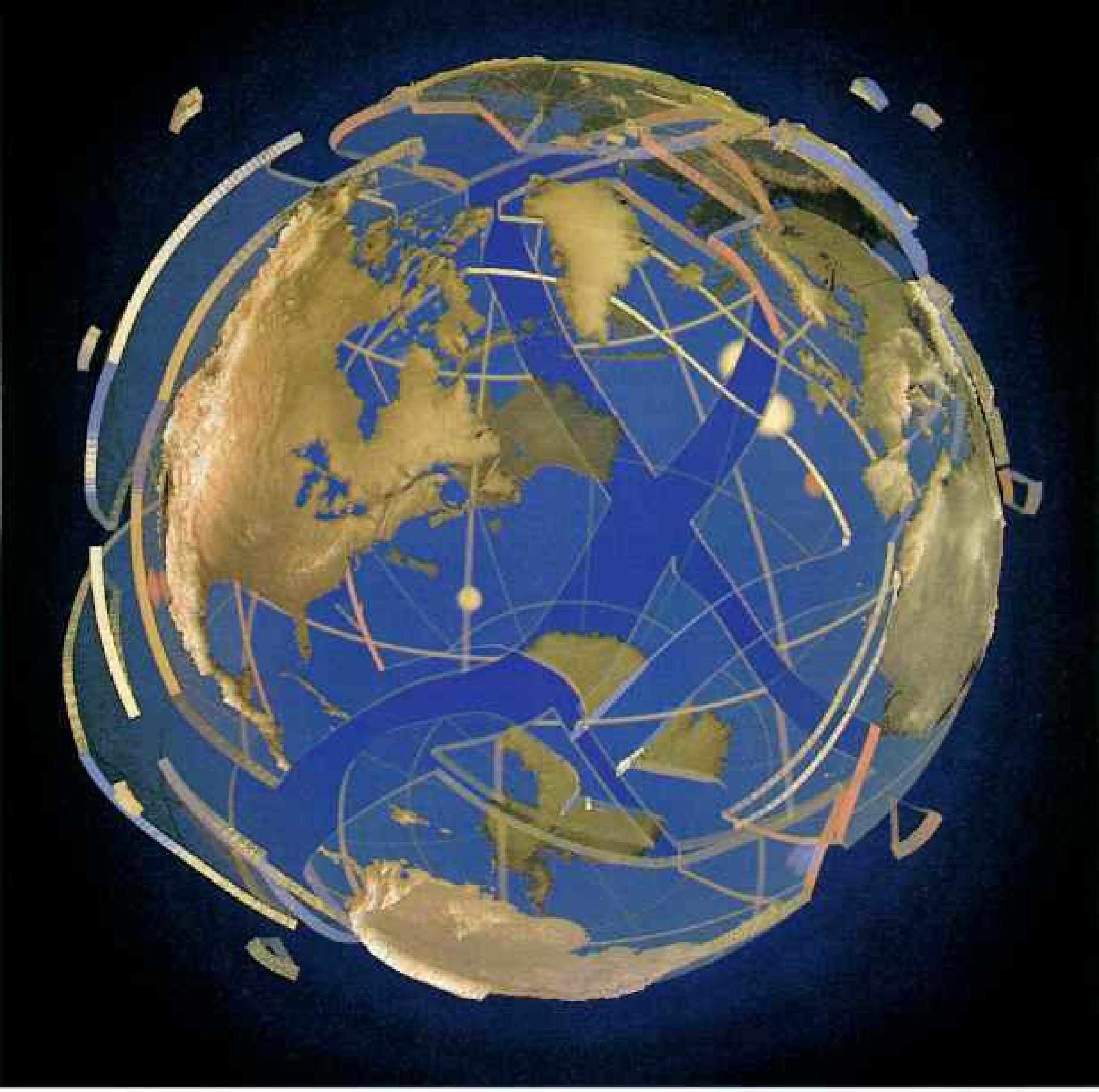
Nearly every field that uses product design, from parts manufacture to cars to architecture, is influenced by CAD/CAM. The so-called what-if concept, which capitalizes on the computer's capacity to analyze a variety of solutions to every problem, makes computer graphics a powerful design tool. Architects can experiment with limitless options before producing blueprints. Clients can examine computer-graphics images of their new buildings from different angles and in different light long before groundbreaking. Architect and client can actually experience the sensation of "walking around" a structure that has not yet been built or even lift the building off its foundation, merely by manipulating the color, shading, and viewpoint of the computer-graphics drawings.

Because of the computer's unique ability to change the point of view on the screen, a structure can be examined from ground level, from across the street, from the window of an airplane flying overhead, in winter or summer, day or night.

IN THE SUBURBAN DALLAS office of Doug Struthers, one of the few male computer artists I met who didn't sport the industry's standard mustache or beard, I gained a better understanding of how it's possible to move objects around a computer screen. Self-taught and enthusiastic, Doug worked on an illustration commissioned for this article as we talked (pages 722-3).

"What makes moving around within a scene possible is the introduction of a third, or depth, dimension," he explained. "Saturday cartoons are usually animated in two dimensions (2-D). Commercials, logos, and show openings where the camera appears to fly through a scene or change viewpoints are 3-D."

Although about a tenth of all U. S. television animation is created on computers, such animation is often limited to show openings (the symbolic lead-ins of the Olympic Games) and "flying" station



logos in which call letters soar through electronic space before falling into place. Any inanimate object singing and dancing across a television screen is probably a computer graphic.

Images that once took hours to draw can now be generated in fractions of a second. A typical graphics workstation (which has shrunk to the shape of an oversize desktop personal computer) now has a million pixels in its screen. The newest Evans & Sutherland flight simulator controls a million pixels on each of its six screens 50 times a second—a mind-boggling 300 million a second.

The most visible beneficiaries of faster processors are the animators, people who make pictures move. John Lasseter, one of the world's best known 3-D animators, and I got an early morning start not long ago at Pixar, in San Rafael, California. An unusual firm evolved from a company begun by moviemaker George Lucas, Pixar is a leader in hardware and software innovation.

Inside Pixar, John settled down in a room full of computers, all

named for cartoon characters, and happily typed instructions into "Minnie." John, a spirited Disney alumnus and insider's folk hero, has inspired a generation of computer artists to coax and stretch the frontiers of animation. Four of his short films, "Tin Toy," "Red's Dream," "Luxo Jr.," and "The Adventures of André and Wally B.," are milestones. The wireframe shape of a small desk lamp coalesced on his screen.

"That's Luxo," John said. "Watch the figure for personality. Anyone can make an object move. The trick is to give it life."

The appealing little figure chased, butted, and then flattened a wireframe ball, all under the watchful eye of a larger lamp I perceived to be Luxo's mother. "Ah, interesting," said John, when I voiced this perception. "I think of him as Luxo's father. But there's no doubt the two have feelings for each other."

Disney, the studio that created the animated cartoon, has begun incorporating computer graphics into its films. But many believe it has taken a conservative approach. Its prizewinning "Oilspot and Lipstick" entry at computer shows combines computer characters with hand-drawn backgrounds. Bob Lambert, Disney's director of technology and development, explained: "We focus on entertainment value and final product over any specific technique. Our most recent full-length animated film, *Oliver and Company*, uses computer graphics for complex shots, such as the high-speed chase through New York subways." As Disney computer artist Tina Price put it, "The computer is doing the difficult and tedious work to free traditional animators for creating characters."

EVERY SUMMER the world's computer animators join with more than 20,000 cartographers, biologists, mathematicians, engineers, designers, manufacturers, and other computer enthusiasts at the annual conference and exhibition of ACM SIGGRAPH (the Association for Computing Machinery's Special Interest Group on Computer Graphics).

Researchers delay publication to present their papers here, and animators spend sleepless nights finishing entries for the video show that is the highlight of the five-day event. The SIGGRAPH conference, the largest force in computer graphics, is the place to be, to see and be seen, and to introduce new products and ideas.

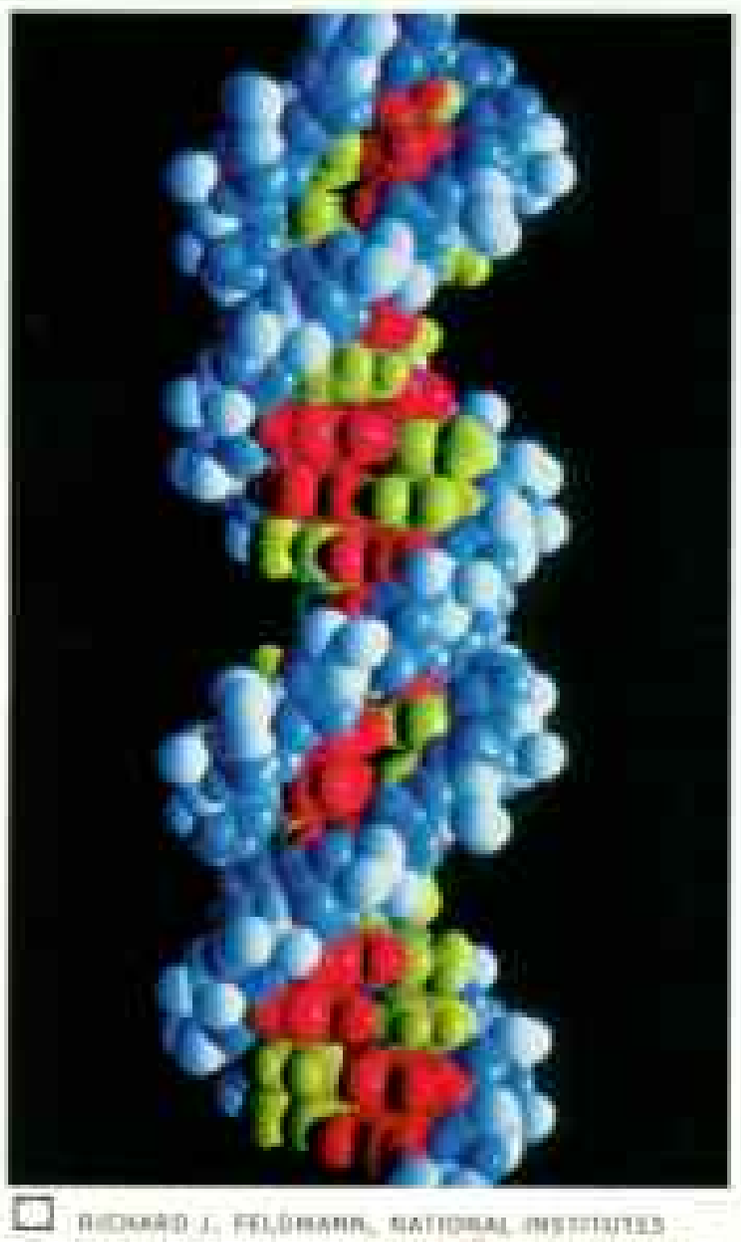
Because topflight computer animation requires a rare combination of skills, it is likely that most computer-graphics designers will continue to be a blend of artist and technician. Says Daniel Borenstein, who works at TDI Studios in Paris: "Remember da Vinci. Computer graphics challenges us to be both artists and technicians, but we seem to be working always to overcome a reluctance among traditional designers. One big problem that bothers artists and designers is that computer-graphics animation costs more."

The costs *are* enormous. Ken Weiss at Digital Art in Los Angeles points out that the cost of the basic equipment can be a barrier to entry: "A retoucher can go into business for $3,000, but even a small computer studio costs $200,000." Millions of dollars in equipment are needed to do broadcast work. Thirty-one-year-old Carl Rosendahl, president of Pacific Data Images, probably sells more broadcast logos to TV networks than anyone in the U. S. It's an expensive business. "We have to charge a client $200,000 for a 30-second spot," Carl says. "By comparison, you can get an entire

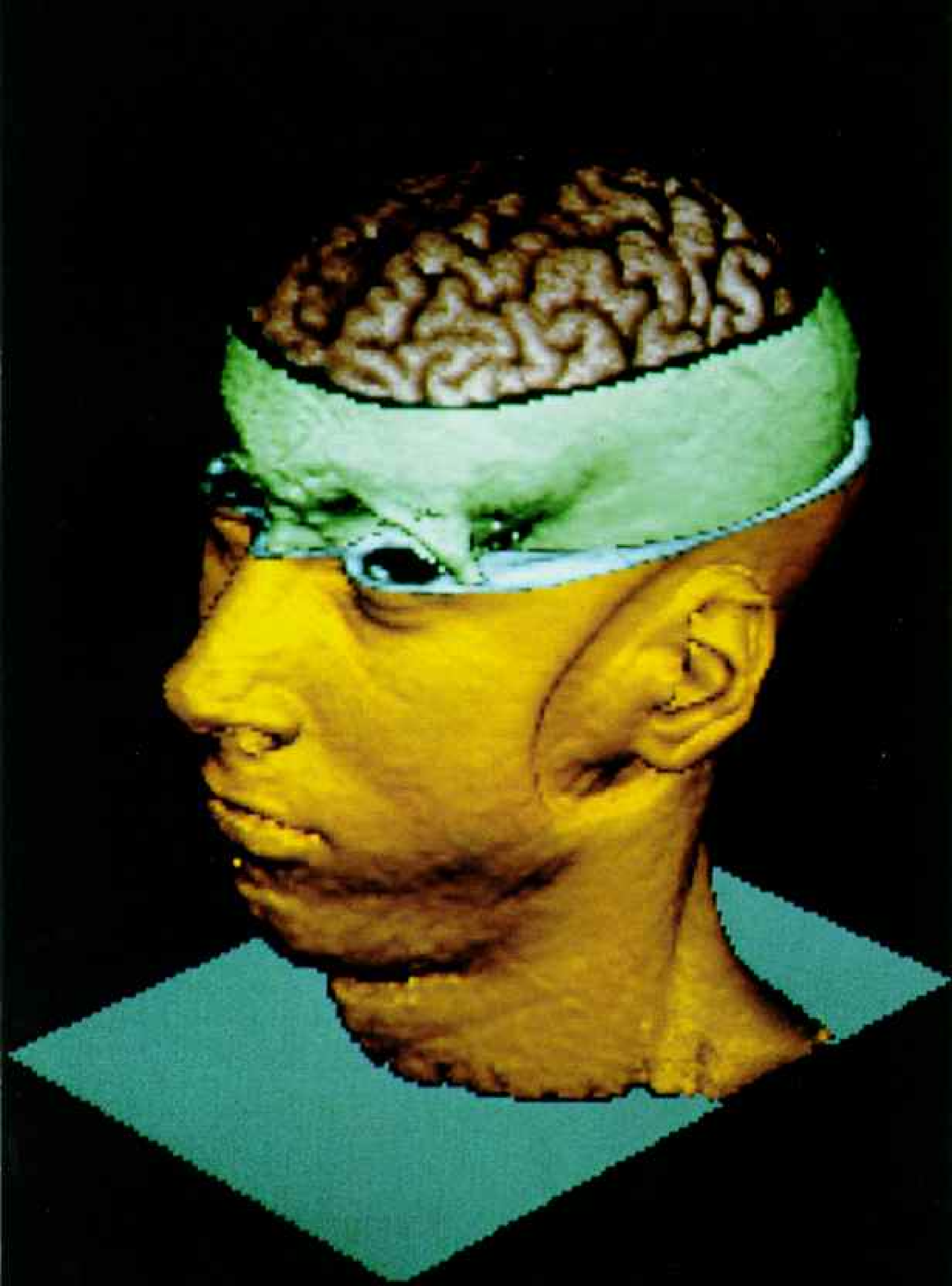
Medicine

Like the layers of an onion, skin and skull are peeled away in a computer-generated image of a patient's head. Synthesized from a sequence of two-dimensional magnetic resonance images, the 3-D reconstruction can be rotated and viewed from any perspective. Before picking up a scalpel, surgeons can use such lifelike models to determine the size and location of brain tumors. Similarly, doctors are using 3-D images from CT scans of fractures before bones are set.

In research laboratories around the world, scientists are using powerful graphics systems to visualize molecules, such as the double-helix structure of DNA (below).



RICHARD J. FELDMANN, NATIONAL INSTITUTES OF HEALTH (ABOVE); KARL-HEINZ HÖHNE, UNIVERSITY HOSPITAL, HAMBURG, WEST GERMANY



Scientific Visualization

Liberated from the chalkboard, the abstract discipline of mathematics is undergoing a renaissance in visual enlightenment. At the Max-Planck-Institut in Dortmund, West Germany, an equation for describing the predictability of the behavior of certain insect populations—such as destructive cicadas and gypsy moths—appears like a psychedelic nightmare in a computer-generated image (left).

At the University of Illinois researchers developed a mathematical model of an epidemic in an insect population, based on 60 years of research on the European corn borer. The supercomputer produced 320,000 bits of data, which were transformed by a graphics workstation into a pictorial model. The scientists also created models to visualize how storms evolve and what happens when neutron stars collide.

Since an estimated one-third of the human brain is devoted to vision and visual memory, engaging that sense can help scientists and nonscientists alike better understand complex natural phenomena. Reduced to visual imagery, vast amounts of abstract data can be conveyed in concise and dramatic form.

☐ MARIO MARKUS AND BERND HESS, MAX-PLANCK-INSTITUT, DORTMUND

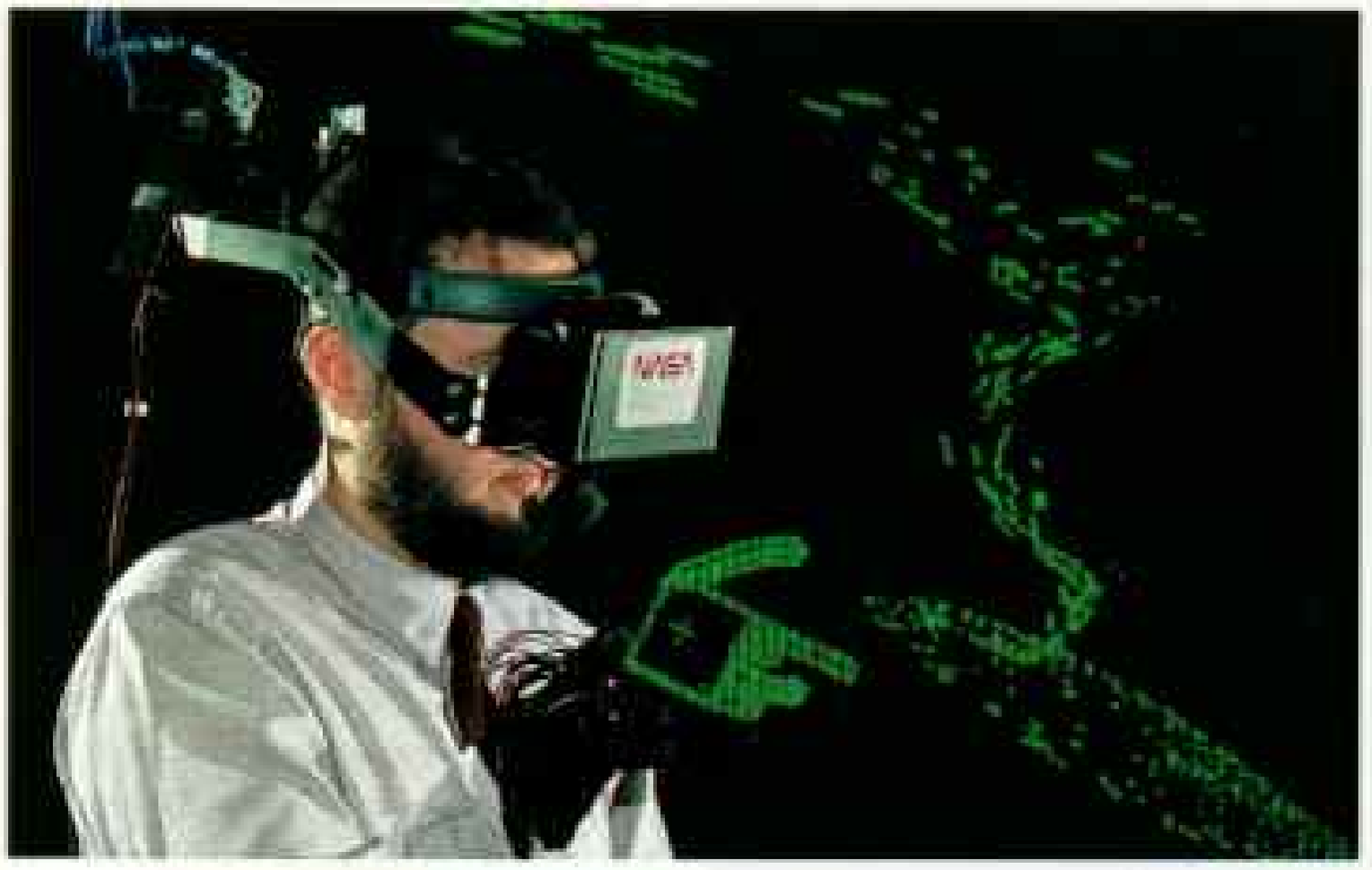
half-hour Saturday-morning hand-drawn cartoon for $250,000."

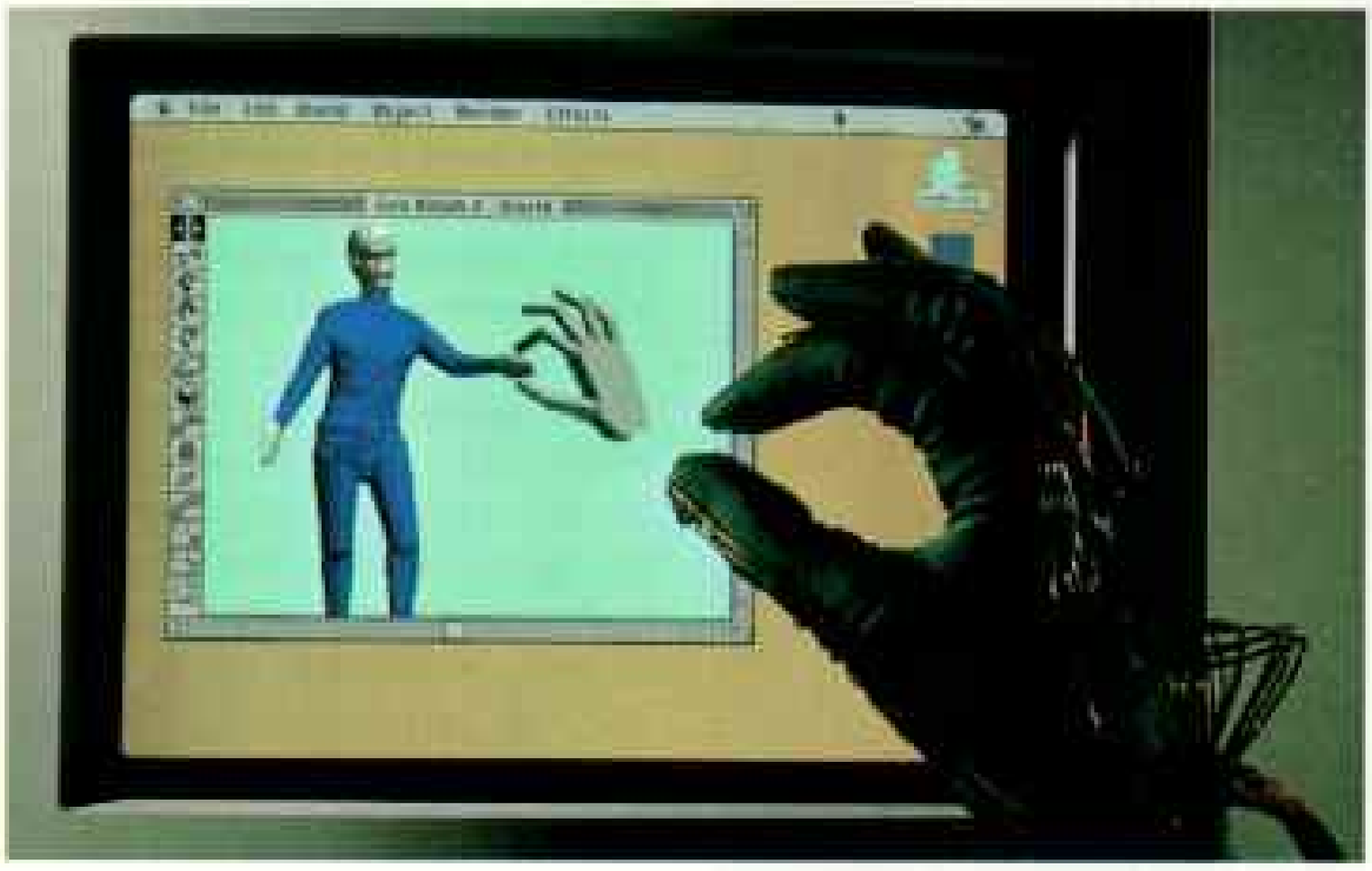
Because electronic equipment tends to become cheaper as time goes by, the early bird in computer graphics has often been financially handicapped. A firm starting today might spend $50,000 per workstation (a term used to describe a powerful scientific or engineering computer used by a single operator) and have more computing power than a competitor who is still paying off computers bought in 1985 for $250,000 each.

Many firms fall by the wayside as a result. Hollywood's Bob Abel, winner of 33 Clio awards for excellence in television commercials, was the first to master commercial computer graphics. Mentor to dozens of computer animators, Bob dropped out of the computer-graphics business for several years. At the height of his success he sold to Canada's Omnibus, which soon closed, continuing a spectacular series of computer-graphics-business failures. His groundbreaking firm, which did the stunning opening to Steven Spielberg's *Amazing Stories*, is remembered for the most complicated and advanced pair of computer-graphics commercials of their day—"Sexy Robot," which showed that computer graphics could duplicate smooth human movements, and the $620,000 Hawaiian Punch "Chain Reaction" spot, a mixture of graphics and live action that is studied as a classic.

"I wanted to make the invisible visible," Bob told me, reminiscing about the birth of computer graphics. No better short description can be imagined for the wonders he and other pioneers brought into being.

There is concern in Europe and Japan that a similarly disastrous economic fate may await their animation businesses. In Paris Daniel Borenstein says, "Europe is believed to be five years behind the U. S. technically, but I think the computer-graphics business is healthier here now." A slightly different view came from Rolf Herken, founder and owner of Berlin's Mental Images. Sitting in his stark white town house just off the Kurfürstendamm, Rolf explained, "The European public accepts computer graphics. Even clients here are willing, but ad agencies and designers are an obstacle. They do not know enough about the technical aspects of computer animation to believe in those who do. In the U. S. you succeed by being innovative. In Germany safe conservatives





Putting himself in the picture, an engineer at NASA's Ames Research Center (top) uses a stereoscopic viewer and DataGlove to manipulate a simulated fuel stream, seen here in a double exposure. With the glove, researchers can maneuver objects inside a computer image (above) or direct a robotic hand in a remote environment.

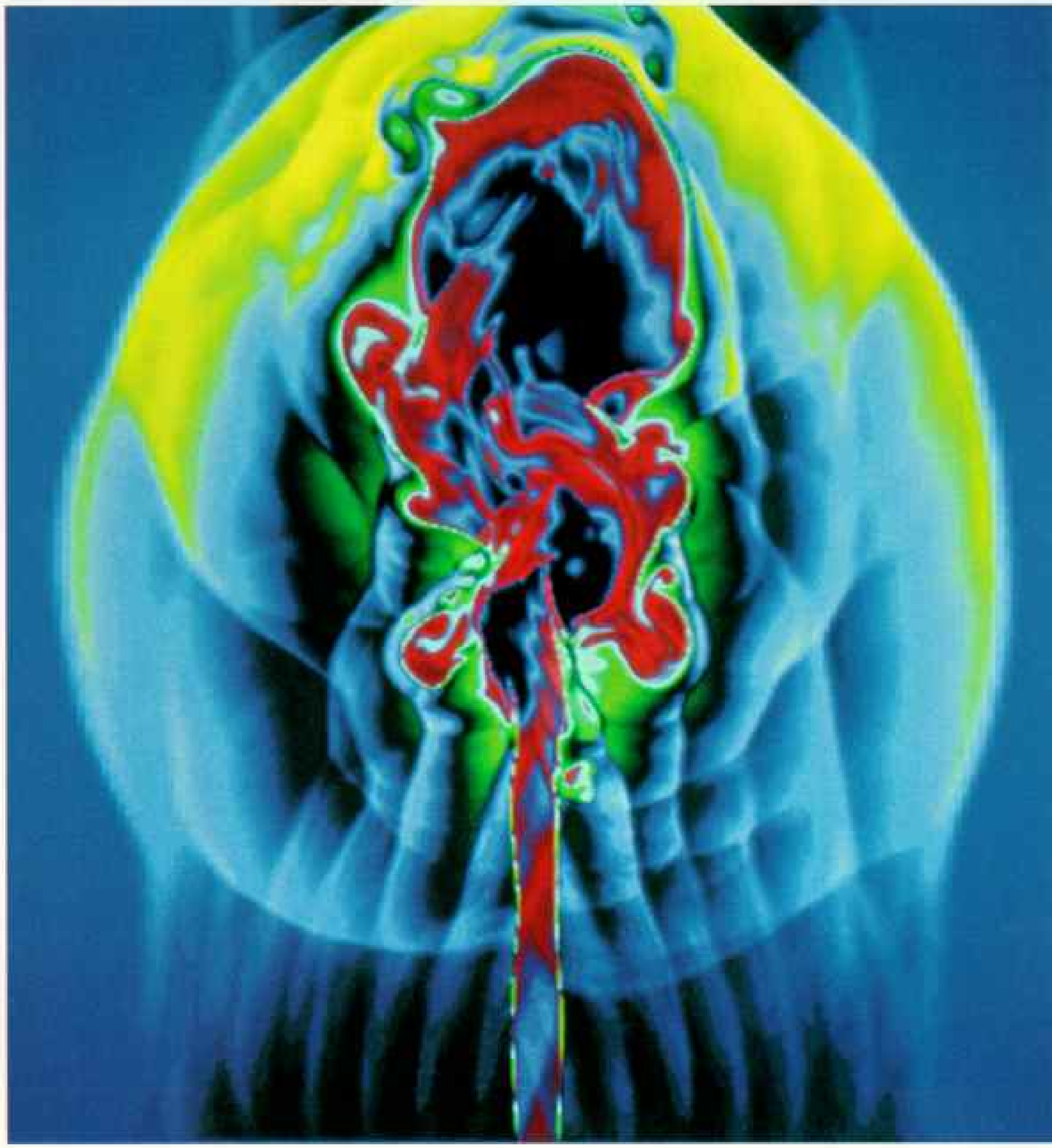
get ahead. The situation in Japan is even more intriguing. Computer people there seem to be cut off from the country's own graphics history."

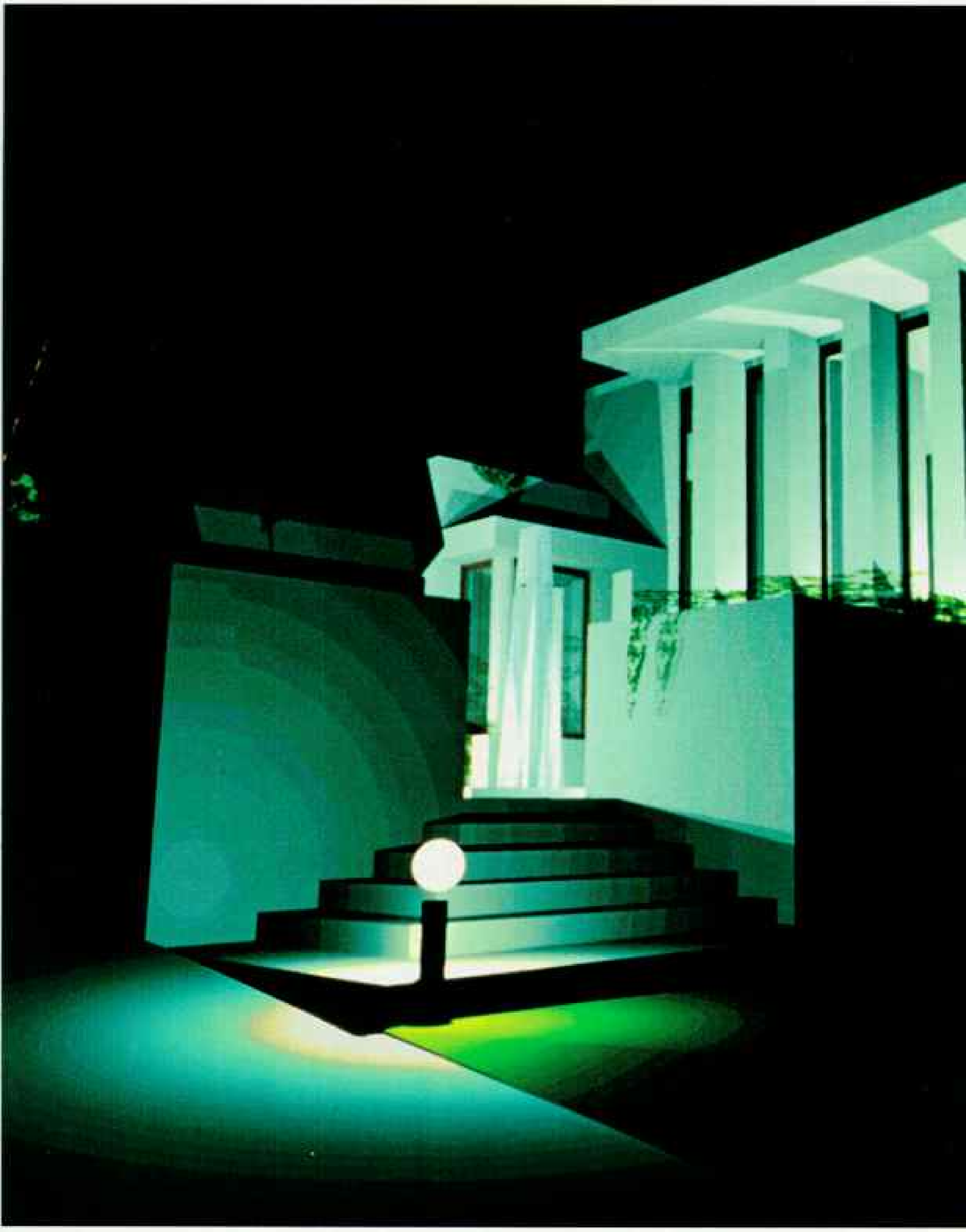
"JAPAN IS IN THE MIDDLE AGES in computer graphics and computers in general. We'll never catch up. It's hopeless." That's what Tosiyasu L. Kunii, professor and chairman of the Department of Information Science at the University of Tokyo, asserts.

In his rabbit-warren office stacked floor to ceiling with books and papers, frail Dr. Kunii paced with a teacup in hand and

A cosmic jet shoots from a galaxy in an image from the National Center for Supercomputing Applications. Barely visible by telescope, these outpourings may be a million light-years in length. Astrophysicists use radio telescopes and supercomputers to observe and simulate such mysterious phenomena.

© MICHAEL L. NORMAN, DONNA J. COX, PHILIP E. HARDEE, AND DAVID A. CLARKE, NATIONAL CENTER FOR SUPERCOMPUTING APPLICATIONS





CAD/CAM

Seeing is believing in the new world of computer-aided design and manufacturing, which now accounts for more than half of all the money spent on computer graphics. Produced by a software package from the Intergraph Corporation of Huntsville, Alabama, a nocturnal image of a Frank Lloyd Wright house—never actually built—boasts remarkably realistic shadowing. A pioneer in the race to provide more computer horsepower for less money, Intergraph now sells workstations with graphics software packages for as little as $20,000. With such equipment an architect can view his creation from any perspective, in any light. A few keystrokes will reveal the structure's internal supports, glowing through transparent walls.

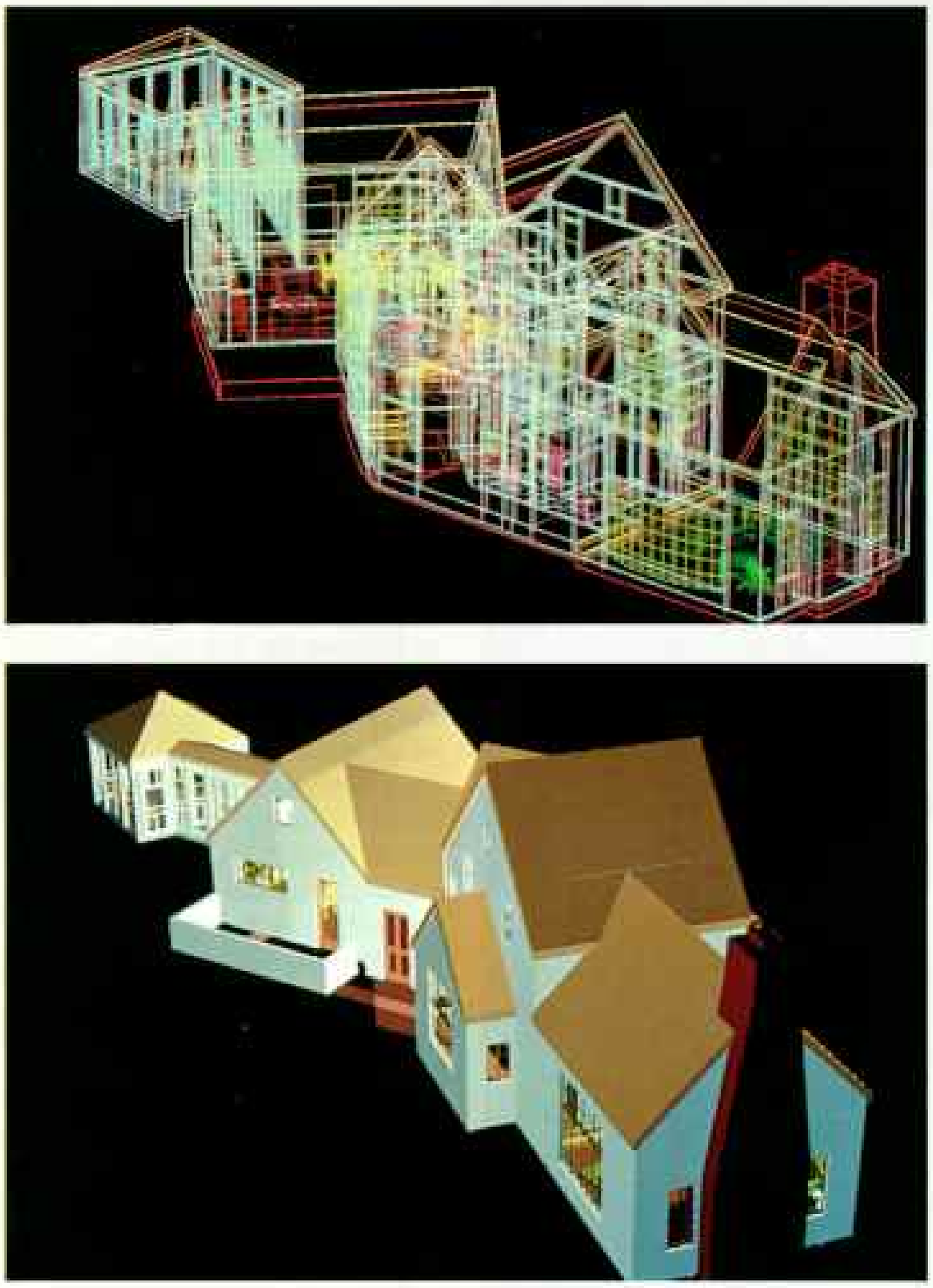
In industries ranging from aerospace and computer chips to the fashion world, product designers are using these workstations to minimize tedious, routine work, thus freeing time for the creative side of design. Because the elapsed time from concept to completion is becoming ever more critical to a product's chances for success, CAD graphics have become a vital component of the process.

lamented: "All we can do is copy Intel chips and U.S. designs. Our government mandates the number of students in every discipline. My limit is just 15. In all Japan there are only a thousand computer-science majors, about the number at the University of Illinois."

As Kinji Odaka of the Links Corporation, a hardware, software, and animation firm, told me, "There are fewer than ten computer-animation companies in Japan. Only three are large, and three either reorganized or went out of business in 1988." There are more firms than that in Los Angeles alone.

In the U. S. and Western Europe computers are a fact of everyday office life. Few Japanese workers use them. As Yasuyuki Inoue of the huge conglomerate NKK explains, "Remember, we never owned typewriters. Japanese basically have no computer experience, and little in their history to prepare them for it. We surveyed 30,000 employees and found that fewer than 800 possessed personal computers or word processors. And this is only one of the barriers."

Other impediments are three different character sets for writing the Japanese language, a complexity compounded by different keyboard layouts from each manufacturer. Almost all computer languages and all major programs are conceived and written in English, a language that is poorly understood by most Japanese.



Drafting without drudgery, architects were among the first beneficiaries of the graphics revolution. Today for less than $12,000 one can set up a computer system that includes a design package from a company like Autodesk, whose software was used to draw this wireframe and shaded design of a custom home. After the customer's wishes have all been satisfied, the computer will generate blueprints and calculate costs.

Bonnie Sullivan, a young American who started a software firm near Tokyo, identifies two additional hurdles. "This culture itself is a barrier," she says. "No Japanese wants to stand out, and to be a good computer programmer it is necessary to be a freethinker and stand out. The Japanese have five-year-old technology and just don't use the kind of logic to make it happen. The result is that the Japanese can't program their way out of a paper bag."

"Complacency could be dangerous," counters NCGA's Joel Orr. "I've been shown a few things that lead me to think the Japanese are doing more than they acknowledge. Unlike their counterparts in the rest of the world, Japan's programmers tend to have no ego, and an ego-free code would be a more error-free code. If Japan ever targets computer graphics as a national priority, as it's done with so many other products, it could be a power in short order."

One outstanding exception to Japan's ego-free culture is

Yoichiro Kawaguchi, a hard-driving, hard-drinking extrovert who defies all the usual Japanese stereotypes (except, perhaps, for the samurai). Kawaguchi works in a dingy office at the private Nippon Electronics College where every desk is piled above and below with bags and bags of unanswered mail. Though he swears that he has erased all his old data tapes, he somehow continues to produce gorgeous transparencies from earlier years.

Born on Tanega Shima, one of Japan's warm southern islands, Kawaguchi's computer art was inspired by early snorkeling experiences. His fanciful, swirling organic shapes are unique and captivating. In the opinion of many, Kawaguchi stands alone in his country.

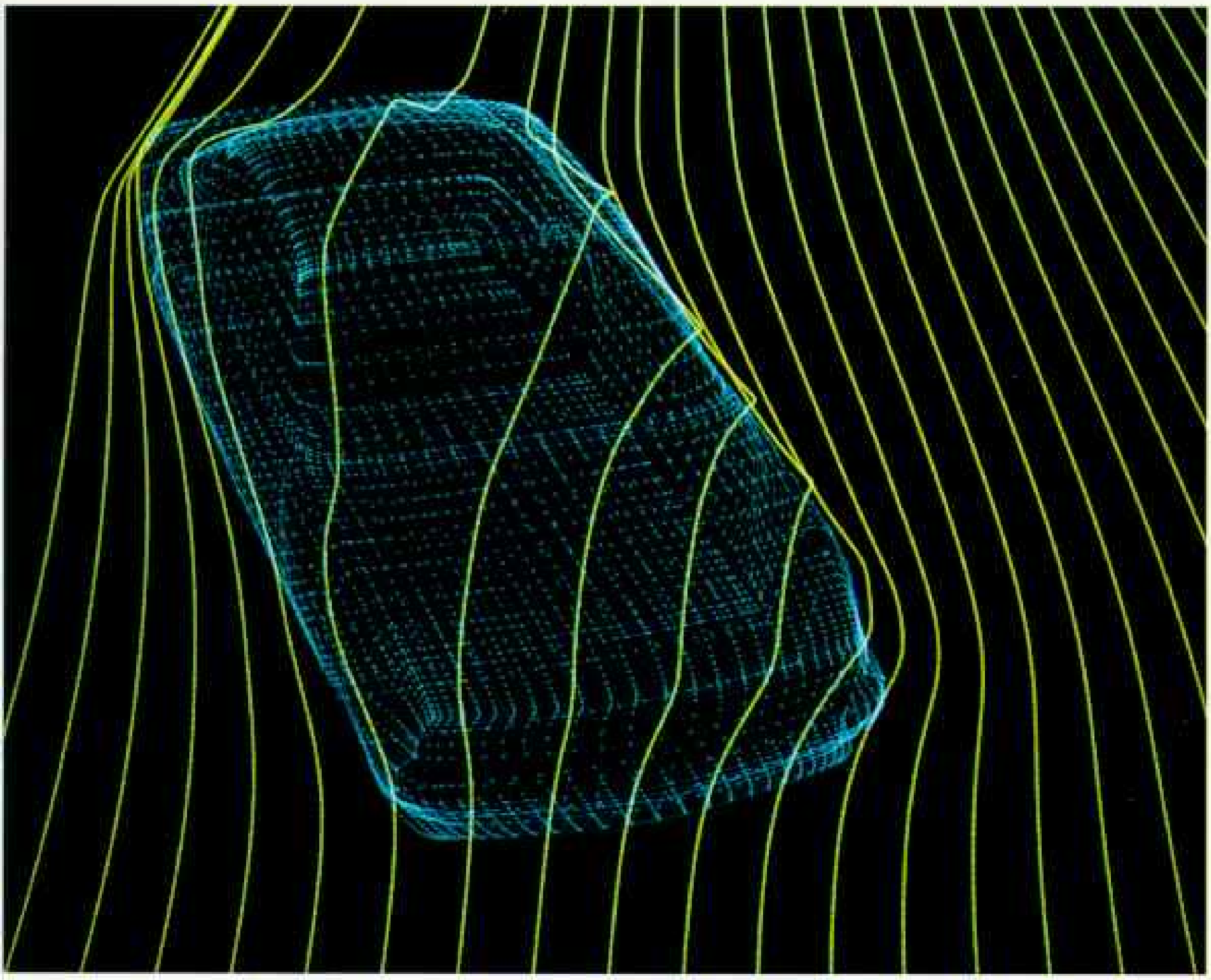
It is an opinion that Kawaguchi himself shares. "With computer graphics I can let my imagination fly," he says, sweeping his hair from his eyes with a nervous gesture. "Artists in other fields can't do what I do. With computer graphics I can combine math, biology, and my dreams."

The fantastic Kawaguchi style represents one pole of the fantasy-versus-realism controversy that raises passions among computer-graphics professionals.

"In art and entertainment most people want fantasy," contends Roy Hall, who was in charge of software development at Santa

On the cutting edge of realism, a simulated image of a steel mill demonstrates the uncanny treatment of light achieved by computer experts at Cornell University, a world leader in graphics research. Using scientific principles of light dispersion, they employ shading and shadows to convey the subtle cues necessary to understand increasingly complex images.

□ S. FELDMAN, J. WALLACE, M. COHN, AND D. GREENBERG, PROGRAM OF COMPUTER GRAPHICS, CORNELL UNIVERSITY (BELOW); AUTODESK



Driven to produce ever more efficient cars, engineers at BMW in Munich use supercomputers to analyze air flow around test models moving at high speed.

Though its dimensions are nearly the same, the more streamlined 1989 5-Series BMW (right, bottom) boasts 10 percent greater fuel economy than the lighter 1982 model (middle). Among the first users of computer-aided design, auto manufacturers continue in the forefront of industries that employ computers throughout the entire manufacturing process.

☐ BMW (TOP)

BMW (ABOVE AND BELOW)

Barbara's Wavefront Technologies, a leading software firm, until he returned to Cornell to teach. Charlie Mullen, formerly at Lucasfilm's Industrial Light & Magic, adds, "Photo-realism is a waste of the medium. If that kind of detail is needed, get a camera."

At Los Angeles' Rhythm & Hues studio, Charles Gibson voices another point of view: "Computer graphics is a way to do things impossible to do in any other way. A motionless aspirin tablet is for photography. One blowing apart in air or dissolving in a stomach is for us."

MAKING UNREAL PICTURES of real accidents forms the core of an innovative application for computer graphics. I watched various tragedies take place in appalling detail on computer screens at Forensic Technologies International in San Francisco, a firm that constructs evidence for court trials, re-creating car or plane accidents so the jury can see what happened. A different video produced by Forensic Technologies used a split screen to show week by week what a building contractor promised and what he actually delivered. The animated comparison resulted in an out-of-court settlement of a civil suit filed against the contractor.

New York artist Nancy Burson and computer scientist David Kramlich deal with another kind of legal and social issue using their patented aging method. They take the last known photograph of a missing child and "average" it with pictures of an adult relative the child resembles to produce pictures of how the child might look after being away for several years. Already their method has been successful in locating lost children. And the FBI employs their techniques to envision how criminals may have altered their appearances to elude identification.

Customers at beauty salons who want to steal an admirer's heart can graphically alter their own appearance on monitors before committing to new colors and hairstyles. What-if comparisons let physicians and patients planning reconstructive or cosmetic surgery preview new noses and figures from a variety of on-screen choices before doing actual procedures.

Other medical fields have also embraced realism in computer graphics as a fundamental tool. At Pixar I saw standard CT scans, normally displayed as flat two-dimensional black-and-white images, reconstructed as color-enhanced 3-D pictures that could be rotated in space for examination and diagnosis.

At the Hamburg University Hospital Karl-Heinz Höhne took me on a tour of a patient's skull. We explored the cranium as if it possessed no tissue inside or out. Then, examining every small deformation, we looked at the brain in exquisite detail, pausing at the flattened area caused by a malignant tumor. Donning red-green glasses, I marveled at the view in stereo.

The patient was fully awake during the procedure, and our simulated sojourn through his head was done without looking directly at him. Afterward 3-D images of his brain were created entirely with computer graphics using magnetic resonance imaging data.

Later, at the German Cancer Research Center in Heidelberg, Hans-Peter Meinzer showed me how computer graphics fills in the spaces between CT-scan slices to reduce patient radiation exposure. His computer program enhances black-and-white lung

Art

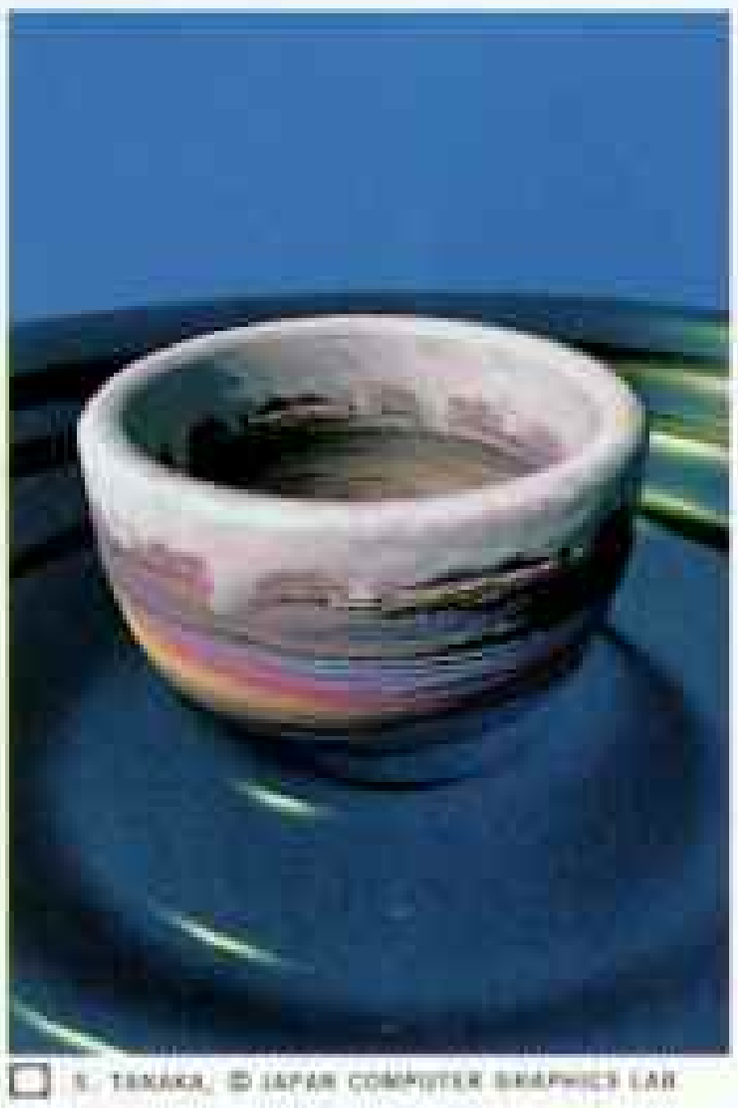
Stuff of dreams, the underwater fantasies of computer artist Yoichiro Kawaguchi are rendered in astonishingly crisp detail by his electronic tools. Like most of his work, the film from which this scene was taken was inspired by his experiences diving off the coast of southern Japan. His films have proved hits at the Special Interest Group on Computer Graphics (SIGGRAPH) conference and exhibition, which attracts professionals from all segments of the computer-graphics industry.

While Kawaguchi revels in the unworldly and bizarre, other computer artists use their computers as "supercameras," painting everyday scenes in startling photo-realism. All would agree, however, that theirs is a powerful new medium, as valid as paint and canvas or the camera. Not only artists but also sculptors, printmakers, and video producers are discovering a freedom and flexibility undreamed of just a decade ago. With as many as 16 million colors in his electronic palette, an artist might recolor a composition in seconds, while changing its perspective and lighting with the touch of a key.

YOICHIRO KAWAGUCHI

X rays to deliver more informative color images. In the same institution Wolfgang Schlegel determines the placement and dosage of tiny radiation capsules in the brains of tumor patients. Describing his technique of implanting the minuscule 0.8-millimeter radioactive metal capsules precisely within a tumor, Schlegel says: "We could never do this before the advent of computer graphics. Being able to see the tumor and surrounding area exactly lets me plan the dose and its placement with great precision."

Molecular biology and genetic engineering also depend on computer graphics. In a darkened computer-graphics room typical of others I saw across the U. S., Genex scientists in Maryland sat before a glowing row of Evans & Sutherland terminals redesigning enzymes to improve detergents. A continent away in San Francisco, Robert Langridge, a leading molecular graphics modeler, uses computers to visualize proteins and DNA, creating images of the building blocks of life that more clearly explain their structure and interactions than a book-length string of words.



S. TANAKA, © JAPAN COMPUTER GRAPHICS LAB

At the altar of imagery, visitors to the Kogyoji, a Buddhist temple near Fukui, Japan, contemplate the harmony between man and nature in a program of computer graphics designed to stimulate interest in religion.

A small number of Japanese artists use the new medium to great effect—as in this delicately wrought depiction of a teacup. Surprisingly, given its prominence in electronics production, Japan lags behind the United States not only in computer graphics but also in the use of personal computers.

LOS ALAMOS NATIONAL LABORATORY in New Mexico, isolated during World War II so that scientists could create the atom bomb in secret, now provides computer facilities for a great range of advanced research. Taking full advantage of the presence of the greatest computing "horsepower" ever assembled under one roof, Karl-Heinz Winkler devises problems that would choke most systems. Rapidly pounding keyboards in a room filled floor to ceiling with the latest digital video technology, the bearded, burly German transplant exuberantly described his progress.

"In 1980 I worked all night to get three images on the first supercomputer, a CRAY-1. Five years ago I was up to one a second. Now look at that monitor . . . I have real-time TV speed, 30 pictures a second, a dream come true. I want to be limited only by my stupidity or my imagination and not by the machine's."

The newest Cray supercomputers used by Winkler have a price tag of some 20 million dollars. Only 250 or so Crays exist in the

world—and 11 of them are housed in one room at Los Alamos.

"Graphics can reduce billions of numbers to a very few concepts," Winkler continued. "Computer simulation is often the only way to get some information. For instance, work is being done on a new hypersonic plane that will fly as fast as Mach 25—17,500 miles an hour—at high altitudes. Because no wind tunnel can handle such conditions, design and testing are done with computer simulation and graphics. Computer graphics makes math visible."

Larry Smarr, director of the National Center for Supercomputing Applications at the University of Illinois, recalls his first exposure to computer graphics at Lawrence Livermore, California's sister lab to Los Alamos. "I was working on general relativity, and when I saw the power emerging with computer graphics, I knew I had to change the way I was doing my research. I realized that by combining supercomputers and computer graphics, we could actually unlock the mysteries of the fundamental laws of nature."

Now creative professionals whom Larry assembled on the Illinois campus at Urbana-Champaign sit in dimly lit high-tech wonderlands deciphering cosmic secrets on high-performance graphics workstations. Donna Cox, the resident artist of the Renaissance Team she organized, shows with her rapid-paced tech talk a deep commitment to and belief in the new technology. "We want to take the best of the Renaissance concept and produce digital harmony with the latest tools," she tells me. "I feel that if we put a scientist or mathematician or both with a computer specialist and an artist, new and wonderful things will emerge."

The scientists on the team agree that their field, called scientific visualization by the profession, is one of the hottest. Astrophysicist Michael Norman sums up the wonder of it all as he stands before the projected video animation of a tumultuously swirling tip of an extragalactic jet that may be a million light-years long: "Look at that motion! The best telescope can only represent these evolving gigantic jets as frozen snapshots at an instant in time. My simulation lets me study them close up in any color at any speed."

A new field of geometry was spawned in 1975 by mathematician Benoit B. Mandelbrot. Its formulas make it possible to generate such wild shapes as the Mandelbrot set (below) and the Julia set (bottom), as well as imaginary clouds, mountains, and other natural forms. Each creation, or "fractal," is made up of similar smaller units (for example, tiny mountains), themselves composed of progressively smaller replications.

A CONSIDERABLE AMOUNT of the history of computer graphics has been written at U. S. colleges. So much of it originated in one place, the University of Utah, that a famous group of graphics pioneers is still called the Utah Mafia. Dave Evans traces its genealogy: "I came here to teach in 1966. It was magic then. Four years after Ivan Sutherland submitted his MIT Ph.D. thesis on Sketchpad, the first modern graphics package, he joined me here. John Warnock left and founded Adobe Systems, which created the PostScript image-and-type-definition language as well as the breakthrough Illustrator designer programs. Alan Kay, one of my former students, described an interactive personal computer in his thesis. He took those ideas to PARC, Xerox's Palo Alto Research Center, where they were the basis for the original graphics workstation."

I met the legendary Kay, now an Apple Fellow, at Apple's crowded West Hollywood offices. Every bit the Californian, Alan arrived wearing a "Mac" T-shirt, running shorts, and Reeboks.

"We built a machine at PARC that was well ahead of its time," he tells me. "The Alto, which cost $20,000 then, was the precursor

of graphics workstations. We had overlapping menus, a mouse, icons, and WYSIWYG [pronounced WIZZY WIG—What-You-See-Is-What-You-Get—and meaning seeing type, pictures, and layout on the screen as they will appear in print]. We had a ten-year lead on the world."

During those heady days at PARC, another powerful force was at work in Silicon Valley: enigmatic Steve Jobs, Apple's co-founder. Although, as Jobs says, "man is a tool builder," it still took humanity two and a half million years to move from making the first tools to constructing the cotton gin. The industrial revolution in the United States required just over half a century. But in only one decade we've become the world's first computer-dependent society.

What now exists is only the beginning. The creative possibilities of mind and chip engaging in a give-and-take process of innovation are as staggering as printing, harnessing electricity, or mastering flight. Change is the only constant in this burgeoning new field; the only limits are the limits of human imagination. What we see, we can understand. Computer graphics is the bridge between humans and the most marvelous machines ever made. □

Imagined worlds, capable of being spun out in infinite profusion, are the stuff of fractal geometry, as practiced by a computer artist at Yale University who created this dreamscape with fractal mountains set against a fractal moon.

More than dream machines, the powerful computers of today, allied with human intelligence and the gift of vision, are the bearers of both progress and pleasure.

□ F. KENTON MUSGRAVE, YALE UNIVERSITY, AND BENOIT B. MANDELBROT, IBM/YALE (ABOVE); © 1988 BENOIT B. MANDELBROT (FACING PAGE, TOP); H. JÜRGENS, H.-O. PEITGEN, D. SAUPE, UNIVERSITY OF BREMEN, WEST GERMANY

The Remote World of

In a lofty realm beyond the Himalaya, nomads lead their sheep, goats, and yaks from pasture to pasture as they have for centuries. Man and beast thrive in the rarefied air of Tibet's starkly beautiful Chang Tang (northern plateau), where a teenage girl, at right, chatting with her sister, toys with a tassle in her hair.

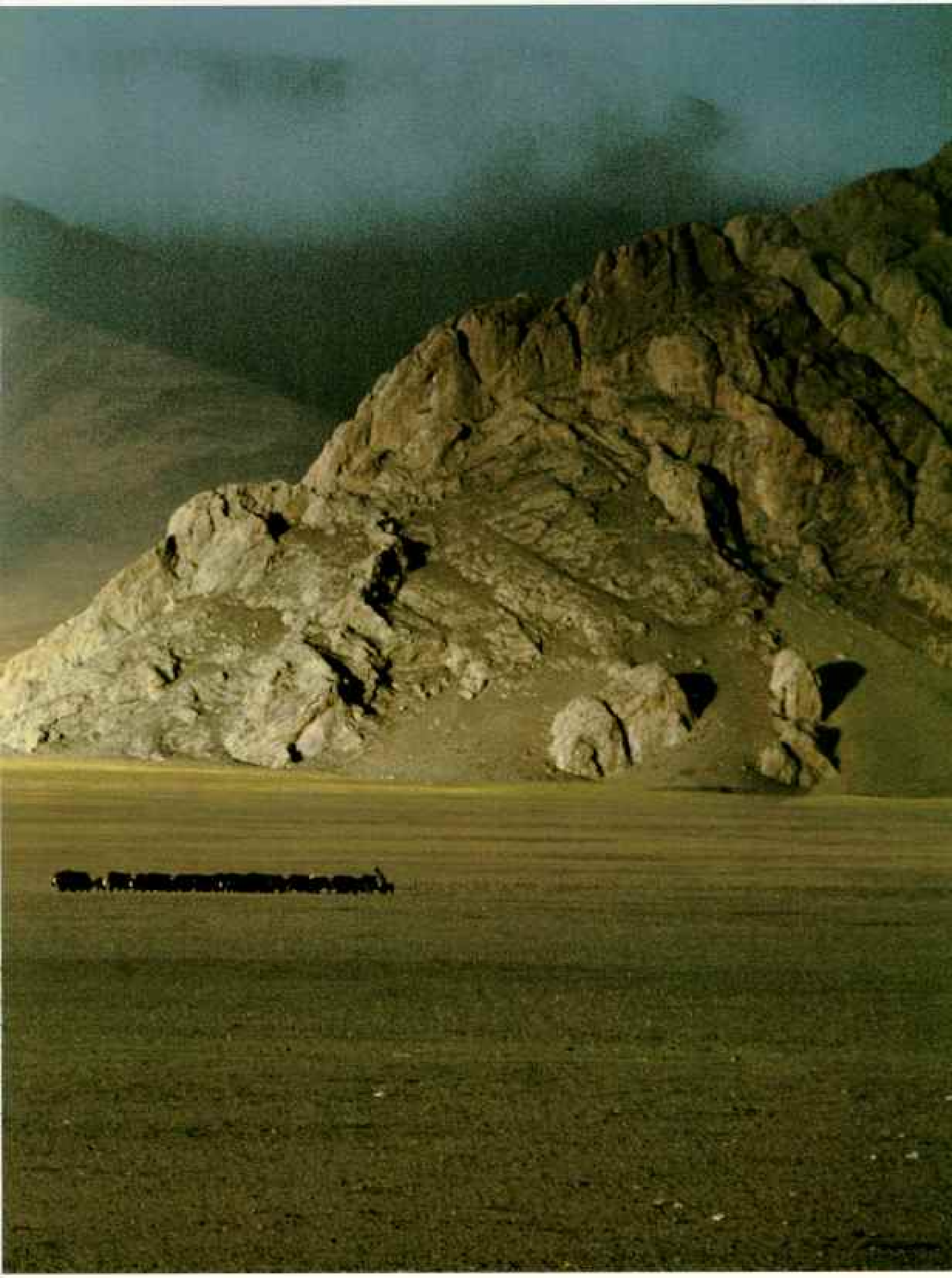
In the late 1960s the Chinese forced the nomads into communes, a policy abandoned in 1980. The authors—first Western anthropologists allowed to do long-term fieldwork in modern Tibet—found a recommitment to traditional ways among one of the world's last great nomadic societies.

Text and photographs by
MELVYN GOLDSTEIN
and
CYNTHIA BEALL

Tibet's Nomads

An afternoon rainbow paints the summer sky as yaks head back to camp after a day of grazing. About half a million nomads live on the forbidding Chang Tang, where dramatic mountain ranges rise from a land dotted with landlocked salt lakes. Here, where the average elevation is 15,000 feet, temperatures can drop 80 degrees in a single day as sudden and ferocious winds usher in stinging hailstorms.

The authors spent 16 months studying a group of 265 nomads who live in widely scattered camps within a 250-square-mile area abutting a lake called Motsobunnyi, meaning "two sisters." With many camps isolated and separated by mountain passes, some nomads never see other group members during their entire lives.



Tethered shoulder to shoulder by a single rope, goats are milked on a snowy summer evening. A mere pull on the rope frees the animals when milking is done. "I was impressed by the nomads' efficiency," says co-author Goldstein. "They perform their tasks with very little wasted motion."

Summer is the busiest time for women. That is when sheep and goats produce the most milk, which must be collected and processed into yogurt, butter, and cheese. Women also tend the fires and cook, all the while watching children.

SITTING BESIDE A DUNG FIRE in his black yak-hair tent, aromatic smoke whirling around his head, Trinley, a 63-year-old Tibetan nomad, rhythmically pumped the fire with his goatskin bellows.

As he offered us the typical nomad hospitality of salted butter tea, yogurt, and *tsamba*—a flour made from roasted barley—we told him of our plan to stay with his group for more than a year. A look of incredulity spread across his face.

"But it is not possible for you to live here on the Chang Tang in tents," he said. "It is bitterly cold and windy in winter, and only we, the *drokba* [nomads], can survive here."

With that sobering introduction we began our study of the inhabitants of one of the world's highest frontiers—the awesome area of Tibet known as the Chang Tang, or northern plateau.

Despite its name the Chang Tang's flat grasslands are broken up by twisting mountain ridges and dotted with bright, sapphire blue lakes. Located in central and northern Tibet, the Chang Tang contains some two-thirds of Tibet's landmass and spans about a thousand miles, from the Indian region of Ladakh in the west into the Chinese province of Qinghai in the east (map, right). With elevations between 14,000 and 18,000 feet, the Chang Tang suffers extremes of weather: daily temperature variations of up to 80 degrees; winter temperatures of minus 40°F; and sudden storms whose gusts can blow a rider off his horse or yak or bury him under drifts of freezing snow.

Yet this bleak, majestic plateau is home to between 400,000 and 500,000 pastoral nomads who for centuries have not merely eked out a living but have so thrived that they are an integral part of Tibet's economy.

We first came to the Chang Tang in June 1986—the only Western anthropologists so far permitted to conduct extensive field research in Tibet, which is known officially as the Tibet Autonomous Region of the People's Republic of China.

During an earlier visit I was struck by the vitality of nomad life on the Chang Tang, one of the last examples of the great nomadic societies that were once widespread throughout the world. On my return to Case Western Reserve University in Ohio, where Cynthia and I both teach, I proposed a joint field study of the Chang Tang nomads.

After winning approval from the Tibet Academy of Social Sciences in Lhasa, the

Tall in the saddle, six-foot Dr. Melvyn Goldstein rides a yak from camp to camp during summer. In winter he walked to

stay warm. Dr. Cynthia Beall measures blood pressure for a hypertension study. The authors plan to publish a book, Nomads of Western Tibet, next year.

capital, we began a 16-month study. We received funds from the National Geographic Society, which had supported projects of ours in Nepal and India, and from the National Academy of Sciences' Committee for Scholarly Communication with the People's Republic of China. The National Science Foundation later gave us supplementary funds.

We chose as our research group 265 pastoral nomads living in Phala, an area about 300 miles northwest of Lhasa. They comprise 57 tents, or households, organized into small camps numbering two to eight tents each. The Phala nomads herd yaks, sheep, goats, and horses, residing throughout the year at sites ranging from 16,000 to 17,500 feet in elevation. Living at such heights makes them the highest resident native population known in the world.

WE KNEW that the nomad herders of Tibet had undergone excruciating changes since 1959, when the Dalai Lama fled to India in exile. First there had been the closing of monasteries, then the Cultural Revolution, with its insane violence and its enforced communes. Then in 1980-81 China reversed itself and implemented the so-called "responsibility" economic system, which restored the family as the basic unit of production.

One day not long after we arrived in Phala, we heard our first account of this from Wanam, a devout Buddhist and head of one of the wealthier families in the area before the Cultural Revolution. Wanam is a pseudonym, as are all other names in our story. Policies have changed too often in China over past years, and we would hate to see one of our friends and neighbors punished later for something they told us.

One morning in 1970, Wanam recalled, the local Tibetan leaders of the Cultural Revolution appeared before his tent and ordered him outside.

"They called me a reactionary and a class enemy," he said. "They told me, 'From today on, your animals and goods are confiscated, and you will live under the guidance of the people, just as the poorest of the poor lived in the old society.'

"They ripped off my earring, my rings, my necklace, and took my silver flint striker and bullet holder," Wanam continued. "They also confiscated my new sheepskin robe, saying that it was too good for the likes of a class enemy such as me. In its place they gave me an old worn-out robe."

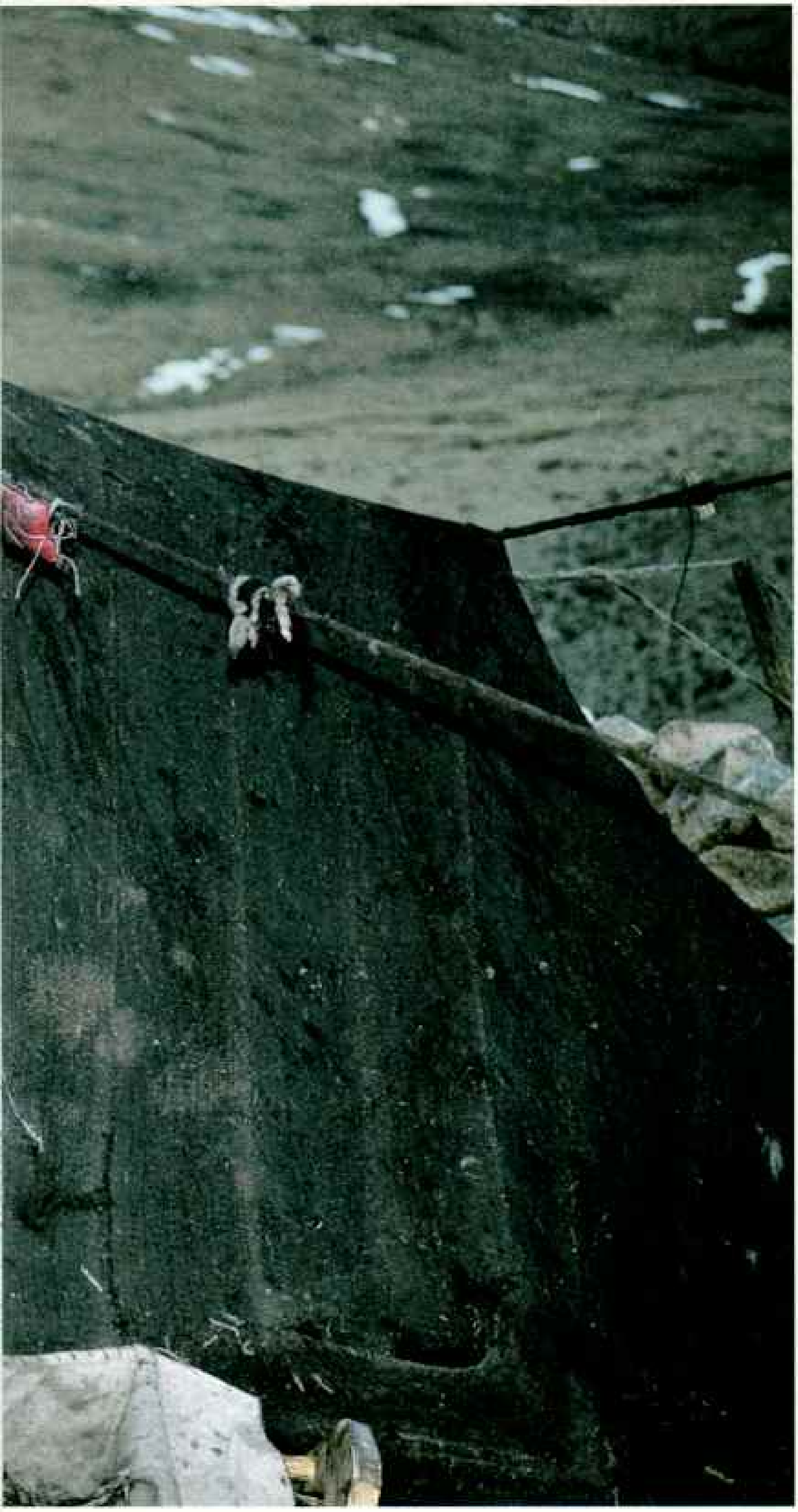
"What happened to the rest of your family's possessions?" we asked.

"We lost them all," Wanam answered. "At the time my family owned about 1,200 sheep and goats and 100 yaks. The new leaders took everything except 40 goats. They left us only one pot, some barley grain, and a little tsamba. And then they took away our fine yak-hair tent, giving us an old, tattered canvas tent in its place." He shook his head.

"We were stunned. Our whole life's wealth was eliminated in minutes. We didn't know how we would survive, since the leaders also said we could *(Continued on page 764)*

Housekeeping beside Motsobunnyi lake, a woman churns yogurt into butter. Added to salted tea, it makes a nutritious beverage drunk as often as 40 times a day. After breaking ice, a woman collects water (right). With lake water too salty to drink, nomads always camp near a spring—in winter seeking one flowing fast enough to prevent the buildup of thick ice.

Devout Buddhist nomads are reluctant to kill an animal. Hence an owner (left, at right) uses hired help to dispatch one of his yaks, though he joins in the butchering.



On a lonely vigil, a woman named Lhamo greets a December day from her tent in the mountains. There she and a younger brother tend yaks while the rest of the family remains in the main camp at a lower elevation.

Most of the world's nomadic peoples keep their animals in valleys during the winter and move them to mountains in summer. Tibetan nomads reverse this with their yaks, which graze in winter on a particular sedge plant plentiful at higher elevations.

At the relatively advanced age of 31, Lhamo remains unmarried. She wanted to wed, but her widowed father asked her to remain at home, and her suitor declined to join her father's household. Though she could have defied her father, her decision to stay reflects the strength of parental authority.

not join the people's commune but had to fend for ourselves."

In fact, Wanam and his family survived only on the meager yield from their milk goats and by doing odd jobs for the commune that they were not allowed to join. Finally, two years later, the leaders relented, and Wanam's family joined the commune.

At 50 Wanam is once again one of the wealthiest nomads in Phala. His recovery typifies the economic and cultural rebirth of the Tibetan nomads after the disastrous decade of enforced communes.

Pastoral nomadism developed relatively late in human history, about 8,000 to 9,000 years ago. The nomads of Phala are descended from people who, perhaps a few thousand years ago, began to move their herds around the Chang Tang, converting the energy locked in wild grasses into food, clothing, and shelter.

THE NOMADS CONTINUE to flourish because they have no competitors. Even with modern technology farmers cannot grow crops in the extreme high altitude and bitter climate of the Chang Tang. If there were no nomads on the high plateau, it would revert to wild animals, not to other humans. Yet the nomads feel their way of life is far easier than that of farmers.

"Look," explained one, "it is obvious that we have a very easy life. The grass grows by

As her children watch, a woman applies ada, a lotion made by boiling whey into a concentrate. A salve to protect the skin, it is also used for beautification.

Although they keep their tents, wealthy nomads also build permanent homes. In a newly built structure (below), a woman tends a fire as sunlight streams through a smoke hole. In the pan, barley obtained from traders is roasted on sand to keep it from scorching.

As his daughter plays with a baby goat (below left), a man uses a hand mill to grind roasted barley into a flour called tsamba. *A dietary staple, tsamba can be eaten dry, stirred into tea, or mixed with tea and butter to form patties.*

itself, the animals reproduce by themselves, they give milk and meat without our doing anything. So how can you say our way of life is hard?"

Although they are looked down upon by farmers and townfolk as simple, uncouth, and backward and although they have little in the way of material possessions, the nomads see themselves as masters of their environment and are proud of the leisurely life such mastery provides.

"We don't build canals to irrigate pastures, and we don't build fences and sow seeds to grow more grass," another nomad remarked. "They tried to make us do this during the Cultural Revolution, but that is not our way. The Chang Tang is a ferocious place. One minute the air is calm and the sun is shining, the next it is hailing. It isn't possible to try to control and alter the Chang Tang. We don't try; instead we use our knowledge to adjust to it."

Traditionally the nomads had a remarkable pasture-management system that allowed them to live a secure existence without destroying their grassland resource base.

The nomads contend that the Chang Tang's extraordinary cold, deadly blizzards, unpredictable rainfall, and occasional catastrophic epidemics maintained livestock numbers below the region's maximum carrying capacity. However, while such a "natural" balance could operate over a large region, it could not always prevent overgrazing and degradation on specific local pastures. Before 1959, when the Chinese took control, the nomads divided the region into scores of discrete pastures registered in a "pasture book," each pasture being permitted only a specified number of livestock—seven goats or six sheep were equal to one yak in this calculation. Every three years a livestock census was taken, and families whose herds had increased received additional pastures while those whose herds decreased relinquished some. Occasionally whole families and their herds were shifted to nearby regions to maintain the balance. In this manner the nomads' grasslands were conserved despite the centuries of continuous use.

THE NOMADS LIVE primarily on food derived from their herds, milk products being one of their main sources of calories. Although yaks, sheep, and goats all provide milk, the sheep do so for just three summer months and the goats for four and a half. The nomads turn much of the summer milk abundance into butter and cheese that can be sold or stored for later use.

Processing dairy products is almost exclusively the responsibility of women. They milk their animals and make yogurt, butter, and cheese. But the backbreaking milking is more than just work. The animals of several families at a campsite are usually tied together, so milking time is also an occasion when the women come together and chat.

Milking invariably brings out their children, who play games beside the animals and often try to help the milkers in sweet and humorous ways. One may try to push back a sheep that has turned out of line, while another earnestly holds the end of the rope that ties the animals head to head while they are milked from behind. Other children pretend they are yaks or antelope, walking around on all fours while holding discarded horns to their heads.

The nomads' herds provide more than dairy products; virtually every part of their animals is used. Sheep provide wool for weaving and barter, meat, stomachs into which butter is

sewn for storage, intestines for sausages. They are also a valuable trade item that the nomads barter with distant farmers.

Goats used to be less valuable than sheep because farmers preferred mutton to goat meat. But goats have become more valuable recently with the expansion of the lucrative international market for cashmere, the soft undercoat of cashmere goats.

The yak furnishes the critical muscle power to transport a nomad tent, each half of which weighs about a hundred pounds, excluding the pegs and poles. The yak's fringe of coarse belly hair is the fiber from which the nomads weave the tough tent fabric. The yak also provides a cashmere-type undercoat used for making cloth and ropes, a thick hide used for boot soles, and, of course, lots of meat. A *dri* (a female yak) also furnishes eight times as much milk per year as a goat and 16 times as much as a sheep, and does so year-round.

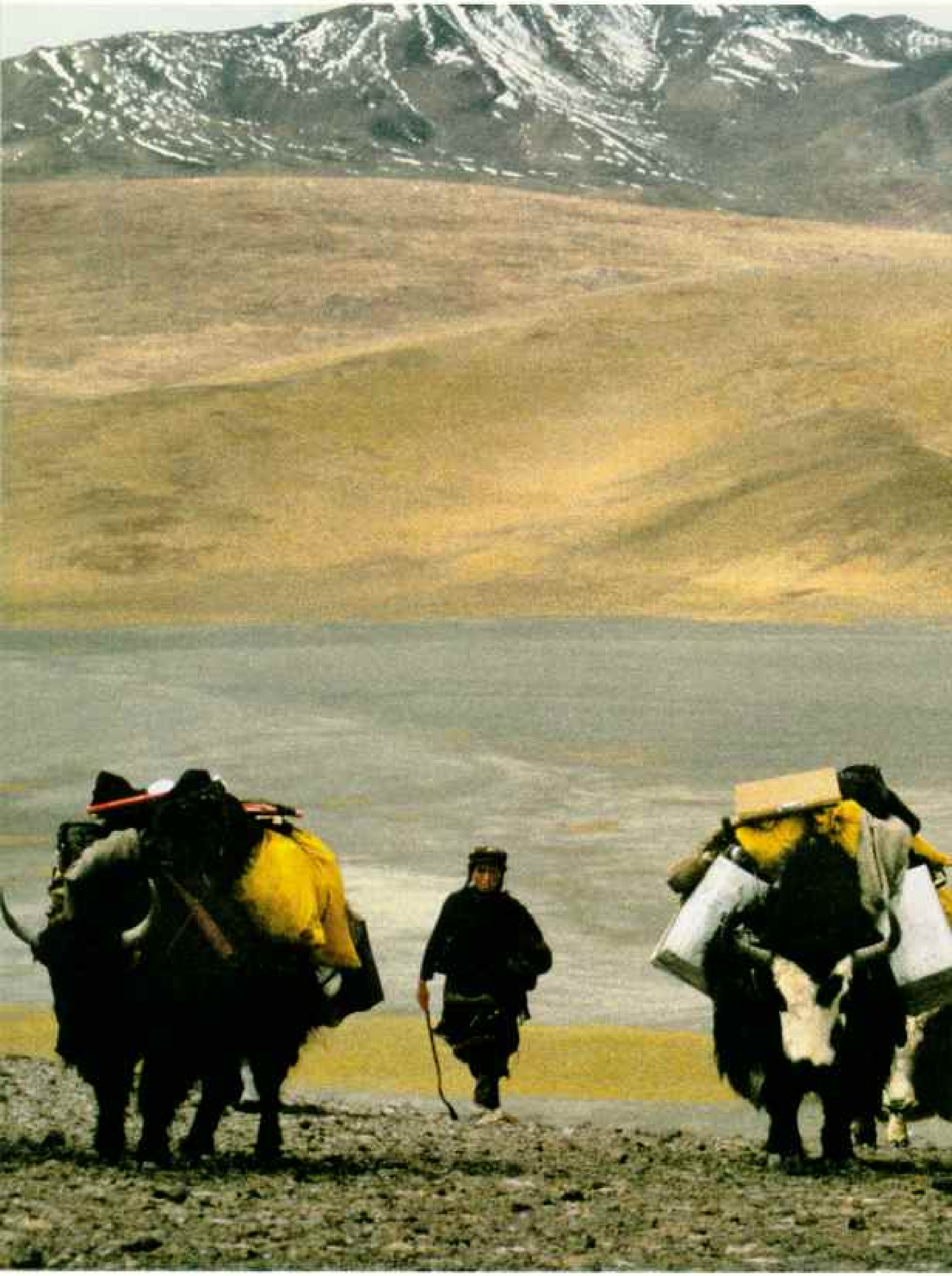
The nomad economy has two other significant components. Since time immemorial Tibetan nomads have been the main source of salt for the villagers and town dwellers of Tibet and the adjacent Himalayan kingdoms of Nepal and Bhutan. Phala men take a salt-collecting trip in spring, driving their animals 140 miles northwest to Lake Drabye, a trek of 20 to 30 days each way. We joined them at Lake Drabye, though we drove there by jeep rather than making the two-month trip with the pack animals.

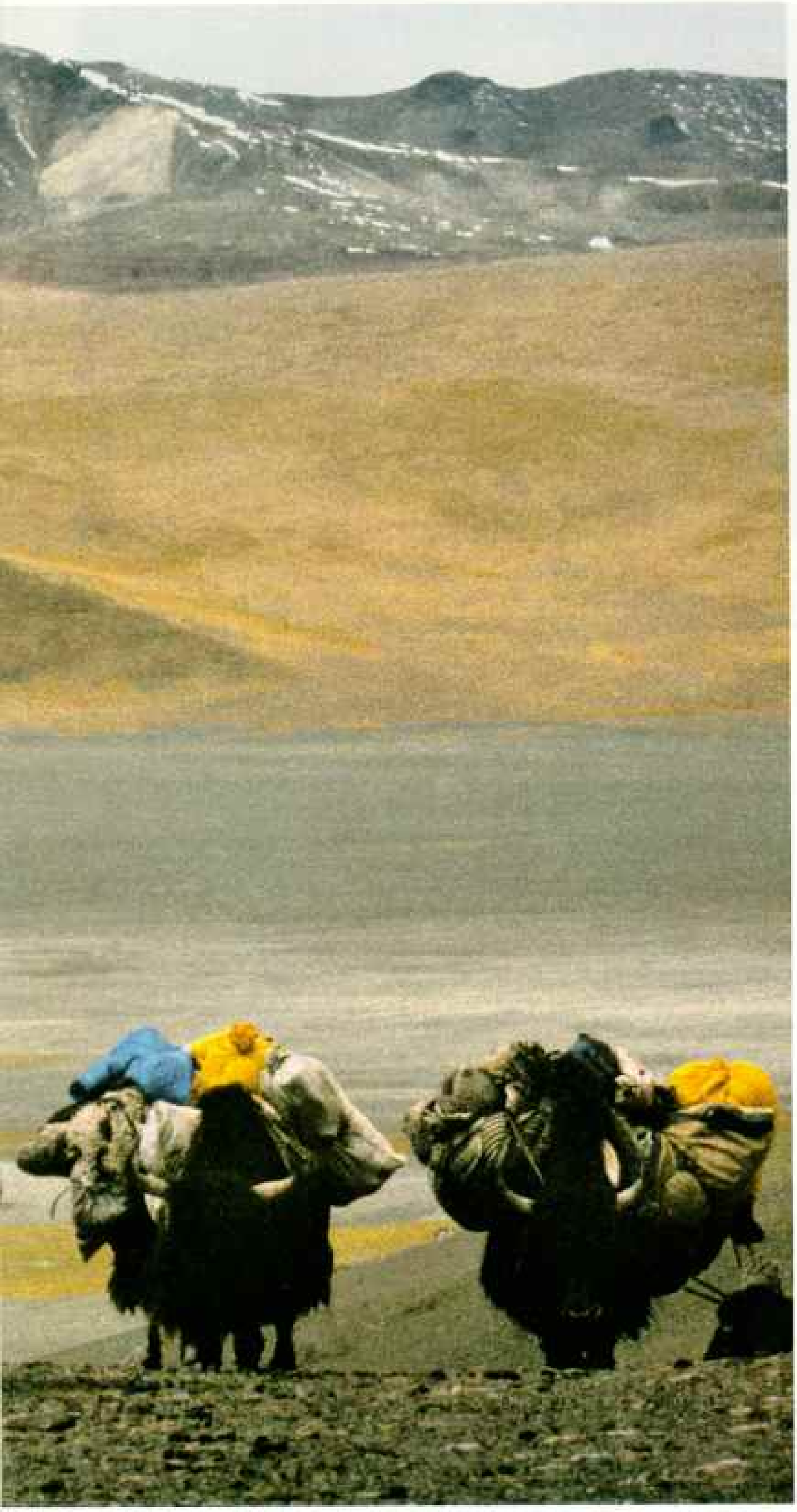
Though yaks can carry four to six times the weight of sheep, few of the Phala nomads have enough male yaks for that purpose, so most of the pack animals are goats or sheep. These can each carry loads up to 30 pounds in saddlebag contraptions like the ones that hikers strap to their dogs. The sheep and goats sleep with the saddlebags on, relieving their owners of the time-consuming task of loading and unloading scores of animals each day.

At the lake the nomads camp on the white salt pans, which look like vast snowfields. The entire process of gathering the salt has been worked out to the last detail. One nomad explained the strategy.

"On the trip to the lake," he said, "we go very leisurely so that our animals can maintain

In worshipful repose with her prayer wheel, a woman bows toward the local mountain god, Dargo, the nomads' protector. Such open displays of faith have increased since 1980, when the Chinese eased a ban on religion. A young boy (facing page) openly displays his love of yogurt.





Marching stolidly over the empty land, a train of yaks carries the authors' belongings. Although the nomads rely heavily on sheep and goats, the yak is their quintessential domesticated animal, making life on the Chang Tang possible.

Besides their carrying capacity, yaks furnish abundant milk, meat, hide for boots, and hair for making tents, cloth, and rope. Only castrated males are called yaks by the nomads; a bull is a boa, *and a cow is a* dri. *So vital is the animal to the economy that the nomads' generic name for the beast is* nor, *meaning "wealth."*

Slow on the draw, a hunter uses a matchlock that requires a brace and manual lighting of a wick to ignite the firing powder. Hunting dogs hold game at bay within the musket's limited range. This hunter felled a blue sheep; other quarry are gazelles, Marco Polo sheep, and wild yaks.

their strength. Pasture is a problem, for the new growth of spring grass has yet to begin and we must depend on the grass left over from last summer. At the lake, pasture is even more critical, since there are so many nomads and animals there. Because of this we send a small advance team of four or five men to the lake to dig and collect the salt, so that when we arrive with the animals we can load up immediately and leave the next day."

By the time the animals have arrived, bricks of salt have been stacked to form a corral into which the sheep and goats are driven. Then the grueling job of loading begins. The salt to be taken has already been pounded into small pieces with old yak horns and stuffed into saddlebags, which have been sewn shut. One nomad guards the entrance to the corral while the others, often singing haunting work songs, single out the animals and load each one. The goats and sheep continually try to escape, and at one point I tried to lend a hand.

The first time I grabbed a sheep by its coat to stop it from escaping, I thought it would be easy, since it seemed quite small. Instead, I was pulled right off my feet by an animal that left me flat on the salt bed, panting for breath. Though the lake is only 14,100 feet in elevation, within 15 or 20 minutes I was drenched with sweat and completely exhausted.

ANOTHER FACET of the nomad economy is hunting. The Chang Tang once abounded with antelope, blue sheep, Marco Polo sheep, gazelles, and wild asses and yaks. Hunting by officials with modern rifles and jeeps—banned a few years ago—has reduced the numbers, but there are still many animals, and men still hunt with the traditional matchlock muskets.

One of the best hunters in Phala is Jigme, a taciturn 47-year-old bachelor. We accompanied him and his three hunting dogs on a trip in search of blue sheep.

Jigme's matchlock seemed no threat to wild sheep, and we asked him about it as we trudged up the slopes.

"It is only accurate up to a hundred feet," he acknowledged, "and it takes a very long time to fire."

Jigme was right. Even though he kept his musket loaded with powder and a lead ball, he had to plant the gun on the ground with its brace, light the wick with a spark from his flint striker, and then put the wick to the small powder pan on the outside of the gun, igniting the powder and firing the musket ball.

"By the time I have done all that, the sheep would be long gone," Jigme said. "That is why we always hunt with our dogs; they tilt the odds in our favor."

These sleek dogs, known as *nakí* (blue-sheep dogs), are bred especially for hunting, the best being worth a yak in trade. We soon saw why. After a time Jigme spied a flock of ten blue sheep on a mountain slope, and his dogs took off like greyhounds at a racetrack. They bounded up a steep, rocky slope whose base was at just over 18,000 feet and were quickly out of sight.

We followed as best we could, moving toward the sound of the dogs' barking. Jigme, who was always complaining that he couldn't work because his lungs were no good, scrambled up the 45-degree slope at a very fast pace without any rest. We tried to keep up with him, but every few minutes we had to stop and gasp for breath. It was a humbling experience; more than anything else it demonstrated the difference between lowlanders living at high altitude and native highlanders.

High-altitude adaptation is Cynthia's specialty. She points out that in the rarefied atmosphere at 17,000 feet, only about half as many oxygen molecules enter our lungs as at sea level. The effect on lowlanders at high altitude is shortness of breath, headaches, and occasionally even death. These effects have been known for centuries—as early as A.D. 100 a Chinese official visiting the Tibetan Plateau referred to the area as "Headache Mountains."

Just how high-altitude natives such as the Tibetan herders adapt to this environment is an important area for research. We know that the nomads have as much as 22 percent more oxygen-carrying hemoglobin in their blood than do lowlanders, giving both groups roughly the same amount of oxygen on their home grounds. But the natives of the high Andes, whom Cynthia has also studied, typically have greater concentrations of hemoglobin than do the Phala nomads, even though the nomads live at higher elevations. Thus humans may have adapted to life at high altitude in more than one way, and further research is needed to identify the physiological mechanisms.

THE HUNT with Jigme was a modest success. Though the main herd of blue sheep escaped his dogs, he bagged two small ones. However, as Buddhists, many nomads are reluctant to hunt or even to butcher domestic animals. This was brought home to us vividly once when we were out of meat in Wanam's campsite. With a thousand sheep and goats in front of us, we waited two days until a poor nomad was summoned from a neighboring camp to slaughter an animal.

The revival of Buddhism has made itself felt in other ways. "Last summer," one of the Phala men told us, "traders from outside came and said they would pay high prices for snow leopard or lynx pelts. I wanted some extra money, so I bought two Chinese steel traps and baited them and killed two snow leopards, which I sold to the traders for a good price."

But during the winter the man's wife, who had always been healthy, suddenly fell ill and died. "I now know," the man said sadly, "that Dargo—our powerful mountain-god protector—was angered by my slaughter of those animals for profit. He showed his displeasure by taking my wife from me." Despite the enormous profits involved, from the day of the woman's death trapping for pelts ended in this region.

Neither herding nor salt collection is sufficient for Phala nomads to survive. There is another dimension to their economy—trade. "All our pastoral skills can't give us a good living by themselves," Pemba, a young man and enterprising trader, proudly explained. "Like hunting and salt collection, trade is a job for men. Personally, I think it is the most important skill."

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One of the vital commodities for which the nomads must trade is barley, which provides about half their calories. They get the barley, as well as flour and even rice, by bartering their animal products with villagers along the southern edge of the Chang Tang.

"This trade is no simple matter," Pemba told us. "I have to choose what and how much to take for trade—yaks, sheep, goats, hides, wool, or butter. I have to decide which farming areas to trade with and what rate of exchange to accept. Then I have to make a month-long round-trip with my animals in winter."

Trading skill is highly valued among nomad men, but in the end the key to survival on the Chang Tang is pasture—its availability and conservation.

In mid-September the grasses stop growing and lie dormant until May. Forage dries and turns color, cloaking the plains and mountains with a beautiful yellow-rust hue. However,

A day in the pasture ends as sheep are led back toward camp for milking. The nomads are skillful in the husbandry of their stock. Ewes and rams are separated until August so that young are born in late winter and early spring. After nursing for several months, lambs are weaned from their mothers in summer, when grass is plentiful, and sent to pasture with another flock. Since a lactating ewe will nurse only her own offspring, the milk is saved for human consumption.

the short growing season creates problems.

"The animals can survive in summer even if the rainfall is poor," a wily old nomad named Dorje explained to us. "But unless there is enough grazing in summer for them to build up stores of fat, many animals cannot survive the harsh winter eating the poor fodder."

For this reason the nomads move their herds in September from the summer camps to pastures one or two days distant that have been left ungrazed for several months. They return to the summer area in December, using the remaining cover of grass that their migration preserved until the new growth of grass begins in early May.

The nomads, therefore, by and large use the same grazing area for winter, spring, and summer. It serves as their home base. There each family's main tent is pitched, and rich families build small storerooms. When the family must move its herds to a pasture beyond the daily range of that base, the husband and wife prefer to remain with the main tent. If possible, adolescent children or hired hands take the animals to a smaller camp in the more distant pasture.

There are ten such home-base camps scattered throughout Phala's 250 square miles of territory. Moving between their home base and fall pasture, these nomads never reside together in a single large settlement.

The nomads of Phala have no romantic illusions about moving. One experienced woman herder echoed the sentiment of almost all nomads when she told us, "We only move when we feel we must." And then they can only move to their own pastures.

A local official explained, "Every pasture in our area is named and given to a family or a small group of families, which has exclusive rights over it. We are allowed to use another group's pasture for one night while moving, but not longer. This is as true of Phala today as it was during traditional times."

By "TRADITIONAL TIMES" the nomads mean the period before 1959, when the Dalai Lama fled into exile. We spent numerous hours sipping butter tea in smoky tents and talking to elderly nomads about that "old society" as they now call it.

"In the old society," said Trinley, the old nomad who feared for our ability to survive the Chang Tang, "we were part of a larger administrative unit of nomad groups. We all belonged to the Panchen Lama," he added, referring to Tibet's second most powerful lama, who died this year. He remained in Tibet when the Chinese took control.

"The Panchen Lama," Trinley continued, "owned areas and appointed officials to settle disputes and collect taxes. He was our lord, although he never came here himself. Our taxes were heavy in those days, but we never went hungry."

Nomad society was similar to that of medieval Europe and tsarist Russia. Though they owned their herds, nomad families were not free to leave their area. They were hereditarily bound to their lord and land and paid taxes to the Panchen Lama according to the number of animals they owned. On the other hand the

Using time-honored but tedious methods, a nomad shears a sheep with a stone-sharpened iron knife. The finished product is displayed at right. Local officials force the nomads to sell as much as 75 percent of their wool to the Chinese government in an unauthorized form of taxation. With growing world demand, cashmere, the soft undercoat of cashmere goats, now rivals sheep's wool in the economy.

lord could not evict them and bring in new nomads. They had their rights as well as obligations.

This somewhat decentralized, feudal-like system ended in 1959 when the Chinese assumed complete control of Tibet.

All the monasteries of the Chang Tang were closed. A formal class system was spelled out, and the wealthy nomad class paid much more in taxes than the poor nomad class. New rules regarding salaries for hired shepherds and servants were also established, the wages varying according to the class of the employer. Nevertheless, on a day-to-day basis, each nomad family continued to decide when to move its animals, and when and for what to barter or sell its products.

THIS SITUATION ENDED in 1968–69, when the Cultural Revolution reached Phala. "Education" of the nomads began in preparation for converting Phala into a nomad commune. At the same time local Communist officials began to pursue the "class struggle" in earnest. In response, the Phala nomads and those in nearby areas rebelled, misunderstanding Mao Zedong's call for the "revolutionary masses" to "pull down those in authority."

The nomads mistakenly believed that the army would remain neutral in their struggle to restore religious and economic freedom. They executed two local officials who had been especially cruel in implementing the class struggle and drove out the rest, taking control of

Readied for a long trek, bags are filled with crushed salt at a salt pan in western Chang Tang. Since yaks are few and quite valuable here, this important staple is carried by sheep and goats during the 140-mile, month-long trip back to camp. Cigarettes are common, although smoking among women dropped sharply in 1985 when a visiting lama warned against it.

their area for three months during the summer of 1969.

But it couldn't last. The army marched to Phala and attacked the nomads, who were armed almost solely with matchlock muskets and swords. The rebellion disintegrated immediately. Nine rebel leaders were executed, more than 30 nomads were imprisoned, and in 1970 a commune system was instituted. It was at this time that Wanam's animals and possessions were confiscated.

The nomads were transformed from private owners of animals to holders of a share in the commune's property. Or, as one more bluntly put it to us, "We were nothing more than servants of the commune."

The quality of life for the overwhelming majority markedly deteriorated. "Before the commune," one nomad explained, "if you were hungry, you could always find work as a herder or servant, or you could beg outright for food. But during the commune you just stayed hungry."

The nomads hated not just the economic hardships they endured but even more the class-struggle sessions, the continuous denigration of their values and beliefs, and the destruction of Buddhism in their society. Temples and prayer walls—walls three to five feet wide, with carved prayer stones placed on top—were pulled down, and no religious rites, even at death, were permitted.

The death of Mao and the overthrow in 1976 of the Gang of Four in China brought a new group of leaders to the fore. They perceived the Cultural Revolution as a catastrophe, abolished communes, and implemented a more market-oriented rural economy called the responsibility system.

Thus, in October 1981, all the Phala commune's animals were divided equally among its members. Every member—infants and elderly alike—received the same share: 5 yaks, 25 sheep, and 7 goats. A household of five, therefore, obtained 25 yaks, 125 sheep, and 35 goats over and above the few "private" goats—perhaps 30 or 40—that the family had been allowed to maintain during the commune era. In addition Beijing decided to excuse Tibetan peasants and nomads from all taxes until at least 1990 because of Tibet's poverty; although in Phala and other parts of the Chang Tang, local officials illegally require nomads to sell quotas of wool to the government.

The new Chinese leadership also forbade persecution on the basis of class background; currently, one of Phala's local heads is a former monk and class enemy. Similarly, the new leaders attempted to right some of the terrible injustices of the Cultural Revolution by a policy of monetary restitution to class enemies whose animals and belongings had been confiscated.

Finally the government reversed its policy on religion. Religious freedom was largely restored, monasteries were allowed to be rebuilt and reopened—albeit with limits on numbers of monks—and traditional rites and practices were again permitted. The nomads of Phala now openly pray with their rosaries and prayer wheels. Even one of Phala's four local Communist Party members frequently chants prayers.

The nomads' depth of religious feeling is obvious. An old woman told us: "I feel sorry for all those who died during the commune period, because they could never say prayers or have the proper death rites. It was a terrible time."

WHAT DO THE NOMADS THINK of the new policies? One middle-aged man told us, "We were shocked, and at first we did not believe it. We thought it was some kind of trick. But after two or three years we came to accept that we really were free to manage our herds and even get rich if we could."

The past seven years have brought a substantial rise in prosperity for Phala's nomads, although it is certainly not a rich area by Chang Tang standards.

A few Phala nomads, however, resent the latest changes. Generally these are individuals from the poorest classes in the old society who were appointed officials during the commune period, wielding tremendous power. Not surprisingly, most nomads, particularly the former class enemies, fear that another shift in policy will occur and such people may again return to power. This fear and the concomitant feeling of powerlessness partly account for the continued resentment against the government despite its recent reforms.

The nomads' tenacious belief in the superiority of their traditional way of life has not made them opposed to change. Over the past decade the government has built a network of crude dirt roads throughout the western Chang Tang, and the administrative center at

As days grow short, a woman bales grass for winter fodder for horses, prized as luxury animals. Left ungrazed throughout summer, a section of communal grassland is opened for a week's unlimited cutting. At night traders sell their wares, offering shoes, saddles, and cassette players for listening to music and Buddhist prayers.

Tsatsey, three days' walk south of Phala, can truck in large quantities of grain and other staples. More and more Phala nomads, therefore, now skip the arduous winter trading trip, bartering instead with the government office at Tsatsey.

The opening of the roads also has facilitated the construction of storerooms and houses at the nomads' home-base campsites. There are no trees on the Chang Tang, and all wood, even for small items such as tent pegs, must be brought from elsewhere. Now large wooden beams and pillars are easily imported by truck from southeast Tibet at relatively low prices, leading to a house-building boom.

The nomads see no contradiction between having a house and being drokba. Rich nomads often slaughter 50 to 75 animals in

December and have difficulty storing the meat and skins (together with their saddles, packs, and other equipment). So they have always built storerooms. Residential houses at the home base were rare in the old days, but prized. As one nomad explained, "Houses completely cut out the wind and are much warmer than tents. They make the long winter less difficult for us, and everyone wants one."

A house, for the nomads, is a substitute for the home-base main tent, and the nomads see it as a symbol of their newfound affluence, not a loss of their identity.

The important changes brought about by the road have had little effect on the attitudes and perceptions of the nomads, who still know little of the tremendous political and economic transformation that has taken place in the rest of China. They do not know, for example, the name of the head of the Tibet Autonomous Region, let alone the leaders in Beijing. No one speaks Chinese, and the district administrative center teaches only Tibetan to the few children sent to its primary school.

The new policies, however, have not benefited all, even though everyone had an equal start in 1981 when the commune ended. As in the old society, lesser degrees of skill and bad luck have seen some nomads lose most of their livestock and forced them to work as herders for others. They receive room and board, some clothes, and 12 sheep for a year's work, but have a much harder life than the newly rich nomads who employ them. And this gap between rich and poor will undoubtedly increase.

Taking pains to protect livestock, a woman places a baby goat in a pen designed to keep newborn animals warm at night. To ward off dust, a man with chronic eye problems wears goggles usually used to prevent snow blindness as he tends a corral for adult animals. Traditional leggings sewn onto sneakers reflect the nomads' willingness to accept some trappings of modern society, while holding fast to ways that have served them well for centuries.

Despite the antiquity of the nomads' pastoral system, the government believes that it leads to overgrazing and environmental degradation. It therefore has set limits on the number of animals per person in some areas, while forcing periodic reductions in herd size in others. In Phala a 20 percent reduction was implemented in 1987 despite the nomads' protestations that there was no shortage of grasses.

The nomads perceive this as a bias against their pastoral system and worry that it could lead to even more inappropriate programs that will impose new patterns of herding that would ultimately destroy their way of life.

Our research supports the nomads' contention that the government's order to reduce livestock in Phala was unwarranted. We found no evidence of overgrazing and pasture degradation.

Preserving the unique environment of the Chang Tang is not only a Chinese but also a world concern, and protection of the indigenous people who reside there is equally important. It would indeed be ironic if after surviving the destructive Cultural Revolution, these nomads' way of life was destroyed by modern notions of conservation and development that are based on faulty evidence and flawed assumptions.

The most striking feature of nomad society today is the powerful revitalization of traditional values and customs and the deep commitment to the traditional way of life. For example, the nomads are again proud that they do not eat fish (though many camp on the shores of lakes teeming with fish), or fowl, or vegetables, or wild asses, or meat from animals killed by women—these all being things that "drokba do not do."

The nomads of Phala like their religion and way of life and want to maintain them in the years ahead, choosing to incorporate or to ignore new items as *they* see fit. Deeply resenting government interference, they want nothing more than to be allowed to live as their ancestors did and to flourish or fail as their gods and their own abilities dictate.

Thus, despite the attempt to destroy the Phala nomads' values and beliefs during the Cultural Revolution, for now, and for the foreseeable future, the nomadic pastoral way of life is alive and well on the Chang Tang, and all of us are richer for it. □

Life in a Nutshell

Article and photographs
by MARK W. MOFFETT

SCURRYING across one nut after another, an acorn weevil searches for a spot to bore into with her snout to feed. Often the first animal to breach an acorn, the weevil strikes while the fruit is still on the tree. As acorns attacked by this and other insects die and decay on the ground, various new animals and plants find their way inside. This community of herbivores, predators, decomposers, and parasites forms a miniature ecosystem in the nutshell. Few acorns escape to become tall oaks.

INTENT on their tasks, scientists tower beside scrub oak trees in the pygmy pine barrens of Long Island, New York (below). The lofty limbs of most oaks put growing acorns out of reach; here, Bob Unnasch must bend over to inspect acorns for weevil damage. Brushing aside huckleberry plants, Robin Stuart checks the ground for hollow shells of decayed acorns occupied by slave-making ants.

As he combs the canopy, Bob shows me half-inch acorn weevils at work. Using tiny teeth at the tip of a long, slender snout, the weevil cuts through the acorn's tough shell. I am amazed to see that as it drills into the meat (facing page), rotating its spherical head back and forth, each eye alternately disappears beneath the "collar" around its neck (diagram, top).

The weevil eats the nutmeat that enters its hollow snout during the drilling, usually stopping only when its head is pressed to the nut's surface. A female's snout, which may be longer than her body, can almost completely pierce small acorns.

Weevils begin feeding several weeks before acorns ripen. A female may lay one egg deep inside each tiny channel she excavates. A larva usually hatches in 5 to 14 days and then spends several weeks eating a larger chamber into the acorn—which continues developing until it falls from the tree. The jolt of the acorn hitting the ground often signals a fully grown weevil larva to emerge. It begins by gnawing a circular hole in the shell about the size of its head. Pushing and squirming, the plump body emerges dramatically through this cramped exit (right).

Once on the ground, the larva burrows into the soil, sometimes as deep as 12 inches. There it lies dormant from one to five years. The irregular timing of this resting stage may be the weevil's response to acorn production that varies from year to year in many oak species; some larvae always will pupate and emerge as adult weevils during an advantageous year of a bumper crop of acorns.

MARK W. MOFFETT is curator of the ant collection at Harvard's Museum of Comparative Zoology.

A field guide: what to expect and when

CRACK OPEN an acorn and find a world of creatures that make it their home during the nut's growth and decay.

What you discover will depend on the condition of the acorn and its surroundings. Nuts lying on dry, bare ground may not have much to show. A decaying acorn protected by a layer of moist leaf litter is more likely to house a group of interacting individuals.

Acorn weevils and filbert worm moths set upon growing nuts during summer and early autumn; their larvae can be found in acorns freshly fallen from the tree.

As the autumn wears on, increasing numbers of acorn moths, short-snouted weevils, and sap beetles gain access to acorns on the ground through insect holes, cracks, and sprouts. Parasites of specific insects follow their hosts inside. Some acorn varieties that wait until spring to sprout are invaded then.

By summer all of last year's acorns have sprouted or been eaten in part or whole. Dead acorns usually contain a community of creatures, some cleaning out the decay. The husks may shelter animals for years before breaking down into humus.

This guide applies to the northeastern United States, where most research on acorns has been done. If you live elsewhere, you may find many of the same animals pictured here—and probably some new ones. Gather fresh acorns and drop them into a container of water. Most with insect damage will float. Open them to find larvae, or keep them damp in a loosely covered container. Moths, parasites, and other inhabitants will mature and emerge.

To trap other attacking insects, place fresh, halved acorns in a jar and keep moist. Cover it with quarter-inch wire mesh to keep out rodents. Bury the jar, preferably under a fruiting oak tree, so that its lip is at ground level. Check periodically for creatures that move in to feed or reproduce.

All acorns and pinned acorn weevil life-size; other specimens magnified four times except microscopic specimens. Species match those photographed.

DAMAGED OR SPROUTING ACORNS

EARLY DECAY

ADVANCED DECAY

ACORN WEEVIL GRUB

FILBERT WORM

ACORN MOTH (VALENTINIA GLANDULELLA)

Acorn moth often lays an egg in the opening of a sprouted or damaged acorn; caterpillar feeds on the meat.

ACORN MOTH CATERPILLAR

LARVA OF SHORT-SNOUTED WEEVIL

Short-snouted weevil feeds and lays an egg in an opening; larva feeds on the meat.

SHORT-SNOUTED WEEVIL (CONOTRACHELUS NASUS)

EARTHWORM

Animals that live in the soil, such as the earthworm and sow bug, compost the very decayed acorn.

SOW BUG

OVERCUP OAK (QUERCUS LYRATA)

CHESTNUT OAK (QUERCUS PRINUS)

CALIFORNIA LIVE OAK (QUERCUS AGRIFOLIA)

Fungi—shown 40 times life-size—and other microorganisms decompose the acorn and the remains of previous inhabitants.

PIN OAK (QUERCUS PALUSTRIS)

SNAILS

FLY MAGGOTS

SPRINGTAIL

MINUTE FUNGUS BEETLE

CHEESE MITE

BEETLE MITE

MAGNIFIED 80 TIMES

WIREWORM

FUNGUS GNAT LARVA

SLUG

CENTIPEDE

SAP BEETLE (STELIDOTA OCTOMACULATA)

Sap beetle enters a damaged or sprouting surface. Adult and larvae feed on meat and may remain during early decay.

The acorn ecosystem may include parasites—often wasps or flies—that live off each species pictured above.

BRACONID WASP (PHAEROTOMA FASCIATA)

TACHINID FLY (PHYTOMYPTERA MELISSOPODOIS)

EULOPHID WASP (MESOLEPTA ISCHNOPTERAE)

MILLIPEDE

QUEEN ANT WITH SLAVE

Wireworms, springtails, fly maggots, cheese mites, minute fungus beetles, and beetle mites eat the decaying nutmeat and fungi. Millipedes, slugs, and snails scavenge. Predators such as centipedes and some fungus gnat larvae attack other inhabitants. Ants sometimes make a home of the hollowed shell.

PAINTING BY NED SEIDLER

ONE OF THE FIRST to invade an acorn, the filbert worm moth presents a fierce visage when seen 40 times life-size. No one knows the purpose of the tiny eye just above the large compound eye.

After a filbert worm gnaws its way inside an acorn, it begins to feed. If it consumes a small acorn, it may move to others in the cluster. After metamorphosis, the moth begins the cycle again, laying an egg on an acorn, a filbert, or another nut.

Like others that take up residence in the acorn, filbert worms are vulnerable to specialized parasites. A braconid wasp will lay her own egg inside that of a filbert worm moth. As the host caterpillar hatches and develops, the wasp larva grows within it, eventually destroying the filbert worm by bursting from its body like a nightmare monster. The tachinid fly operates in similar fashion.

Round holes created by acorn weevil larvae and filbert worms often serve as entryways for other animals unable to breach the shell themselves. Called secondary colonists because they usually follow a first strike, such creatures also penetrate untouched acorns that are broken or sprouted. The short-snouted weevil, for example, hunts for openings, where it then feeds or lays eggs. When startled, it rolls over and plays dead.

Some sap beetles can detect damaged acorns from a distance, often swarming in and quickly destroying them. Although partial to tender acorn sprouts, sap beetles unleash their large appetites on a variety of plants. The one pictured even briefly gnawed at a spider's egg case inside an acorn.

As acorns die, more animals move in among remains of former inhabitants. Breaking open a large acorn, I find a millipede eating detritus near pale galls (foldout, left). Holes in the galls indicate that gall wasp larvae have matured and adult wasps have left the acorn. A new species of eulophid wasp surprised me by emerging from a similar gall. Apparently it is a parasite of the gall wasp larva.

FILBERT WORM

BRACONID WASP

At the other end of the shell, green fungus grows into the decaying meat. Hidden in crevices, minute springtails and maggots feed on both. I also find refuse of a weevil grub, a moth pupal skin, and broken snail shells—clues to the lives of a series of inhabitants that made up the history of this acorn.

EULOPHID WASP

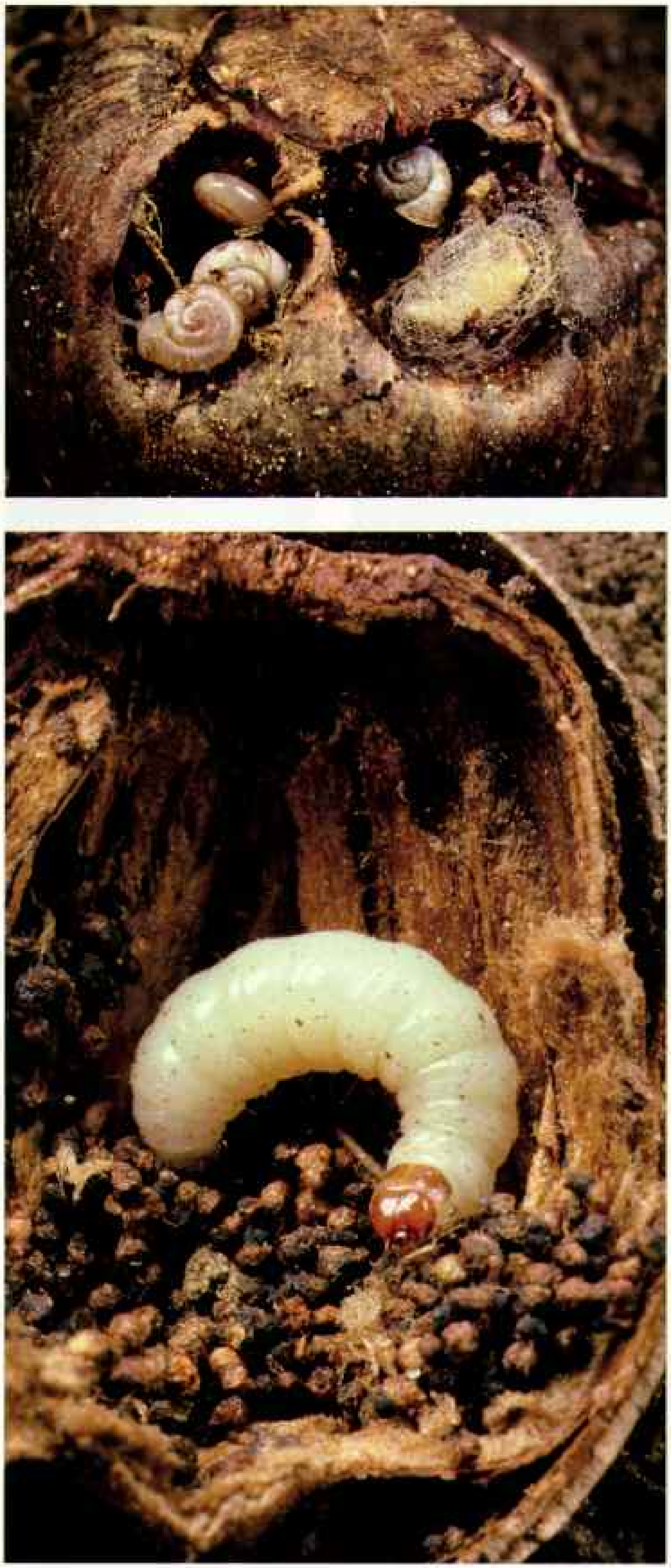
HEAD OF FILBERT WORM MOTH

FILBERT WORM MOTH

TACHINID FLY

SAP BEETLE

SHORT-SNOUTED WEEVIL



HOW LONG an acorn survives invasion depends on its size and the sequence of insects involved. One acorn weevil larva or filbert worm can completely consume a small scrub oak acorn, for instance, but often will eat only part of a large acorn from a red oak.

The acorn moth, found in the eastern U. S., often lays eggs in nuts damaged by these two insects. After a caterpillar hatches, it creates a web across the opening in the shell, which keeps competitors out. It may then finish the contents, leaving a home neatly emptied of everything but frass—insect droppings (bottom left).

Wintering in the shell, some caterpillars emerge in the spring and find a sprouting acorn to continue feeding on. These insects do little permanent damage, since they confine meals to the meat near the cap. As long as the plant embryo at the pointed tip remains undisturbed, the acorn can produce a seedling.

While it lives, the acorn offers inhabitants a comfortable refuge. It protects them from most predators, shelters them from weather, and keeps them moist, cool, and away from sunlight. It also provides a diet rich in fats and carbohydrates.

Once dead, acorns contain plenty of pickings for scavengers. Lifting the cap off one rotting nut, I find the cocoon of a parasitic wasp alongside several snails (top left). The size of pinheads, the snails are browsing in pits that may have been chewed out by an acorn moth caterpillar while the nut was still alive. A close look at one snail in another acorn reveals an even more minute resident: a beetle mite (top center) with a bivalve shell that allows it to close up like a clam for protection. Soft, decaying acorn meat,

now interlaced with fungus, feeds snails and mites.

With their variety of scavengers, decaying acorns make ideal hunting grounds for carnivores. A fierce predator, this centipede (below) roams through one acorn after another in search of prey. Waiting on its web, a fungus gnat larva (right) will feast on the unwary insects that the poisonous strands kill on contact.

IN THE PALM of my hand I hold part of a tiny ant colony: three *Myrmica* workers tending a brood (left). Gently, so as not to disturb the inhabitants, I have broken this fragment from a hollow acorn filled with about 50 adults and their young. This species of ant often expands the colony into nearby nutshells when space gets tight. Although they may live in different quarters, colony members recognize one another by scent.

In another shell I find a society of slave workers, *Leptothorax*, attending to slave-making *Harpagoxenus* ants. A red slave grooms the large, black, slave-making queen, while others in the background groom and carry larvae (bottom center).

A slave-making worker's sole duty is to raid nests of slave species. Releasing a pheromone that confuses adult ants in the colony under attack, slave makers seize young and take them back to their own nest. When they mature, captured ants imprint on the slave makers and treat them as kin that need to be cared for. Receiving no benefits, the slaves gather food, tend the queen, nurse slave makers' young, and tidy up. As slaves die and food gets low, slave makers raid more often.

Hollow acorns may house other animals, large and small. A slug occupies almost the entire chamber of one nut I slice open (bottom far left). I find no major entryway in the shell—yet the slug must have squeezed in somehow. Able to stretch its body 11 times normal length and become correspondingly thinner, a slug can get through incredibly tight spaces.

At the other extreme, a minute fungus beetle (left) about the size of the period at the end of this sentence feeds on a fungus bed between the layers of an acorn shell.

POISED on a scrub oak branch, a white-footed mouse plucks an acorn from its cap. Most probably the nut will wind up as a winter meal. But it just may be that one, among many thousands, destined to sprout and carry on the species.

In the pygmy pine barrens of Long Island, mice subsist mostly on insects during the warmer months. In an autumn scramble, they bury small caches of one to three acorns, called scatter hoards, in preparation for the approaching cold weather.

Never satisfied, they move the hoards around each night. The mice rely on smell to locate the acorns underground—seemingly unaware of where they last dug—and thus constantly steal from one another. When Bob Unnasch buried a thousand marked acorns, mice had moved every one by the next morning.

More than 80 North American birds and mammals—from wild turkeys, bobwhites, and wood ducks to bears, deer, and gray foxes—include fresh acorns in their diet. Some collect right from trees. Others must wait until the nuts fall to the ground.

In addition to mice, a number of animals bury what they harvest. Magpies and jays create small hoards by poking acorns into the soil. Gray squirrels bury individual acorns as well as groups of hundreds, called larder hoards. Animals eat most of what they store, drawing their sustenance from the energy-packed part of the nut meant to nourish a new plant.

But hoarders sometimes lose track of the acorns they bury, leaving a few underground. Though termites or fungi may strike, the soil protects the nuts from foraging insects and larger animals above. Kept damp and cool, these acorns have a much better chance to take root and grow than those that remain exposed on the ground.

On a seedling that I dug up in Massachusetts (left), the remnant of a buried acorn hangs from the stem by a filament—evidence that some animal unwittingly helped nature renew a stand of sturdy oaks. □

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FROM THE PRESIDENT

Back in the U.S.S.R.

THE NATIONAL GEOGRAPHIC SOCIETY

TAKING ADVANTAGE of an opportunity to visit the closed city of Norilsk —once a dreaded gulag and now a major mining center —News Service Director Steve Raymer, Senior Writer Mike Edwards, and interpreter Barbara Skinner stopped by a local museum.

"Welcome," said museum director Lila Pecherskaya. "And congratulations on your hundredth anniversary!"

Word of the Society's centennial, it seems, had reached this city north of the Arctic Circle through a special program on Soviet television. The show was prompted by the opening in Moscow of the "Odyssey" exhibition of National Geographic photographs.

That exhibit, and the media coverage that accompanied it, created a ground swell of interest among the Soviet people in what we do. More than 100,000 came to see "Odyssey" during its four-week run in Moscow, exceeding attendance figures in Washington, New York, or San Diego.

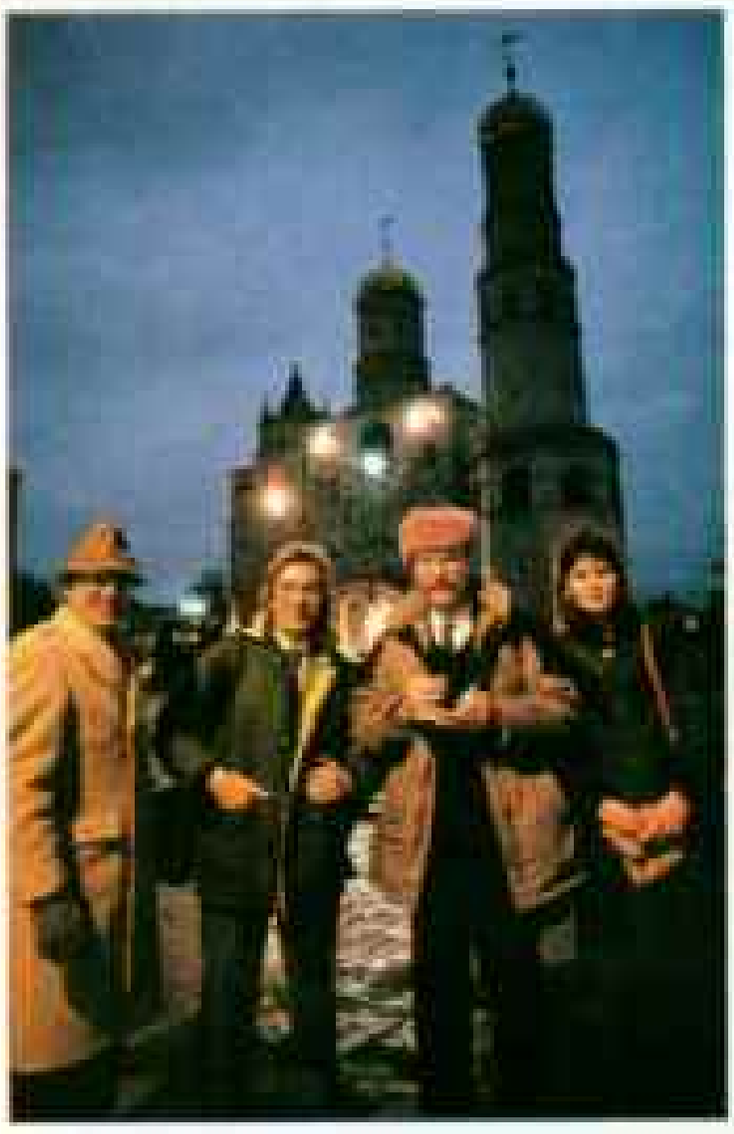
Our fascination with the Soviets is just as strong. Since last fall the Society has had nearly a score of writers, photographers, filmmakers, and other members of the staff in the U.S.S.R., working on a comprehensive book, *The Soviet Union Today;* a 30-minute video, "Discover Russia"; and articles about the Kremlin and Siberia, among other projects. A piece on Leningrad is planned for the July/August issue of TRAVELER, and two films by Irina Mishina, a Russian director living in Great Britain, were recently produced for our EXPLORER series on SuperStation TBS.

All this activity, of course, reflects a willingness by Soviet authorities to give us greater access to their society. An impressive example of what is now possible is a ten-year agreement we have just completed with the world renowned State Hermitage Museum in Leningrad to organize traveling exhibitions. The Hermitage, a complex of buildings dominated by the former Winter Palace of the tsars, preserves everything from European art to Russian archaeological treasures. Working with museum directors Boris Piotrovksy and V. A. Suslov, the Society has been given access to some three million items for an extraordinary series of traveling exhibits in the U. S.

Another illustration of Soviet cooperation is a remarkable deep-sea voyage we are about to embark on with the P. P. Shirshov Institute of Oceanology. Staff photographer Emory Kristof will join Soviet scientists this month in one of two new submersibles, *Mir I* or *Mir II*, to explore thermal vents in the Mid-Atlantic Ridge. If all goes well, a Geographic team will accompany the Soviets next year on a dive in Lake Baykal, the world's deepest freshwater lake.

Covering the U.S.S.R. as a foreign journalist can still be extraordinarily difficult. The Soviets' desire to be helpful doesn't always triumph over old habits of bureaucratic control.

But there is no disputing the fact that we are seeing an exciting moment in that nation's history, and we look forward to new opportunities for mutual understanding.



ASSOCIATE ART DIRECTOR J. ROBERT TERINGO, PHOTOGRAPHER CARY WOLINSKY, AUTHOR JON THOMPSON, AND AN INTERPRETER (TOP) STAND INSIDE THE KREMLIN DURING COVERAGE OF THAT CITADEL. ON A MOSCOW STREET, DIRECTOR WILLIAM LIVINGSTON SHOOTS FOOTAGE FOR THE VIDEO, "DISCOVER RUSSIA." PHOTOGRAPHS BY DEAN CONGER, NATIONAL GEOGRAPHIC STAFF (TOP), AND JEANNE BRYAN RAWLINGS

Gilbert M. Grosvenor

JUNE 1989

GEOGRAPHICA

NATIONAL GEOGRAPHIC MAGAZINE

Careful Study Reverses "Proof" of Peary Fraud

Did Robert E. Peary lie about having reached the North Pole in 1909? While his claim has often been disputed, and a recent study by explorer Wally Herbert (NATIONAL GEOGRAPHIC, September 1988) concluded that Peary's party may have been 30 to 60 miles off course, last fall "proof" was presented that Peary had actually faked his claim.

SIDNEE BRUMBERG

Astronomer Dennis Rawlins of Baltimore, Maryland, made national headlines when he released his interpretation of a copy of an undated work sheet, whose original was in the National Archives. Rawlins said the original came from an envelope identified by Peary's wife, Jo, as containing observations made at the North Pole on April 5 and 6, 1909.

One set of figures, said Rawlins, were observations of the sun that showed it was rising early in the morning of April 7, proof that the Peary party was 121 miles from the Pole. Rawlins said another set of numbers were calculations to check compass variation near the Pole, and he established Peary's position to be far to the right of the track the explorer said he followed. Finally, Rawlins charged that Peary had written the name of a star, Betelgeuse, on the sheet to disguise its true purpose. Rawlins told one journalist that the work sheet exposed Peary's claim as "one of the greatest scientific frauds of this century."

But the Navigation Foundation, a 500-member nonprofit organization commissioned by the National Geographic Society to "conduct the most careful objective study possible" of the Peary controversy, reported at a February news conference that Rawlins was wholly mistaken. Instead of solar observations made in April 1909, the work sheet represents observations of Betelgeuse and another star, probably made in February 1906 during an earlier attempt by Peary to reach the Pole. What Rawlins took to be angles of a rising sun were actually "time sights," using Betelgeuse to determine the exact time and thus allowing Peary to check the accuracy of the expedition's three watch-type chronometers. By displaying Peary's chronometers, Adm. Thomas D. Davies, the foundation's president, pointed out a glaring error by Rawlins: What he thought were figures for compass readings were, in fact, the serial numbers of the chronometers. Other time sights by Peary using the same technique and the same chronometers leave no doubt as to the foundation's interpretation.

Admiral Davies said that a letter written by Peary's daughter, Marie, concluded that her mother had put the wrong work sheet into the polar observations envelope.

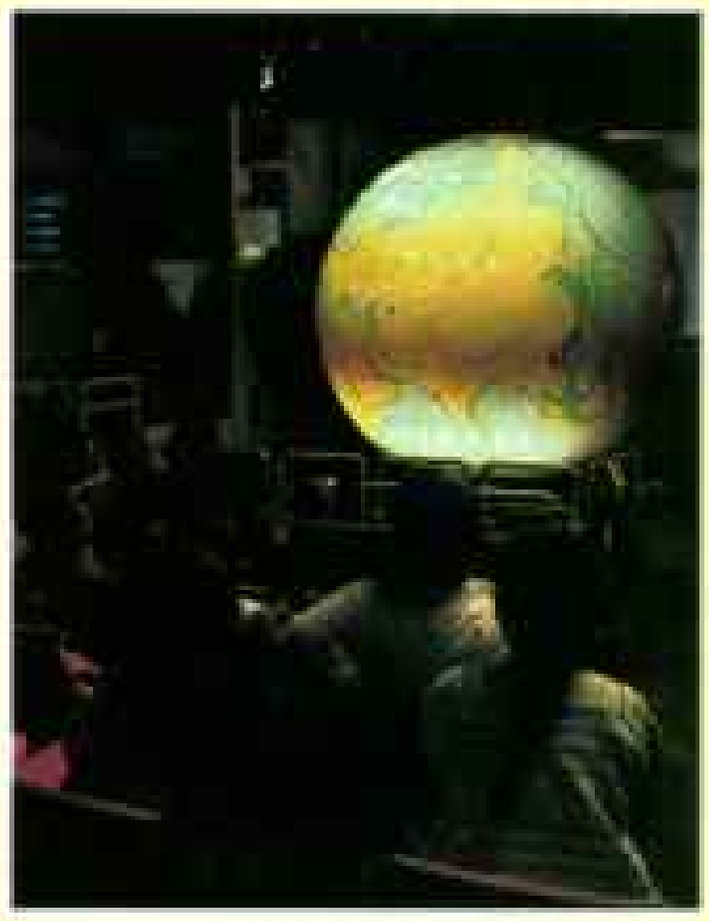
Davies said his group's report "does not reflect any conclusion regarding the ultimate question whether Peary reached the Pole." But he also noted that the work sheet "provides no evidence Peary faked his claim." Society President Gilbert M. Grosvenor said: "Suggesting that Peary might not have reached the Pole is one thing. Declaring Peary a fraud is quite another."

According to the *Boston Globe* the report "blew out of the water" Rawlins's charge.

New Globe Reflects 25 Years of Change

As the world turns, it changes. Change is particularly evident on the huge globe (below) recently installed in the headquarters of the National Geographic Society in Washington, D. C. The globe, produced by the Society's Cartographic Division, replaces a political representation of the world that had been the centerpiece of Explorers Hall since it opened in 1964. The new version emphasizes the planet's physiography on land and underwater, depicting deserts, mountain ranges, and forests as well as ocean-bottom ridges and rifts.

But it also contains the names of the countries, capitals, and major cities of the world, and it is here that differences are especially notable. Some are due to political change: British Honduras has become Belize, and what had been East Pakistan is now Bangladesh. Some changes result from nations choosing new names: the Republic of the Congo has become Zaire, Ceylon is now Sri Lanka, Cambodia is Kampuchea, and Upper Volta is Burkina Faso. Other changes involve spelling modifications: Surinam has become Suriname, and under the Pinyin system of transliterating Chinese into the Latin alphabet, Peking is now Beijing.



NGS PHOTOGRAPHER JOSEPH H. BAILEY

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Alvin's Friends Mark 25 Years of Deep Dives

They're singing a watery chorus of "Happy Birthday" this month: *Alvin*, the world's best known manned submersible, is 25 years old.

Alvin, which carries a crew of three and can dive to 13,124 feet, was built with U. S. Navy funds and is operated by Woods Hole Oceanographic Institution. Named for Allyn Vine, a Woods Hole scientist and early advocate of manned underwater research, *Alvin* was christened on June 5, 1964. Since then *Alvin* has undergone numerous modifications and made more than 2,200 dives.

In 1966 it first gained renown by finding a hydrogen bomb on the Mediterranean seafloor after two U. S. Air Force planes collided over the coast of Spain.

Alvin became familiar to a generation of GEOGRAPHIC readers through its participation in a series of major oceanographic expeditions. These included Project FAMOUS, a joint French-American study of the Mid-Atlantic Ridge; a Galápagos Rift survey that discovered strange new life in lightless depths; and a probe of the East Pacific Rise that revealed hot-water vents, or "black smokers." Perhaps *Alvin*'s most famous dives, however, were to the *Titanic* (GEOGRAPHIC, December 1986), providing closeup photographs of the hulk of the luxury liner.

Tracking the Trail of Early Equestrians

Scientists are working to pin down a crucial moment in human history: the time when human beings began to use horses as something other than a source of meat.

David Anthony of Hartwick College in Oneonta, New York, believes the first horseback riders were people of the Sredni Stog culture, who lived east of the Dnieper River, in what is now the Soviet Union, between 4200 and 3500 B.C. Archaeologists have discovered scraps of bone and horn that might have been the cheek pieces of bridles. Using a scanning electron microscope to examine the teeth of horses found at Sredni Stog sites, Anthony is looking for signs of wear from metal or rope bits. "When horses are ridden, all things are possible," he says. Once the Sredni Stog began to ride, they could roam great distances, herd sheep more easily, and wage war more effectively.

Chinese Ice Festival Rises in Wyoming

Peggy Truman of Worland, Wyoming, saw a photograph of the Ice Lantern Festival in Harbin, China, in the March 1988 GEOGRAPHIC and decided to duplicate it. Last winter, with the help of the Chinese Embassy in Washington, D. C., she staged the first Worland Harbin Ice Lantern Festival.

Mrs. Truman (below, at center), who operates a preschool, said she realized that winter in Worland—population about 7,000—was nearly as cold as in Harbin and that an ice festival would provide Worland children a perspective on the outside world. Liu Haiming, the embassy's first secretary of culture, made the contacts in China and arranged for three Harbin ice sculptors—Jiang Yuku, Zhang Shuguo, and Yang Shi Chang—to come to Wyoming. The town raised $4,100 for airfares, and Mrs. Truman's husband, John, cut 60 tons of ice out of a local pond for the sculptures.

During their four weeks in Worland the sculptors visited schools and demonstrated their skills. Most of their sculptures were similar to those they create in Harbin. But in honor of their trip to Wyoming they also carved a 20-foot rendition of a cowboy atop a bucking bronco.

JAMES RICHARDSON

Dorcas Gazelle **Genus:** *Gazella* **Species:** *dorcas* **Adult size:** Length of head and body, 0.9-1.1m; tail, 15-20cm; shoulder height, 55-65cm **Adult weight:** 15-23kg
Habitat: Savannah, semidesert and desert ranging from North Africa to central India
Surviving number: Unknown Photographed by Alain Dragesco

Wildlife as Canon sees it

A lone dorcas gazelle stands alert amidst the vast dunes of North Africa. Once abundant and widespread, this slender and graceful creature now survives only in scattered populations and has become extinct in many parts of its range. The dorcas gazelle is well adapted to its arid habitat, being able to tolerate high temperatures and subsist on little water. It has been unable, however, to find safe refuge from man, even in the midst of its desolate environment. Like other endangered desert antelopes in Africa, such as the addax and the scimitar-horned oryx, the dorcas gazelle is today a rare sight.

To save endangered species, it is vital to protect their habitats. Understanding the fragile balance of our world's ecosystem holds the promise for the future. Photography, both as a scientific research tool and as a means of recording the world around us, can help promote a greater awareness and understanding of the dorcas gazelle and how it lives within its natural environment.

And understanding is perhaps the single most important factor in saving the dorcas gazelle and all of wildlife.

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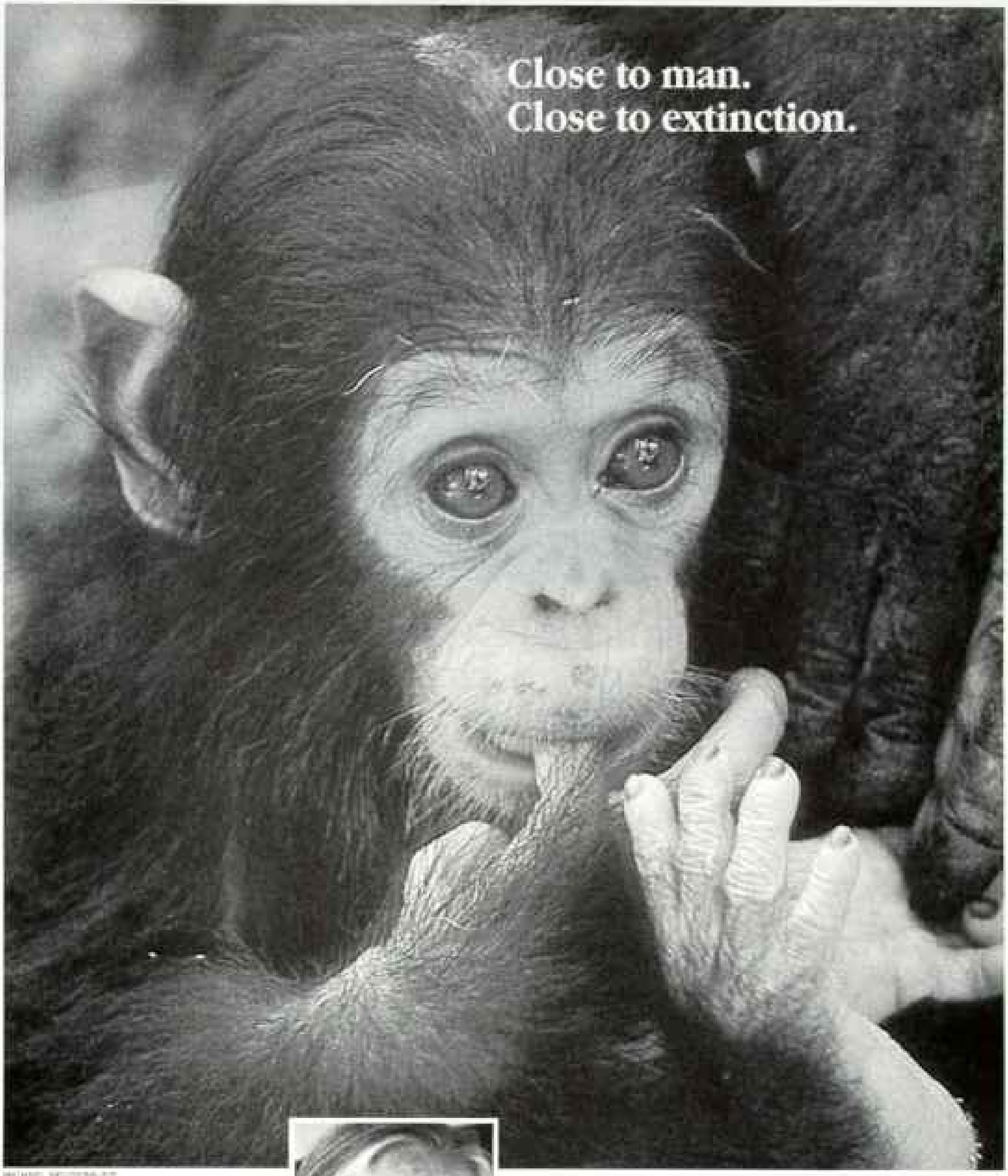

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Members Forum

Skyscrapers

How right to begin an article on skyscrapers (February 1989) by quoting Louis Sullivan that a skyscraper must be "every inch a proud and soaring thing." It is precisely the embodiment of pride, not the mere fact of height, that defines this building type. William Ellis captured its essence by focusing on individuals. The skyscraper is surely America's greatest contribution to architecture.

THOMAS MELLINS
New York, New York

Mr. Mellins co-authored New York 1930: Architecture and Urbanism Between the Two World Wars *(Rizzoli, 1987) and "Pride of Place: Building the American Dream," a PBS documentary.*

Whatever sense they may have made in the past, skyscrapers make none today, except as expressions of corporate or personal ego. In this computer age, business can get done without loading thousands of people atop one another on small lots in Manhattan. Bravo, San Francisco. Take a hike, Donald Trump.

RICHARD HEALEY
Huntington Beach, California

I found your article a colossal bore and a blatant example of American chauvinism. One could draw the conclusion that the only buildings of note are in the United States.

GEORGE M. GRILLS
Toronto, Ontario

Well-done and informative, but the posing of these talented architects was equivalent to a broadside for a sideshow. The *Fountainhead* image of the architect as an omnipotent, arrogant prima donna is unfortunate.

ROGER A. WEAVER
Mars, Pennsylvania

The GEOGRAPHIC can be relied upon to set a wonderful table for us photographers, but the February issue was a feast indeed, especially the work of Nathan Benn in "Skyscrapers." I would like to know more about this talented photographer. Or is this Irving Penn having a little fun with us?

DAVID CARL MILWARD
San Diego, California

Throughout American and Canadian cities we often find that the most admired and revered


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buildings are churches. I would suggest that humility, and not ego, is involved in these truly great buildings.

WALTER PEACE
McMaster University
Hamilton, Ontario

Hancock Center

Among all those carefully chosen photographs of busy activity and comfortable domesticity, there was one incongruously disturbing image—the girl Carrie displaying a drawing of her family's home as a box, indistinguishable from all the other boxes around it, enclosed in a green grid. The image remains disturbing, an emblem of the human attempt to color in one bare corner of identity in an infinite, undifferentiated expanse of featureless confines and cubicles.

TIMOTHY KREIDER
Baltimore, Maryland

William Henry Jackson

Your article about the life and works of my grandfather William Henry Jackson brought back warm memories of this great and gentle man who recorded and preserved an important part of this country's history. Many thanks from all our family.

BARBARA J. GRIFFITH
San Francisco, California

The Kodak Bantam that Jackson is holding (page 251) is not a 35-mm camera but one that took 828 "bantam" film. The negative size was 28-mm x 40-mm instead of the standard 24 x 36 of 35-mm film.

DUANE C. SCOTT
Overland Park, Kansas

The 828 film used by the f/4.5 Kodak Bantam was actually 35-mm size without the sprocket holes, a source of misunderstanding.

The writer of a letter in the April 1906 GEOGRAPHIC, having seen glaciers on Fremont Peak in 1904-05, wished to name them after Theodore Roosevelt. I was sure Jackson had some earlier involvement with this peak, as his photo of it appears in your February 1989 On Assignment page. Sure enough, the October 1906 issue carried a letter from Jackson himself noting that he had "made a series of negatives showing the entire extent of the glacial field" in 1878. That early version of Members Forum I found to be just as interesting as the current forum.

JOHN SOMMER
Ossining, New York

Yellowstone Fires

David Jeffery's article went a long way toward placing the Yellowstone fires of 1988 in perspective. Early reports had as many as 1.1 million

acres within the park consumed by flames; subsequent surveys have shown that only about 440,000 acres—about 20 percent of the park area—were affected by fire, and less than one percent of those acres were subjected to ground fires hot enough to damage the soil. The Park Service's natural-burn policy, developed over a period of years by land managers and scientists, deserves as careful and balanced a retrospective as Jeffery gave the occurrence of the fires.

DAVID W. KNOTTS
Boise, Idaho

By what logic is a natural fire beneficial and a man-caused fire disastrous? How can natural-is-best advocates shrug off thousands of acres of burn as a rejuvenation and come unglued at a 20-acre harvest on commercial timberland?

If the area is to be managed to serve the people who own it (the public), discrete development of roads, transient housing, and maintenance facilities are necessary, as are insect control, wildfire control, wildlife management, controlled burns, and removal of excess dead vegetation. "Let it burn" is a management policy but a myopic one. There is, in fact, no "unmanaged" land in the United States, only land on which the management policy is to exclude application of modern tools and knowledge.

RICHARD K. KELLY
Redding, California

What other country would have watched billions of feet of good lumber go up in smoke? Why shouldn't the Park System through good forestry cut mature timber and help reduce its budget?

D. KILTON ANDREW, SR.
Falmouth, Maine

Timber-harvesting programs are regarded as incompatible with the natural-preserve philosophy of our National Park System.

On the west side of the Bighorns, about 150 miles from the Yellowstone fires, half of a big flat-topped mountain named Copeman's (or Coppman's) Tomb burned around 1900. The burned portion was still bare as a bone 75 years later, until a replanting project was started. That is my worst fear for Yellowstone Park.

PATRICIA R. BRUNE
Ridgecrest, California

Small Towns

Having come out of Lapel, Indiana, where we had to throw a bone in the road to get the Greyhound to stop, I was intrigued by "Small Town America." I love to read about small-town life. I enjoy the hometown newspaper; it's a great place to visit, but I wouldn't want to live there.

DELBERT BIXLER
Sarasota, Florida

You clearly showed that we (in small out-of-the-way communities) are not so much an endangered species as a changing species. Like an onion cooking alongside other vegetables, we are losing some of our distinct, localistic flavor, while taking on that of our fellow Americans with whom we share the pot.

NEAL NETT
Malone, Wisconsin

None of the businesses shown in your photo of the intersection in Rolla (page 187) are still there, and at one time within the last two to three years probably 30 to 40 percent of the buildings on Pine Street were vacant. Fortunately there seems to be some reversal of this situation, but service operations have replaced retailers. Small towns are going through an evolutionary process, just as our large metropolitan communities are.

DOUGLAS SMITH
Leawood, Kansas

The message was that of a rural and simple, if not backward, existence. The wonders of the Missouri country lands are understated. It takes patience and depth to realize the majesty in rural wonders: the curious sight of a knee-high cocklebur bush; walking pastures and woods to find the best cedar tree to fill a home with the smell of nature's Christmas; sauntering along a railroad track forgotten by time; the irritating sting of smartweed; a meandering creek as enticing as any French country scene; access to the sun and the stars with your feet solidly planted on the midwestern ground. If sophistication is lacking, it has been sacrificed for these rewards.

JACI L. MORGAN
Kansas City, Missouri

Nature Conservancy

In the December 1988 issue you refer to ANCON as "its [the Nature Conservancy's] local creation" (page 844). In fact ANCON is a private, nonprofit, and independent Panamanian conservation organization created in 1985 by local community leaders to initiate and support programs for the protection of our extraordinary natural heritage. Several international organizations including the Nature Conservancy have provided valuable support.

JUAN CARLOS NAVARRO Q.
Executive Director, ANCON
Panama, Panama

Letters should be addressed to **Members Forum,** *National Geographic Magazine, Box 37448, Washington, D. C. 20013, and should include sender's address and telephone number. Not all letters can be used. Those that are will often be edited and excerpted.*

How one air conditioner handled the heat in the toughest challenge of all

by
General Chuck Yeager, USAF Ret.
Test Pilot

General Yeager is our nation's most respected test pilot.

The folks at Bryant say they've got a pretty fine air conditioner in their new Reliant. But I don't believe we should take their word for it.

Sure, they built it from top-quality materials, constructed the compressor valves out of hardened steel, the exterior valves from brass, the cabinet from galvanized steel. Then they checked it out and rechecked it out in one of the most sophisticated air conditioner research facilities on the planet.

Mother Nature's Lab

Next, they torture-tested the Reliant, set it out on the beach and just left it there. That may seem strange but, you see, they figured if it could stand all that salt air, it could stand the conditions in your backyard.

One More Test

But no matter how much they did in the lab, Bryant's engineers couldn't be really certain the Reliant air conditioner would do the job till it faced a real live challenge.

It had to pass the toughest challenge of all: the Yeager test.

Nothing too fancy, just me, a comfortable recliner and a scorching hot day. See, I don't much care how it did in the lab if it can't take the sweat off my brow.

Let me tell you, I've tested jets for the Air Force for quite some time and I know high technology and good engineering when I see it. And I'm gratified to report that all of the quality of the Reliant air conditioner shows in its operation.

The Reliant undergoing the grueling Yeager test.

Thumbs Up

It's quiet (purrs like a kitten), efficient, dependable and built to last. That means it'll get you cool and keep you cool. Where it really counts, the Reliant proves it has the right stuff.

Introducing our newest air conditioner, the 1989 Bryant Reliant.

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EVERYBODY LOVES a dinosaur. Maybe that's because they're no longer here to bother us. According to Assistant Editor Rick Gore's article on extinctions, we can be glad they're not for another reason. If they were, we wouldn't be.

The 800-million-year fossil record shows five extinctions of extraordinary magnitude that we can only study, learn from, and marvel at. A sixth, Rick tells us, is happening right now, differs dramatically from the first five, and should concern all of us because we can do something about it—and should. Humans for the first time are the cause and the ultimate victims. It's said that before humans appeared, extinctions of flora and fauna ran about one species a year. Now it is estimated that four species go belly-up per hour, indicating a total of a million by the year 2015.

In Kenya Iain Douglas-Hamilton and his wife, Oria, are concerned and risk their lives to do something. They're trying to save the African elephant but aren't too optimistic. If ivory poachers maintain their rate of slaughter, all free-ranging herds could be gone by 2020.

Iain sent me an article from an American fashion magazine featuring a model wearing a pound or two of ivory bracelets. Cost—according to the caption: $1,710. Not listed as part of the cost—the slaughter of elephants and, indirectly, the lives of African rangers who tried to protect them.

We have survived the loss of the dodo bird, and we can live—though not so well—without the blue whale, the giant panda, and the elephant. And women can learn to live without ivory bracelets. But some of us may not live without some of the still unknown plant species of the tropical forest. More species live there than in all the rest of the world combined, and many thousands of those have not yet been assessed by science. But population pressure and profitable logging reduce this pharmacopoeia by a hundred acres a minute. At the present rate of destruction, we can expect to lose at least one-fourth of the extant species within the next few decades, almost certainly including life-sustaining drugs. Reading about massive extinctions should help us appreciate how great the world is the way it is. And maybe more of us will do our bit to keep it the way it is.

Wilbur E. Garrett

EDITOR

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On Assignment

THE MEDIUM was the message when Assistant Art Director ALLEN CARROLL (above, at left) visited Pixar, a computer-graphics firm in San Rafael, California, to see the cutting edge of a new technology. A specialist in translating scientific concepts into comprehensible images, Allen felt at home with Ralph Guggenheim, right, Eben Ostby, center, and William Reeves, who created an animated sequence of a shattering crystal globe (pages 732-3). A leading producer of computer-graphics hardware and software, Pixar is reinventing the art of animation. "The team looked at broken glass to get the shattering right," says Carroll, "details that really made a difference." Art director for our *Historical Atlas of the United States*, Carroll is now associate director for design in the Cartographic Division.

The images generated by computer number crunching can be astoundingly realistic, as author-photographer FRED WARD (below, at left) learned at a General Dynamics flight simulator in Fort Worth, Texas. With manager Jack Drewett in the stationary cockpit, he found the experience of flying through an illusory landscape beamed by six projectors onto an overhead dome to be "absolutely mind-blowing."

For Ward, a computer enthusiast, this assignment was like a busman's holiday. In his office in his Bethesda, Maryland, home he keeps four of his seven computers on a large oval table, with two printers in the center. With his chair on casters, he wheels from screen to screen. "I'll be creating graphics on my Macintosh II," he says, "while I'm writing text on the IBM."

As broad in his scope of interests as he is in his talents, Ward now has 15 GEOGRAPHIC articles to his credit—nine of which he wrote as well as photographed. If he could claim a specialty, it might be gemstones and precious metals, which have been the subject of four of his previous assignments.

GEORGE OLSEN (TOP); MARK JONES

NATIONAL GEOGRAPHIC (ISSN 0027-9358) IS PUBLISHED MONTHLY BY THE NATIONAL GEOGRAPHIC SOCIETY, 17TH AND M STS. N.W., WASHINGTON, D. C. 20036. $18.00 A YEAR, $2.25 A COPY. SECOND-CLASS POSTAGE PAID AT WASHINGTON, D. C., AND ELSEWHERE. POSTMASTER: SEND ADDRESS CHANGES TO NATIONAL GEOGRAPHIC, P. O. BOX 2174, WASHINGTON, D. C. 20013.

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