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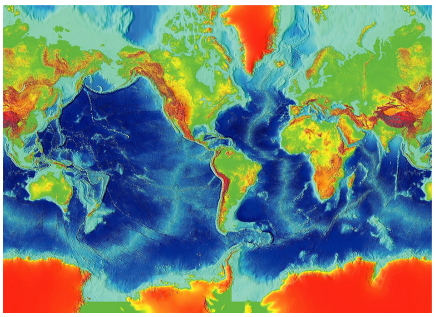
Geomorphology

Geomorphology (from Greek: γῆ, *ge*, "earth"; μορφή, *morfé*, "form"; and λόγος, *logos*, "study") is the scientific study of landforms and the processes that shape them. Geomorphologists seek to understand why landscapes look the way they do, to understand landform history and dynamics, and to predict future changes through a combination of field observation, physical experiment, and numerical modeling. Geomorphology is practiced within geography, geology, geodesy, engineering geology, archaeology, and geotechnical engineering, and this broad base of interest contributes to a wide variety of research styles and interests within the field.



Surface of the Earth

The form of the Earth's surface evolves in response to a combination of natural and anthropogenic processes, and responds to the balance between processes that add material and those that remove it. Such processes may act across very many lengthscales and timescales. On the broadest scales, the landscape is built up through tectonic uplift and volcanism. Denudation occurs by erosion and mass wasting, which produces sediment that is transported and deposited elsewhere within the landscape or off the coast.[1] On progressively smaller scales, similar ideas apply, where individual landforms evolve in response to the balance of additive (tectonic or sedimentary) and subtractive (erosive) processes. Modern geomorphology can be thought of as the study of the divergence of fluxes of material on a planetary surface, and as such is closely allied with sedimentology, which can equally be seen as the convergence of that flux.

Geomorphic processes are influenced by tectonics, climate, ecology, and human activity, and equally, many of these drivers can be affected by the ongoing evolution of the Earth's surface, for example, via isostasy or orographic precipitation. Many geomorphologists are particularly interested in the potential for feedbacks between climate and tectonics mediated by geomorphic processes.[2]

Practical applications of geomorphology include hazard assessment (such as landslide prediction and mitigation), river control and restoration, and coastal protection.

History

With some notable exceptions (see below), geomorphology is a relatively young science, growing along with interest in other aspects of the Earth Sciences in the mid 19th century. This section provides a very brief outline of some of the major figures and events in its development.

Ancient geomorphology

Perhaps the earliest one to devise a theory of geomorphology was the polymath Chinese scientist and statesman Shen Kuo (1031-1095 AD). This was based on his observation of marine fossil shells in a geological stratum of a mountain hundreds of miles from the Pacific Ocean. Noticing bivalve shells running in a horizontal span along the cut section of a cliffside, he theorized that the cliff was once the pre-historic location of a seashore that had shifted hundreds of miles over the centuries. He inferred that the land was reshaped and formed by soil erosion of the mountains and by deposition of silt, after observing strange natural erosions of the Taihang Mountains and the Yandang Mountain near Wenzhou. Furthermore, he promoted the theory of gradual climate change over centuries of time once ancient petrified bamboos were found to be preserved underground in the dry, northern climate zone of *Yanzhou*, which is now modern day Yan'an, Shaanxi province.

Early modern geomorphology

The first use of the word geomorphology was likely to be in the German language when it appeared in Laumann's 1858 work. Keith Tinkler has suggested that the word came into general use in English, German and French after John Wesley Powell and W. J. McGee used it in the International Geological Conference of 1891.[3]

An early popular geomorphic model was the *geographical cycle* or the *cycle of erosion*, developed by William Morris Davis between 1884 and 1899. The cycle was inspired by theories of uniformitarianism first formulated by James Hutton (1726–1797). Concerning valley forms, uniformitarianism depicted the cycle as a sequence in which a river cuts a valley more and more deeply, but then erosion of side valleys eventually flatten the terrain again, to a lower elevation. Tectonic uplift could start the cycle over. Many studies in geomorphology in the decades following Davis' development of his theories sought to fit their ideas into this framework for broad scale landscape evolution, and are often today termed "Davisian". Davis' ideas have largely been superseded today, mainly due to their lack of predictive power and qualitative nature, but he remains an extremely important figure in the history of the subject.

In the 1920s, Walther Penck developed an alternative model to Davis', believing that landform evolution was better described as a balance between ongoing processes of uplift and denudation, rather than Davis' single uplift followed by decay. However, due to his relatively young death, disputes with Davis and a lack of English translation of his work his ideas were not widely recognised for many years.

These authors were both attempting to place the study of the evolution of the Earth's surface on a more generalized, globally relevant footing than had existed before. In the earlier parts of the 19th century, authors - especially in Europe - had tended to attribute the form of landscape to local climate, and in particular to the specific effects of glaciation and periglacial processes. In contrast, both Davis and Penck were seeking to emphasize the importance of evolution of landscapes through time and the generality of Earth surface processes across different landscapes under different conditions.

Quantitative geomorphology

While Penck and Davis and their followers were writing and studying primarily in Western Europe, another, largely separate, school of geomorphology was developed in the United States in the middle years of the 20th century. Following the early trailblazing work of Grove Karl Gilbert around the turn of the 20th century, a group of natural scientists, geologists and hydraulic engineers including Ralph Alger Bagnold, John Hack, Luna Leopold, Thomas Maddock and Arthur Strahler began to research the form of landscape elements such as rivers and hillslopes by taking systematic, direct, quantitative measurements of aspects of them and investigating the scaling of these measurements. These methods began to allow prediction of the past and future behavior of landscapes from present observations, and were later to develop into what the modern trend of a highly quantitative approach to geomorphic problems. Quantitative geomorphology can involve fluid dynamics and solid mechanics, geomorphometry, laboratory studies, field measurements, theoretical work, and full landscape evolution modeling. These approaches are used to understand weathering and the formation of soils, sediment transport, landscape change, and the interactions between climate, tectonics, erosion, and deposition.

Contemporary geomorphology

Today, the field of geomorphology encompasses a very wide range of different approaches and interests. Modern researchers aim to draw out quantitative "laws" that govern Earth surface processes, but equally, recognize the uniqueness of each landscape and environment in which these processes operate. Particularly important realizations in contemporary geomorphology include:

1) that not all landscapes can be considered as either "stable" or "perturbed", where this perturbed state is a temporary displacement away from some ideal target form. Instead, dynamic changes of the landscape are now seen as an essential part of their nature.[4] [5]

2) that many geomorphic systems are best understood in terms of the stochasticity of the processes occurring in them, that is, the probability distributions of event magnitudes and return times.[6] This in turn has indicated the importance of chaotic determinism to landscapes, and that landscape properties are best considered statistically.[7] The same processes in the same landscapes does not always lead to the same end results.

Processes

Modern geomorphology focuses on the quantitative analysis of interconnected processes. Modern advances in geochronology, in particular cosmogenic radionuclide dating, optically stimulated luminescence dating and low-temperature thermochronology have enabled us for the first time to measure the rates at which geomorphic processes occur.[8] [9] At the same time, the use of more precise physical measurement techniques, including differential GPS, remotely sensed digital terrain models and laser scanning techniques, have allowed quantification and study of these processes as they happen.[10] Computer simulation and modeling may then be used to test our understanding of how these processes work together and through time.

Grand Canyon, Arizona

Geomorphically relevant processes generally fall into (1) the production of regolith by weathering and erosion, the transport of that material, and its eventual deposition. Although there is a general movement of material from uplands to lowlands, erosion, transport, and deposition often occur in closely-spaced tandem all across the landscape.

The nature of the processes investigated by geomorphologists is strongly dependent on the landscape or landform under investigation and the time and length scales of interest. However, the following non-exhaustive list provides a flavor of the landscape elements associated with some of these.

Primary surface processes responsible for most topographic features include wind, waves, chemical dissolution, mass wasting, groundwater movement, surface water flow, glacial action, tectonism, and volcanism. Other more exotic geomorphic processes might include periglacial (freeze-thaw) processes, salt-mediated action, or extraterrestrial impact.

Fluvial processes

Rivers and streams are not only conduits of water, but also of sediment. The water, as it flows over the channel bed, is able to mobilize sediment and transport it downstream, either as bed load, suspended load or dissolved load. The rate of sediment transport depends on the availability of sediment itself and on the river's discharge.[11]

Rivers are also capable of eroding into rock and creating new sediment, both from their own beds and also by coupling to the surrounding hillslopes. In this way, rivers are thought of as setting the base level for large scale landscape evolution in nonglacial environments.[12] [13] Rivers are key links in the connectivity of different landscape elements.

The geomorphology of the large Pantanal wetland in South America is dominated by fluvial processes.

As rivers flow across the landscape, they generally increase in size, merging with other rivers. The network of rivers thus formed is a drainage system and is often dendritic, but may adopt other patterns depending on the regional topography and underlying geology.

Aeolian processes

Aeolian processes pertain to the activity of the winds and more specifically, to the winds' ability to shape the surface of the Earth. Winds may erode, transport, and deposit materials, and are effective agents in regions with sparse vegetation and a large supply of unconsolidated sediments. Although water and mass flow tend to mobilize more material than wind in most environments, aeolian processes are important in arid environments such as deserts.[14]

Wind-eroded alcove near Moab, Utah

Mesquite Flat Dunes in Death Valley looking toward the Cottonwood Mountains from the north west arm of Star Dune (2003)

Hillslope processes

Soil, regolith, and rock move downslope under the force of gravity via creep, slides, flows, topples, and falls. Such mass wasting occurs on both terrestrial and submarine slopes, and has been observed on Earth, Mars, Venus, Titan and Iapetus.

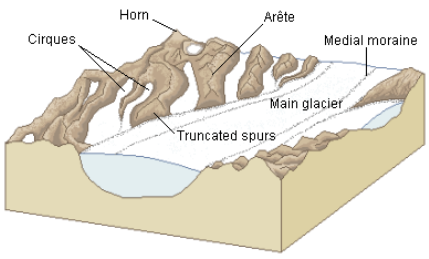
Example of mass wasting at Palo Duro Canyon, Texas

Ongoing hillslope processes can change the topology of the hillslope surface, which in turn can change the rates of those processes. Hillslopes that steepen up to certain critical thresholds are capable of shedding extremely large volumes of material very quickly, making hillslope processes an extremely important element of landscapes in tectonically active areas.[15]

On Earth, biological processes such as burrowing or tree throw may play important roles in setting the rates of some hillslope processes.[16]

Glacial processes

Glaciers, while geographically restricted, are effective agents of landscape change. The gradual movement of ice down a valley causes abrasion and plucking of the underlying rock. Abrasion produces fine sediment, termed glacial flour. The debris transported by the glacier, when the glacier recedes, is termed a moraine. Glacial erosion is responsible for U-shaped valleys, as opposed to the V-shaped valleys of fluvial origin.[17]



Features of a glacial landscape

The way glacial processes interact with other landscape elements, particularly hillslope and fluvial processes, is an important aspect of Plio-Pleistocene landscape evolution and its sedimentary record in many high mountain environments. Environments that have been relatively recently glaciated but are no longer may still show elevated landscape change rates compared to those that have never been glaciated. Nonglacial geomorphic processes which nevertheless have been conditioned by past glaciation are termed paraglacial processes. This concept contrasts with periglacial processes, which are directly driven by formation or melting of ice or frost.[18]

Tectonic processes

Tectonic effects on geomorphology can range from scales of millions of years to minutes or less. The effects of tectonics on landscape are heavily dependent on the nature of the underlying bedrock fabric that more less controls what kind of local morphology tectonics can shape. Earthquakes can, in terms of minutes, submerge large extensions creating new wetlands. Isostatic rebound can account for significant changes over thousand or hundreds of years, and allows erosion of a mountain belt to promote further erosion as mass is removed from the chain and the belt uplifts. Long-term plate tectonic dynamics give rise to orogenic belts, large mountain chains with typical lifetimes of many tens of millions of years, which form focal points for high rates of fluvial and hillslope processes and thus long-term sediment production.

Features of deeper mantle dynamics such as plumes and delamination of the lower lithosphere have also been hypothesised to play important roles in the long term (> million year), large scale (thousands of km) evolution of the Earth's topography. Both can promote surface uplift through isostasy as hotter, less dense, mantle rocks displace cooler, denser, mantle rocks at depth in the Earth.[19] [20]

Igneous processes

Both volcanic (eruptive) and plutonic (intrusive) igneous processes can have important impacts on geomorphology. The action of volcanoes tends to rejuvenize landscapes, covering the old land surface with lava and tephra, releasing pyroclastic material and forcing rivers through new paths. The cones built by eruptions also build substantial new topography, which can be acted upon by other surface processes.

Subsurface movement of magma also plays a role in geomorphology. Migrating melts beneath the surface can cause the inflation and deflation of the land surface, and a partially molten crustal layer beneath Tibet has even been implicated in controlling the geomorphology of the Tibetan plateau across many thousands of kilometres.[21]

Biological processes

The interaction of living organisms with landforms, or biogeomorphologic processes, can be of many different forms, and is probably of profound importance for the terrestrial geomorphic system as a whole. Biology can influence very many geomorphic processes, ranging from biogeochemical processes controlling chemical weathering, to the influence of mechanical processes like burrowing and tree throw on soil development, to even controlling global erosion rates through modulation of climate through carbon dioxide balance. Terrestrial landscapes in which the role of biology in mediating surface processes can be definitively excluded, are extremely rare, but may hold important information for understanding the geomorphology of other planets, such as Mars.[22]

Beaver dams, as this one in Tierra del Fuego, constitute a specific form of zoogeomorphology, a type of biogeomorphology

Scales in geomorphology

Different geomorphological processes dominate at different spatial and temporal scales. Moreover, scales on which processes occur may determine the reactivity or otherwise of landscapes to changes in driving forces such as climate or tectonics.[23] These ideas are key to the study of geomorphology today.

To help categorize landscape scales some geomorphologists might use the following taxonomy:

- 1st - Continent, ocean basin, climatic zone (~10,000,000 km^2)
- 2nd - Shield, e.g. Baltic Shield, or mountain range (~1,000,000 km^2)
- 3rd - Isolated sea, Sahel (~100,000 km^2)
- 4th - Massif, e.g. Massif Central or Group of related landforms, e.g., Weald (~10,000 km^2)
- 5th - River valley, Cotswolds (~1,000 km^2)
- 6th - Individual mountain or volcano, small valleys (~100 km^2)
- 7th - Hillslopes, stream channels, estuary (~10 km^2)
- 8th - gully, barchannel (~1 km^2)
- 9th - Meter-sized features

Overlap with other fields

There is a considerable overlap between geomorphology and other fields. Deposition of material is extremely important in sedimentology. Weathering is the chemical and physical disruption of earth materials in place on exposure to atmospheric or near surface agents, and is typically studied by soil scientists and environmental chemists, but is an essential component of geomorphology because it is what provides the material that can be moved in the first place. Civil and environmental engineers are concerned with erosion and sediment transport,

especially related to canals, slope stability (and natural hazards), water quality, coastal environmental management, transport of contaminants, and stream restoration. Glaciers can cause extensive erosion and deposition in a short period of time, making them extremely important entities in the high latitudes and meaning that they set the conditions in the headwaters of mountain-born streams; glaciology therefore is important in geomorphology.

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External links

- International Association of Geomorphologists (http://www.geomorph.org)
- Geomorphology in the Association of American Geographers (http://aag-gsg.org)
- British Society for Geomorphology (http://www.geomorphology.org.uk)
- Association of Polish Geomorphologists (http://www.sgp.org.pl)
- German Geomorphologists Group (Deutscher Arbeitskreis fuer Geomorphologie (http://www.giub.uni-bonn.de/akgeomorphologie/englishindex.html)
- Model of landscape evolution by William Morris Davis (by GEOMORPHLIST) (http://www.sgp.org.pl/gw/wmd/wmd.html)
- The Geographical Cycle, or the Cycle of Erosion (1899) (http://www.abdn.ac.uk/~geo337/gg4514/davis.htm)
- Geomorphology from Space (http://disc.gsfc.nasa.gov/geomorphology/index.shtml) (by NASA)
- USDA-NRCS Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx) Survey of surficial geologic deposits and geomorphology across the U.S.
- The American Geophysical Union Earth and Planetary Surface Processes focus group (http://www.agu.org/focus_group/epsp/about/)

Aeolian processes

Aeolian (or **Eolian** or **Æolian**) processes pertain to the activity of the winds and more specifically, to the winds' ability to shape the surface of the Earth and other planets. Winds may erode, transport, and deposit materials, and are effective agents in regions with sparse vegetation and a large supply of unconsolidated sediments. Although water is a much more powerful eroding force than wind, aeolian processes are important in arid environments such as deserts.

The term is derived from the name of the Greek god, Æolus, the keeper of the winds.

Wind-carved alcove in the Navajo Sandstone near Moab, Utah.

Wind erosion

Wind erodes the Earth's surface by deflation (the removal of loose, fine-grained particles), by the turbulent eddy action of the wind and by abrasion (the wearing down of surfaces by the grinding action and sandblasting of windborne particles).

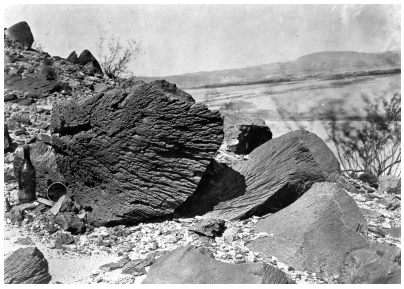
Regions which experience intense and sustained erosion are called deflation zones. Most aeolian deflation zones are composed of desert pavement, a sheet-like surface of rock fragments that remains after wind and water have removed the fine particles. Almost half of Earth's desert surfaces are stony deflation zones. The rock mantle in desert pavements protects the underlying material from deflation.

A dark, shiny stain, called desert varnish or rock varnish, is often found on the surfaces of some desert rocks that have been exposed at the surface for a long period of time. Manganese, iron oxides, hydroxides, and clay minerals form most varnishes and provide the shine.

Deflation basins, called blowouts, are hollows formed by the removal of particles by wind. Blowouts are generally small, but may be up to several kilometers in diameter.

Wind-driven grains abrade landforms. Grinding by particles carried in the wind creates grooves or small depressions. Ventifacts are rocks which have been cut, and sometimes polished, by the abrasive action of wind.

Sculpted landforms, called yardangs, are up to tens of meters high and kilometers long and are forms that have been streamlined by desert winds. The famous Great Sphinx of Giza in Egypt may be a modified yardang.



Rock carved by drifting sand below Fortification Rock in Arizona (Photo by Timothy H. O'Sullivan, USGS, 1871)

A rock sculpted by wind erosion in the Altiplano region of Bolivia

Sand blowing off a crest in the Kelso Dunes of the Mojave Desert, California.

Transport

Particles are transported by winds through suspension, saltation (skipping or bouncing) and creeping (rolling or sliding) along the ground.

Small particles may be held in the atmosphere in suspension. Upward currents of air support the weight of suspended particles and hold them indefinitely in the surrounding air. Typical winds near Earth's surface suspend particles less than 0.2 millimeters in diameter and scatter them aloft as dust or haze.

Saltation is downwind movement of particles in a series of jumps or skips. Saltation normally lifts sand-size particles no more than one centimeter above the ground, and proceeds at one-half to one-third the speed of the wind. A saltating grain may hit other grains that jump up to continue the saltation. The grain may also hit larger grains that are too heavy to hop, but that slowly creep forward as they are pushed by saltating grains. Surface creep accounts for as much as 25 percent of grain movement in a desert.

Aeolian turbidity currents are better known as dust storms. Air over deserts is cooled significantly when rain passes through it. This cooler and denser air sinks toward the desert surface. When it reaches the ground, the air is deflected forward and sweeps up surface debris in its turbulence as a dust storm.

Crops, people, villages, and possibly even climates are affected by dust storms. Some dust storms are intercontinental, a few may circle the globe, and occasionally they may engulf entire planets. When the Mariner 9 spacecraft entered its orbit around Mars in 1971, a dust storm lasting one month covered the entire planet, thus delaying the task of photo-mapping the planet's surface.

Most of the dust carried by dust storms is in the form of silt-size particles. Deposits of this windblown silt are known as loess. The thickest known deposit of loess, 335 meters, is on the Loess Plateau in China. In Europe and in the Americas, accumulations of loess are generally from 20 to 30 meters thick.

Aeolian transport from deserts plays an important role in ecosystems globally, e.g. by transport of minerals from the Sahara to Amazonia.[1] Aeolian processes are affected by human activity, such as the use of 4x4 vehicles on deserts.

Small whirlwinds, called dust devils, are common in arid lands and are thought to be related to very intense local heating of the air that results in instabilities of the air mass. Dust devils may be as much as one kilometer high.

Dust storm approaching Spearman, Texas April 14, 1935.

Dust storm in Amarillo, Texas. FSA photo by Arthur Rothstein (1936)

A massive sand storm cloud is about to envelop a military camp as it rolls over Al Asad, Iraq, just before nightfall on April 27, 2005.

Deposition

Wind-deposited materials hold clues to past as well as to present wind directions and intensities. These features help us understand the present climate and the forces that molded it. Wind-deposited sand bodies occur as sand sheets, ripples, and dunes.

Sand sheets are flat, gently undulating sandy plots of sand surfaced by grains that may be too large for saltation. They form approximately 40 percent of aeolian depositional surfaces. The Selima Sand Sheet, which occupies 60,000 square kilometers in southern Egypt and northern Sudan, is one of the Earth's largest sand sheets. The Selima is absolutely flat in some places; in others, active dunes move over its surface.

Wind blowing on a sand surface ripples the surface into crests and troughs whose long axes are perpendicular to the wind direction. The average length of jumps during saltation corresponds to the wavelength, or distance between adjacent crests, of the ripples. In ripples, the coarsest materials collect at the crests causing inverse grading. This distinguishes small ripples from dunes, where the coarsest materials are generally in the troughs. This is also a distinguishing feature between water laid ripples and aeolian ripples.

Wind-blown sand moves up the gentle upwind side of the dune by saltation or creep. Sand accumulates at the brink, the top of the slipface. When the buildup of sand at the brink exceeds the angle of repose, a small avalanche of grains slides down the slipface. Grain by grain, the dune moves downwind.

Accumulations of sediment blown by the wind into a mound or ridge, dunes have gentle upwind slopes on the windward side. The downwind portion of the dune, the lee slope, is commonly a steep avalanche slope referred to as a slipface. Dunes may have more than one slipface. The minimum height of a slipface is about 30 centimeters.

Some of the most significant experimental measurements on aeolian sand movement were performed by Ralph Alger Bagnold, a British engineer who worked in Egypt prior to World War II. Bagnold investigated the physics of particles moving through the atmosphere and deposited by wind. He recognized two basic dune types, the crescentic dune, which he called "barchan," and the linear dune, which he called longitudinal or "seif" (Arabic for "sword").

Cross-bedding of sandstone near Mount Carmel road, Zion Canyon, indicating wind action and sand dune formation prior to formation of rock (NPS photo by George A. Grant, 1929)

Mesquite Flat Dunes in Death Valley looking toward the Cottonwood Mountains from the north west arm of Star Dune (2003)

Holocene eolianite deposit on Long Island, The Bahamas. This unit is formed of wind-blown carbonate grains. (2007)

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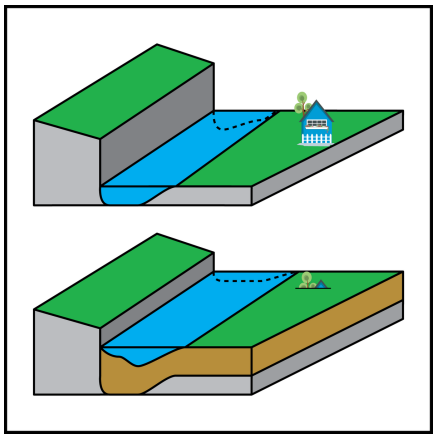
External links

- The Bibliography of Aeolian Research (http://www.lbk.ars.usda.gov/wewc/biblio/bar.htm)
- *Facts about wind erosion and dust storms on the Great Plains* (http://digital.library.unt.edu/permalink/meta-dc-1551:1) hosted by the UNT Government Documents Department (http://digital.library.unt.edu/browse/department/govdocs/)
- Aeolian Research (the Journal) (http://www.sciencedirect.com/science/journal/18759637)
- the International Society for Aeolian Research, ISAR (http://www.aeolianresearch.org/index.htm)

Aggradation

Aggradation is the term used in geology for the increase in land elevation due to the deposition of sediment. Aggradation occurs in areas in which the supply of sediment is greater than the amount of material that the system is able to transport. The mass balance between sediment being transported and sediment in the bed is described by the Exner equation.



Schematic of sediment accumulation (aggradation) in a river channel. The sediment is brown. The river is flowing on bedrock in the upper image, but because sediment was deposited over time the riverbed has risen. This has caused the house to be buried in the lower image.

Typical aggradational environments include lowland alluvial rivers, river deltas, and alluvial fans. Aggradational environments are often undergoing slow subsidence which balances the increase in land surface elevation due to aggradation. After millions of years, an aggradational environment will become a sedimentary basin, which contains the deposited sediment, including paleochannels and ancient floodplains.

Aggradation can be caused by changes in climate, land use, and geologic activity, such as volcanic eruption, earthquakes, and faulting. For example, volcanic eruptions may lead to rivers carrying more sediment than the flow can transport: this leads to the burial of the old channel and its floodplain. In another example, the quantity of sediment entering a river channel may increase when climate becomes drier. The increase in sediment is caused by a decrease in soil binding that results from plant growth being suppressed. The drier conditions cause river flow to decrease at the same time as sediment is being supplied in greater quantities, resulting in the river becoming choked with sediment.

In 2009, a report by researchers from the University of Colorado at Boulder in the journal Nature Geoscience said that reduced aggradation was contributing to an increased risk of flooding in many river deltas.[1]

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- John B. Southard, MIT OpenCourseWare - 12.110: Sedimentary Geology - Spring 2007 [5]

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[4] http://ocw.mit.edu/OcwWeb/Earth--Atmospheric--and-Planetary-Sciences/12-110Fall-2004/CourseHome/index.htm
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Alluvial river

An **alluvial river** is river in which the bed and banks are made up of mobile sediment and/or soil. Alluvial rivers are self-formed, meaning that their channels are shaped by the magnitude and frequency of the floods that they experience, and the ability of these floods to erode, deposit, and transport sediment. As such, alluvial rivers can assume a number of forms based on the properties of their banks; the flows they experience; the local riparian ecology, and the amount, size, and type of sediment that they carry. These forms can be meandering, braiding, wandering and (occasionally) straight.[1]

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Anabranch

An **anabranch** is a section of a river or stream that diverts from the main channel or stem of the watercourse and rejoins the main stem downstream. Local anabranches can be the result of small islands in the watercourse. In larger anabranches, the flow can diverge for a distance of several kilometers before rejoining the main channel.

Anabranches at the junction of the Yukon River and the Koyukuk River in Alaska, August 24, 1941.

Word usage and related terms

The term *anabranch*, in its hydrological meaning, is used more frequently in Australia than in the rest of the English-speaking world.

The term anastomose river describes a river with many anabranches.

The term braided river describes watercourses which are divided by small islands into multiple channel threads within a single main channel, but the term does not describe the multiple channels of an anabranching river.

A distributary is a branch of a river that does not rejoin the main channel; these are common on and near river deltas.

A bayou is often anabranch.

Examples

- In the Fraser River delta of British Columbia, Canada, North Arm Fraser River, Middle Arm Fraser River, and South Arm Fraser River each fall into Georgia Strait separately. On the other hand, Annacis Island splits (South Arm) Fraser River into the (main) Annievile Channel and the (smaller) Annacis Channel, which rejoin below the island.
- In western New South Wales the Great Darling Anabranch is the ancestral path of the Darling River, dividing south of Menindee and extending for 460 km before joining the Murray River[1] . The anabranch contains flowing water only in wetter years.
- The Bahr el Zeraf in southern Sudan splits from the Bahr al Jabal section of the White Nile and flows for 240 km (150 mi), before rejoining the White Nile proper upriver from Malakal.
- Approximately twenty-five minutes out of Charters Towers is a section of the Burdekin River known as 'the anabranch'. This strip of water is separate from the main flood way, and is typically dry during the sunnier months. Once there is consistent rain, it will meet up with the river again and flood with fresh water. It is well

known for barramundi fishing.

References

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Antecedent drainage stream

An **antecedent stream** or **antecedent drainage** is a stream that follows a course that formed before the tectonic uplift of the surrounding terrain and maintained its course through continuous downcutting of its valley.

Armor (hydrology)

Armor, in hydrology and geography is the association of surface pebbles, rocks or boulders with stream beds or beaches. Most commonly hydrological armor occurs naturally; however, a man-made form is usually called riprap, when shorelines or stream banks are fortified for erosion protection with large boulders or sizable manufactured concrete objects. When armor is associated with beaches in the form of pebbles to medium sized stones grading from two to 200 millimeters across, the resulting landform is often termed a *shingle beach*. Hydrological modeling indicates that stream armor typically persists in a flood stage environment.[1]

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Avulsion (river)

In sedimentary geology and fluvial geomorphology, **avulsion** is the rapid abandonment of a river channel and the formation of a new river channel. Avulsions occur as a result of channel slopes that are much lower than the slope that the river could travel if it took a new course.[1]

Deltaic and net-depositional settings

Avulsions are common in deltaic settings, where sediment deposits as the river enters the ocean and channel gradients are typically very small.[2] This process of avulsion in deltaic settings is also known as **delta switching**.

Plumes of sediment enter the ocean from mouths of the Mississippi River bird's-foot delta. This sediment is responsible for building the delta and allowing it to advance into the sea. As it extends further offshore, the channel slope will decrease and its bed will aggrade, promoting an avulsion.

Deposition from the river results in the formation of an individual deltaic lobe that pushes out into the sea. An example of a deltaic lobe is the bird's-foot delta of the Mississippi River, pictured at right with its sediment plumes. As the deltaic lobe advances, the slope of the river channel becomes lower because the river channel is longer but has the same change in elevation (see slope or gradient). As the slope of the river channel decreases, it becomes unstable for two reasons. First, water under the force of gravity will tend to flow in the most direct course downslope. If the river could breach its natural levees (i.e., during a flood), it would spill out onto a new course with a shorter route to the ocean, thereby obtaining a more stable steeper slope.[1] Second, as its slope is reduced, the amount of shear stress on the bed will decrease, resulting in deposition of sediment within the channel and raising of the channel bed relative to the floodplain. This will make it easier for the river to breach its levees and cut a new channel that enters the ocean at a steeper slope.

When this avulsion occurs, the new channel carries sediment out to the ocean, building a new deltaic lobe.,[3] [4] The abandoned delta eventually subsides.[5] Because this process results in the formation of a series of lobes, it is also known as **delta switching**.

This process is also related to the distributary network of river channels that can be observed within a river delta. When the channel does this, some of its flow can remain in the abandoned channel. When these channel switching events happen repeatedly over time, a mature delta will gain a distributary network.[6]

Subsidence of the delta and/or sea-level rise can further cause backwater and deposition in the delta. This deposition fills the channels and leaves a geologic record of channel avulsion in sedimentary basins. On average, an avulsion will occur every time the bed of a river channel aggrades enough that the river channel is superelevated above the floodplain by one channel-depth. In this situation, enough hydraulic head is available that any breach of the natural

levees will result in an avulsion.[7] [8]

Erosional avulsions

Rivers can also avulse due to the erosion of a new channel that creates a straighter path through the landscape. This can happen during large floods in situations in which the slope of the new channel is significantly greater than that of the old channel. Where the new channel's slope is about the same as the old channel's slope, a *partial avulsion* will occur in which both channels are occupied by flow.[9] An example of an erosional avulsion is the 2006 avulsion of the Suncook River in New Hampshire, in which heavy rains caused flow levels to rise. The flow level rise was pronounced behind an old mill dam, which produced a shallowly-sloping pool that overtopped a sand and gravel quarry, connected with a downstream section of channel, and cut a new (and shorter) channel at a rate of 25–50 meters per hour.[10] Interestingly enough, sediment mobilized by this erosional avulsion produced a depositionally-forced meander cutoff further downstream by superelevating the bed around the meander bend to nearly the level of the floodplain.[11]

Meander cutoffs

An example of a minor avulsion is known as a meander cutoff, where the high-sinuosity meander bend is abandoned in favor of the high-slope. This occurs when the ratio between the channel slope and the potential slope after an avulsion is less than 1/6.[1]

Occurrence

Avulsion typically occurs during large floods which carry the power necessary to rapidly change the landscape.

Avulsions usually occur as a downstream to upstream process via head cutting erosion. If a bank of a current stream is breached a new trench will be cut into the existing floodplain. It either cuts through floodplain deposits or reoccupies an old channel.[12]

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External links

- In this link small avulsions can be seen breaking from the main channel in a delta created in a lab at Western Washington University. This is a time lapse image of the delta. (http://mswebtest.admcs.wwu.edu/deltacam/main.aspx)

Badlands

A **badlands** (also **badland**) is a type of dry terrain where softer sedimentary rocks and clay-rich soils have been extensively eroded by wind and water. It can resemble malpaís, a terrain of volcanic rock. Canyons, ravines, gullies, hoodoos and other such geological forms are common in badlands. They are often difficult to navigate by foot. Badlands often have a spectacular color display that alternates from dark black/blue coal stria to bright clays to red scoria.

The Chinle Badlands at Grand Staircase-Escalante National Monument in southern Utah.

Features

The term *badlands* represents a consensus in North America. The Lakota called the topography "*Makhóšiča*", literally *bad land*, while French trappers called it "*les mauvaises terres à traverser*" – "the bad lands to cross". The Spanish called it *tierra baldía* ("waste land") and *cárcava*. The term badlands is also apt: badlands contain steep slopes, loose dry soil, slick clay, and deep sand, all of which impede travel and other uses. Badlands form in semi-arid or arid regions with infrequent but intense rain-showers, sparse vegetation, and soft sediments: a recipe for massive erosion.

Toadstool Geologic Park in northwestern Nebraska.

Some of the most famous fossil beds are found in badlands, where erosion rapidly exposes the sedimentary layers and the scant cover of vegetation makes surveying and fossil hunting relatively easy.

Coal seams are also exposed in some badlands, so historically, coal mining districts have developed in badlands areas. An example of this is the Drumheller district of the Red Deer River in Alberta, where the Atlas Coal Mines is the last of 149 mines that operated in those badlands.

Badlands near Drumheller, Alberta.

Locations

Some of the best-known badland formations can be found in the United States and Canada. In the U.S., Makoshika State Park in Montana, Theodore Roosevelt National Park in North Dakota and Badlands National Park in South Dakota together form a series of extensive badland formations. Another popular area of badland formations is Toadstool Geologic Park in the Oglala National Grassland of

northwestern Nebraska. Dinosaur National Monument in Colorado and Utah are also badlands settings. A small badland called Hell's Half-Acre is present in Natrona County, Wyoming. Additional badlands also exist in various places throughout southwest Wyoming, such as near Pinedale and in the Bridger Valley near the towns of Lyman and Mountain View, near the high Uintah Mountains.

The Big Muddy Badlands in Saskatchewan, Canada gained notoriety as a hideout for outlaws. There is a large badland area in Alberta, Canada, particularly in the valley of the Red Deer River where Dinosaur Provincial Park is located. The Royal Tyrrell Museum of Palaeontology in Drumheller, Alberta.

Arguably the most well known badlands formation in New Zealand, the Putangirua Pinnacles – formed by the erosion of the conglomerate of an old alluvial fan – are located at the head of a small valley near the southern tip of the North island.

The Bardenas Reales near Tudela, Spain is an example in Europe.

Although most badland scenery is natural, there are some examples produced by mining, such as the Roman gold mine of Las Médulas in northern Spain. An example of badlands produced by poor farming practices is the Cheltenham Badlands in Caledon Hills, Ontario.

Badlands of Hell's Half-Acre, Natrona County, Wyoming.

Panoramic view of Las Médulas, Spain.

References

External links

- http://www.nps.gov/badl/

Badlands Guardian

The **Badlands Guardian** is a geomorphological feature located near Medicine Hat in the south east corner of Alberta, Canada. Viewed from the air, the feature bears a strong resemblance to a human head wearing a full native American headdress, facing directly westward. Because of additional man-made structure, it also appears to be wearing earphones.[1] The apparent earphones are a road and an oil well, which has been recently installed.[2]

The head is a drainage feature created through erosion of soft, clay-rich soil by the action of wind and water.[1] [3] The arid badlands are typified by infrequent but intense rain-showers, sparse vegetation and soft sediments. The 'head' may have been created during a short period of fast erosion immediately following intense rainfall. Although the image appears to be a convex feature, it is actually concave — that is, a valley,[4] an instance of the Hollow-Face illusion.

In 2006 Medicine Hat's CHAT-TV Reporter Dale Hunter did a short feature on the Badlands Guardian.[5] It was the winner of the RTNDA National- TV - short feature award for that year.[5]

The feature was originally discovered by Lynn Hickox while examining images on the *Google Earth* application.[1] Suitable names were canvassed by CBC Radio One program *As It Happens*. Out of 50 names submitted, seven were suggested to the Cypress County Council. They altered the suggested 'Guardian of the Badlands' to become *Badlands Guardian*.[3]

The Badlands Guardian was also described by the *Sydney Morning Herald* as a "net sensation".[1] *PCWorld* magazine has referred to the formation as a "geological marvel".[6] The Guardian was also covered by Canada's Global Television.[2]

Citations and notes

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- Gran's canyon is a net sensation (http://www.smh.com.au/news/web/grans-canyon-sensation/2006/11/13/1163266420400.html), The Sydney Morning Herald. Published 13 November 2006.
- CBC Radio program As It Happens. Story and Radio interviews with Supergranny, the person who discovered the feature on Google Earth. (http://www.cbc.ca/asithappens/features/2006/alberta_rock_sculpture_20061026.html)
- 3D diagram of Badlands Guardian topography, prepared by Lutz Perschon for CBC Radio. (http://www.cbc.ca/asithappens/features/2006/GIANTHEAD_3d.jpg)
- Google Earth Community (http://bbs.keyhole.com/ubb/ubbthreads.php?ubb=showflat&Main=55887&Number=166213#Post166213) Page about the discovery of the feature.
- Photo of the Badlands Guardian taken from a paraglider (http://www.panoramio.com/photo/2331889)

Baer's law

In geology, **Baer's law**, named after Karl Ernst von Baer, says that, because of the rotation of the earth, in the Northern Hemisphere, erosion occurs mostly on the right banks of rivers and in the Southern Hemisphere on the left banks. In 1926, Albert Einstein wrote a paper explaining the causes of the phenomenon.

Although it is possible that an aggregate measurement of all rivers would lead to a correlation, the Coriolis force is orders of magnitude weaker than the local forces on the river channel from its flow. Therefore, this is unlikely to be important in any given river.[1]

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Bank (geography)

A ***geographic*** **bank** has four definitions and applications:

1. **Limnology**: The shoreline of a pond, swamp, estuary, reservoir, or lake. The grade (slope) can vary from vertical to a shallow slope.[1]
2. **Freshwater ecology**: (1) The location of a riparian zone habitats: along the upland and lowland river and stream beds. (2) The ecology around and depending on a marsh, swamp, slough, or estuary.
3. **Fluvial**: A riverbank or stream-bank: the terrain alongside the bed of a river, creek, or stream.
4. **Navigation**: A singular or succession of shoals of alluvium, such as silt and sand, constricting or blocking access to an area. This can be in the course of or at the mouth of a navigable river, in a harbor, or on the continental shelves. An example is a sandbar.

A man-made lake in Keukenhof, Netherlands with grass banks.

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A sloping sandy point bar (close side) and the vegetation-stabilized cut bank (far side) on the Namoi River, New South Wales, Australia. These two constitute the banks of the river.

Bar (river morphology)

A **bar** in a river is an elevated region of sediment (such as sand or gravel) that has been deposited by the flow. Types of bars include mid-channel bars (also called braid bars, and common in braided rivers), point bars (common in meandering rivers), and mouth bars (common in river deltas). Bars are typically found in the slowest moving, shallowest parts of rivers and streams,[1] and are often parallel to the shore and occupy the area farthest from the thalweg.[2]

The locations of bars are determined by the geometry of the river and the flow through it. Point bars form on the inside of meander bends in meandering river because the shallow flow and low shear stresses there reduce the amount of material that can be carried there. The excess material falls out of transport and forms the bar.

Gravel bar in the American River, Washington, USA.

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Further reading

- John Bridge and Robert Demicco (2008). *Earth Surface Processes, Landforms and Sediment Deposits*. Cambridge, UK: Cambridge University Press. ISBN 9780521857802.

Base level

The **base level** of a river or stream is the lowest point to which it can flow, often referred to as the 'mouth' of the river. For large rivers, sea level is usually the base level, but a large river or lake is likewise the base level for tributary streams. All rivers and streams erode toward sea level, which is also known as the "ultimate base level." If a river is dammed, a new base level (the level of the reservoir) replaces the ultimate base level. As a result, the stream's base level is raised. Consequently, this reduces the stream's velocity, leads to deposition, and a reduction of the gradient upstream from the reservoir. A rather rare exception can be seen in the Jordan River, for which the base level is the Dead Sea, 417 m below modern sea level.

Base level is also significant for subsurface drainage. A low base level is a prerequisite for the formation of karst topography, a network of sinkholes and caverns that can develop as slightly acidic groundwater enlarges joints (by solution) in limestone rock. Often this network of underground drainage feeds back to surface drainage along the edges of larger rivers, which are the effective base level.

When the source of a stream is very high relative to its base level (high stream gradient), erosion proceeds rapidly due to the energy of the rapidly moving water and the topography becomes rugged, and it is considered a *young* stream (geologically speaking). When erosion has acted for a long geologic time, wearing down the high points and making a small difference between the source and the base level of a stream (low stream gradient), then the stream is called *mature*. Mature stream valleys have gentle slopes, rounded higher points and meandering courses.

A very hard layer of rock can form a temporary base level, until it is cut through. For example, Lockport dolomite has created a temporary base level for the Niagara River. Eventually this will be cut through as Niagara Falls recedes, and Lake Erie will be drained to near the lower base level of Lake Ontario.

Movements of land can greatly affect base levels. As an illustration, the uplift of the Colorado Plateau, combined with the opening of the Gulf of California to the sea, established sea level as the base level for the Colorado River and led to the (geologically) rapid erosion that resulted in the Grand Canyon.

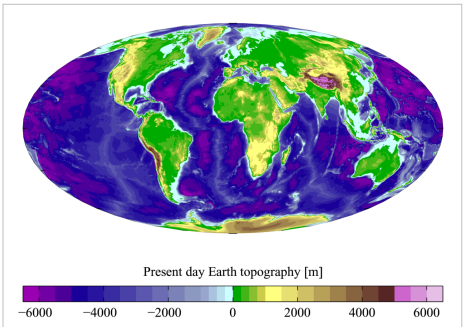
The many meanders of the Kentucky River show that it was a mature stream with little relief. Uplift of the central Kentucky area *rejuvenated* the stream, causing it to cut a deep canyon, but preserving the meanders that indicate the stream existed prior to the uplift.

Other geologic processes can affect base levels. In the Finger Lakes of New York, Ice age glaciation greatly deepened the lake valleys and rejuvenated tributary streams. These streams have deep ravines and often waterfalls where hard rock layers slow erosion; they are said to be *hanging valleys*.

Sea level can also change (primarily due to the formation or melting of continental ice sheets), and raise or lower the final base level for coastal rivers. Along the east coast of North America, river valleys extend out onto the continental shelf, indicating a time when erosion was possible due to the lower base level of a lower sea level in the past. Today many of these same rivers end in bays, indicating that sea level has risen in recent geologic time. This is referred to as a *drowned coastline*.

Bathymetry

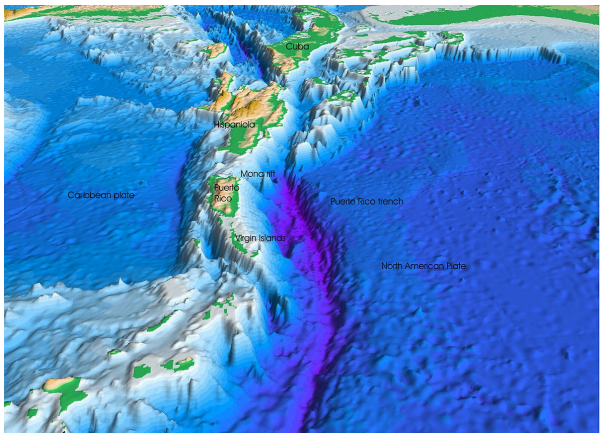
Bathymetry is the study of underwater depth of lake or ocean floors. In other words, bathymetry is the underwater equivalent to hypsometry. The name comes from Greek βαθύς (*bathus*), "deep",[2] and μέτρον (*metron*), "measure".[3] Bathymetric (or hydrographic) charts are typically produced to support safety of surface or sub-surface navigation, and usually show seafloor relief or terrain as contour lines (called **depth contours** or **isobaths**) and selected depths (**soundings**), and typically also provide surface navigational information. Bathymetric maps (a more general term where navigational safety is not a concern) may also use a Digital Terrain Model and artificial illumination techniques to illustrate the depths being portrayed. **Paleobathymetry** is the study of past underwater depths.



Present day Earth bathymetry (and altimetry). Data from the National Geophysical Data Center's TerrainBase Digital Terrain Model [1].

Measurement

Originally, bathymetry involved the measurement of ocean depth through depth sounding. Early techniques used pre-measured heavy rope or cable lowered over a ship's side. This technique measures the depth only a single point at a time, and so is inefficient. It is also subject to movements of the ship and currents moving the line out of true and therefore is inaccurate.



The seafloor topography near the Puerto Rico Trench

The data used to make bathymetric maps today typically comes from an echosounder (sonar) mounted beneath or over the side of a boat, "pinging" a beam of sound downward at the seafloor or from remote sensing LIDAR or LADAR systems.[4] The amount of time it takes for the sound or light to travel through the water, bounce off the seafloor, and return to the sounder tells the equipment what the distance to the seafloor is. LIDAR/LADAR surveys are usually conducted by airborne systems.

Since the early 1930s, and more commonly from the 1940s onwards, the occasional pings of a single-beam sounder might be averaged to make a map. Today, a multibeam echosounder (MBES) may be used, featuring hundreds of very narrow adjacent beams arranged in a fan-like swath of perhaps 90 to 170 degrees across. The tightly packed array of narrow individual beams provides very high angular resolution and accuracy. In general a wide swath, which is depth dependent, allows a boat to map more seafloor in less time than a single-beam echosounder by making fewer passes. The beams update many times per second (typically 0.1-50 Hz depending on water depth), allowing faster boat speed while maintaining 100% coverage of the seafloor. Attitude sensors allow for the correction of the boat's roll, pitch and yaw on the ocean surface, and a gyrocompass provides accurate heading information to correct for vessel yaw. (Most modern MBES systems use an integrated motion-sensor and position system that measures yaw as well as the other dynamics and position.) The Global Positioning System (or other Global Navigation Satellite System (GNSS)) positions the soundings with respect to the surface of the earth. Sound speed profiles (speed of sound in water as a function of depth) of the water column correct for refraction or "ray-bending" of the sound waves owing to non-uniform water column characteristics such as temperature, conductivity, and pressure. A computer system processes all the data, correcting for all of the above factors as well

as for the angle of each individual beam. The resulting sounding measurements are then processed either manually, semi-automatically or automatically (in limited circumstances) to produce a map of the area. As of 2010 a number of different outputs are generated, including a sub-set of the original measurements that satisfy some conditions (e.g., most representative likely soundings, shallowest in a region, etc.) or integrated Digital Terrain Models (DTM) (e.g., a regular or irregular grid of points connected into a surface). Historically, selection of measurements was more common in hydrographic applications while DTM construction was used for engineering surveys, geology, flow modeling, etc. Since ca. 2003-2005, DTMs have become more accepted in hydrographic practice.

Satellites are also used to measure bathymetry. Satellite radar maps deep-sea topography by detecting the subtle variations in sea level caused by the gravitational pull of undersea mountains, ridges, and other masses. On average, sea level is higher over mountains and ridges than over abyssal plains and trenches.[5]

Most surveys of navigable waterways in the United States are performed or commissioned by the United States Army Corps of Engineers, for inland waterways, and the National Oceanic and Atmospheric Administration (NOAA) for oceans. Coastal bathymetry data is available from NOAA's National Geophysical Data Center (NGDC) [6] [7]. Bathymetric data is usually referenced to tidal vertical datums.[8] For deep-water bathymetry, this is typically Mean Sea Level (MSL), but most data used for nautical charting is referenced to Mean Lower Low Water (MLLW) in American surveys, and Lowest Astronomical Tide (LAT) in other countries. Many other datums are used in practice, depending on the locality and tidal regime.

Occupations or careers related to bathymetry include the study of oceans and rocks and minerals on the ocean floor, and the study of underwater earthquakes or volcanoes. The taking and analysis of bathymetric measurements is one of the core areas of modern hydrography, and a fundamental component in ensuring the safe transport of goods worldwide.

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[4] Olsen, R. C. (2007), *Remote Sensing from Air and Space*, SPIE, ISBN 9780819462350

[5] Thurman, H. V. (1997), *Introductory Oceanography*, New Jersey, USA: Prentice Hall College, ISBN 0132620723

[6] http://www.ngdc.noaa.gov

[7] NGDC-Bathymetry, Topography, & Relief (http://www.ngdc.noaa.gov/mgg/bathymetry/relief.html)

[8] NGDC/WDC MGG, Boulder-Coastal relief model development (http://www.ngdc.noaa.gov/mgg/coastal/model.html)

External links

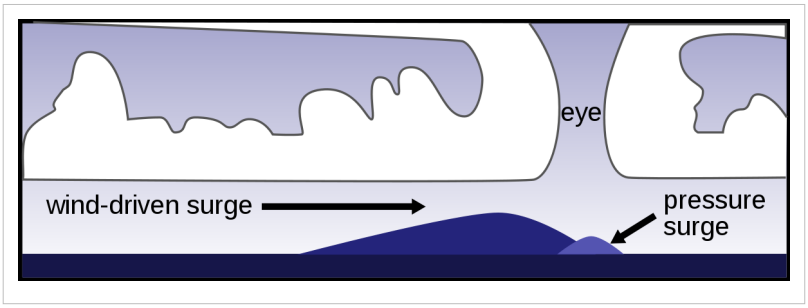
- Overview for underwater terrain, data formats, etc. (http://www.vterrain.org/Elevation/Bathy/) (vterrain.org)
- High resolution bathymetry for the Great Barrier Reef and Coral Sea (http://e-atlas.org.au/content/gbr_jcu_bathymetry-3dgbr)
- A.PO.MA.B.-Academy of Positioning Marine and Bathymetry (http://apomabdoc.altervista.org/index.html)

Beach evolution

The shoreline is where the land meets the sea and it is continually changing. Over the long term, the water is eroding the land. Beaches represent a special case, in that they exist where sand accumulated from the same processes that strip away rocky and sedmientary material. I.e., they can grow as well as erode. River deltas are another exception, in that silt that erodes up river can accrete at the river's outlet and extend ocean shorelines. Catastrophic events such as tsunamis, hurricanes and storm surges accelerate beach erosion, potentially carrying away the entire sand load. Human activities can be as catastrophic as hurricanes, albeit usually over a longer time interval.

Erosion and accretion

Extraordinary processes: tsunamis and hurricane-driven storm surges



Tsunamis, potentially enormous waves often caused by earthquakes, have great erosional and sediment-reworking potential. They may strip beaches of sand that may have taken years to accumulate and may destroy trees and other coastal vegetation. Tsunamis are also capable of flooding hundreds of meters inland past the typical high-water level and fast-moving water, associated with the inundating tsunami, can crush homes and other coastal structures.

A storm surge is an onshore gush of water associated with a low pressure weather system—storms. Storm surges can cause beach accretion and erosion.[1] Historically notable storm surges occurred during the North Sea Flood of 1953, Hurricane Katrina, and the 1970 Bhola cyclone.

Gradual processes

The gradual evolution of beaches often comes from the interaction of longshore drift, a wave-driven process by which sediments move along a beach shore, and other sources of erosion or accretion, such as nearby rivers.

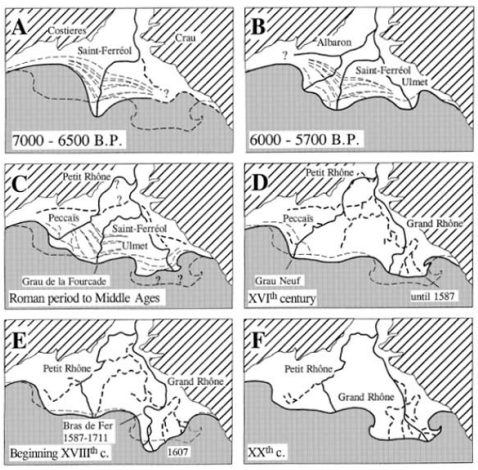
Deltas

Deltas are nourished by alluvial systems and accumulate sand and silt, growing where the sediment flux from land is large enough to avoid complete removal by coastal currents, tides, or waves.

Most modern deltas formed during the last five thousand years, after the present sea-level high stand was attained. However, not all sediment remains permanently in place: in the short term (decades to centuries), exceptional river floods, storms or other energetic events may remove significant portions of delta sediment or change its lobe distribution and, on longer geological time scales, sea-level fluctuations lead to destruction of deltaic features.

Historical accretion of European beaches

In the Mediterranean sea, deltas have been continuously growing during for the last several thousand years. Six to seven thousand years ago, the sea level stabilized, and continuous river systems, ephemeral torrents, and other factors began this steady accretion. Since intense human use of coastal areas is a relatively recent phenomenon (except in the Nile delta), beach contours were primarily shaped by natural forces until the last centuries.



Main stages of Holocene evolution of the Rhone delta

In Barcelona, for example, the accretion of the coast was a natural process until the late Middle Ages, when harbor-building increased the rate of accretion.

The port of Ephesus, one of the great cities of the Ionian Greeks in Asia Minor, was filled with sediment due to accretion from a nearby river; it is now 5 kilometers (3.1 mi) from the sea. Likewise, Ostia, the once-important port near ancient Rome, is now several kilometers inland, the coastline having moved slowly seaward.

Bruges became a port during the early Middle Ages and was accessible by sea until around 1050. At that time, however, the natural link between Bruges and the sea silted up. In 1134, a storm flood opened a deep channel, the Zwin, linking the city to the sea until the fifteenth century via a canal from the Zwin to Bruges. Bruges had to use a number of outports, such as Damme and Sluis, for this purpose. In 1907, a new seaport was inaugurated in Zeebrugge.

Modern beach recession

At the present time important segments of low coasts are in recession, losing sand and reducing beach dimensions. This loss could can very rapidly. Examples of this are occurring at Sète, in California, in Poland, in Aveiro (Portugal), and in Holland and elsewhere along the North Sea. In Europe, coastal erosion is widespread (at least 70%) and distributed very irregularly.

Eroding beach in Portugal.

Relative sea level changes

Several geological events and the climate can change (progressively or suddenly) the relative height of the Earth's surface to the sea-level. These events or processes continuously change coastlines.

Vulcanism and Earthquakes

Volcanic activity can create new islands. The 800 meters (2600 ft) in diameter Surtsey Island, Iceland, for example, was created between November 1963 and June 1967. The island has since partially eroded, but it is expected to last another 100 years.

Old sea level mark before these tremors.

Some earthquakes can create sudden variations of relative ground level and change the coastline dramatically. Structurally controlled coasts include the San Andreas fault zone in California and the seismic Mediterranean belt (from Gibraltar to Greece).

The Bay of Pozzuoli, in Pozzuoli, Italy experienced hundreds of tremors between August 1982 and December 1984. The tremors, which reached a peak on October 4, 1983, damaged 8,000 buildings in the city center and raised the sea bottom by almost 2 meters (6.6 ft). This rendered the Bay of Pozzuoli too shallow for large craft and required the reconstruction of the harbour with new quays. The photo at the upper right shows the harbor before the uplift while the one on the bottom right shows the new quay.

New quay at the Bay of Pozzuoli

Gradual processes: subsidence and uplift

Subsidence is the motion of the Earth's surface downward relative to the sea level due to internal geodynamic causes. The opposite of subsidence is uplift, which increases elevation.

Venice is probably the best-known example of a subsiding location. It experiences periodic flooding when extreme hight tides or surges arrive. This phenomenon is caused by the compaction of young sediments in the Po River delta area, magnified by subsurface water and gas exploitation. Man-made works to solve this progressive sinking have been unsuccessful.

St. Mark's Square, Venice, during flooding

Mälaren, the third-largest lake in Sweden, is an example of deglacial uplift. It was once a bay on which seagoing vessels were once able to sail far into the country's interior, but it ultimately became a lake. Its uplift was caused by deglaciation: the removal of the weight of ice-age glaciers caused rapid uplift of the depressed land. For 2,000 years as the ice was unloaded, uplift proceeded at about 7.5 centimeters (3.0 in)/year. Once deglaciation was complete, uplift slowed to about 2.5 centimeters (0.98 in) annually, and it decreased exponentially after that. Today, annual uplift rates are 1 centimeter (0.39 in) or less, and studies suggest that rebound will continue for about another 10,000 years. The total uplift from the end of deglaciation may be up to 400 meters (1300 ft).

Notes

[1] (http://gsa.confex.com/gsa/2005AM/finalprogram/abstract_96788.htm)

External links

- Delta-Global Change Program (http://www.nmnh.si.edu/paleo/deltas/index.htm)
- Mediterranean Prodelta Systems (http://www.tos.org/oceanography/issues/issue_archive/issue_pdfs/17_4/17.4_trincardi_et_al.pdf)
- EUROSION project web site (http://www.eurosion.org/)

Beachrock

Beachrocks are created by the rapid cementation of beach sediments in the intertidal zone which leads to the formation of characteristic synsedimentary lithified structures.

Beachrock along Réunion island seashore

Detail showing fragments of coral and shells

Overview

Beachrock units form under a thin cover of sediment and generally overlie unconsolidated sand. They typically consist of multiple units, representing multiple episodes of cementation and exposure. The mineralogy of beachrocks is mainly high-magnesium calcite or aragonite. The main processes involved in the cementation are : supersaturation with $CaCO_3$ through direct evaporation of seawater (Scoffin, 1970), groundwater CO_2 degassing in the vadose zone (Hanor, 1978), mixing of marine and meteoric water fluxes (Schmalz, 1971) and precipitation of micritic calcium carbonate as a byproduct of microbiological activity (Neumeier, 1999).

On retreating coasts, outcrops of beachrock may be evident offshore where they may act as a barrier against coastal erosion. Beachrock presence can also induce sediment deficiency in a beach and out-synch its wave regime. Because beachrock is lithified within the intertidal zone and because it commonly forms in a few years, its potential as an indicator of past sea level is important.

Cementation and position of beachrock

Beachrocks are located along the coastline in a parallel term and they are usually a few meters offshore. They are generally separated in several levels which may correspond to different generations of beachrock cementation. Thus, the older zones are located in the outer part of the formation when the younger ones are on the side of the beach, possibly under the unconsolidated sand. They also seem to have a general inclination to the sea (50 – 150). There are several appearances of beachrock formations which are characterized by multiple cracks and gaps. The result from this fact is an interruptible formation of separated blocks of beachrock, which may be of the same formation.

The length of beachrocks varies from meters to kilometers, its width can reach up to 300 meters and its height starts from 30 cm and reaches 3 meters.

Following the process of coastal erosion, beachrock formation may be uncovered. Coastal erosion may be the result of sea level rise or deficit in sedimentary equilibrium. One way or another, unconsolidated sand that covers the beachrock draws away and the formation is revealed. If the process of cementation continues, new beachrock would be formed in a new position in the intertidal zone. Successive phases of sea level change may result in sequential zones of beachrock.

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Bed load

The term **bed load** or **bedload** describes particles in a flowing fluid (usually water) that are transported along the bed. Bed load is complementary to suspended load and wash load.

Bed load moves by rolling, sliding, and/or saltating (hopping).

Bed load sediment in the thalweg of Campbell creek in Alaska.

Generally, bed load downstream will be smaller and more rounded than bed load upstream (a process known as downstream fining). This is due in part to attrition and abrasion which results from the stones colliding with each other and against the river channel, thus removing the rough texture (rounding) and reducing the size of the particles. However, selective transport of sediments also plays a role in relation to downstream fining: smaller-than average particles are more easily entrained than larger-than average particles, since the shear stress required to entrain a grain is linearly proportional to the diameter of the grain. However, the degree of size selectivity is restricted by the **hiding effect** described by Parker and Klingeman (1982), wherein larger particles protrude from the bed whereas small particles are shielded and hidden by larger particles, with the result that nearly all grain sizes become entrained at nearly the same shear stress.

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Bed material load

The **bed material load** is the portion of the sediment that is transported by a stream that contains material derived from the bed.[1] Bed material load typically consists of all of the bed load, and the proportion of the suspended load that is represented in the bed sediments. Its importance lies in that its composition is that of the bed, and the material in transport can therefore be actively interchanged with the bed. For this reason, bed material load exerts a control on river channel morphology. Bed load and wash load (the sediment that rides high in the flow and does not extract non-negligible momentum from it) together constitute the total load of sediment in a stream.[2]

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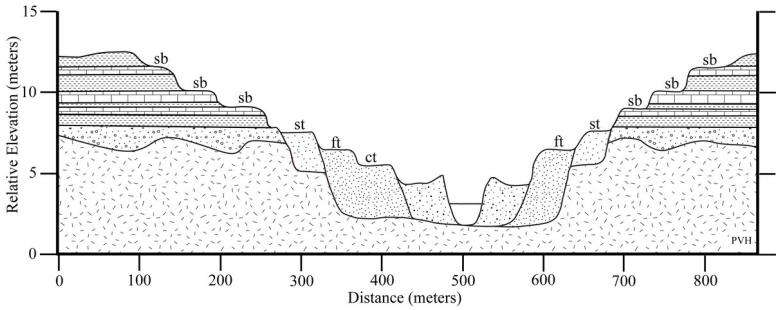
Bench (geology)

In geomorphology, geography and geology, a **bench** or **benchland** is a long, relatively narrow strip of relatively level or gently inclined land that is bounded by distinctly steeper slopes above and below it. Benches can be of different origins and created by very different geomorphic processes.[1]

First, the differential erosion of rocks or sediments of varying hardness and resistance to erosion can create benches. Earth scientists called such benches "structural benches." Second, other benches are narrow fluvial terraces created by the abandonment of a floodplain by a river or stream and entrenchment of the river valley into it. Finally, a bench is also the name of a narrow flat area often seen at the base of a sea cliff that was created by waves or other physical or chemical erosion near the shoreline. These benches are typically referred to as either "coastal benches," "wave-cut benches," or "wave-cut platforms."[2] [3]



Hypothetical cross-section of a river valley showing different types of benches. They include structural benches (sb) formed by the differential erosion of shale beds overlying limestone beds. Also, they include benches in the form of narrow strath terraces (st), fill terraces (ft), and cut terraces (ct) underlain by fluvial sediments.

In mining, a bench is a narrow, strip of land cut into the side of an open-pit mine. These step-like zones are created along the walls of an open-pit mine for access and mining.[1]

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Bifurcation lake

Bifurcation lake is a lake that naturally has outflows into two different drainage basins and thus the drainage divide cannot be defined exactly because it is situated in the middle of the lake.

Examples

Two nearby lakes in Finland are Vesijako (the name *Vesijako* actually means "drainage divide") and Lummene in the finnish Lakeland that both drain in two directions: into the Kymijoki basin that drains into the Gulf of Finland and into the Kokemäenjoki basin that drains into the Gulf of Bothnia.

Similarly the lakes Isojärvi and Inhottu in the Karvianjoki basin in the Satakunta region in western Finland both have two outlets: from Inhottu the waters flow into the Gulf of Bothnia trough Eteläjoki in Pori and into the lake Isojärvi trough the Pomarkunjoki River; and from the lake Isojärvi the waters flow to the Gulf of bothnia trough the Pohjajoki river in Pori and trough the Merikarvianjoki river in Merikarvia. In the Karvianjoki basin there has formerly been also two other bifurcations which however no longer exist due to human action.

Lake Diefenbaker is a reservoir created by damming South Saskatchewan River and Qu'Appelle River. The lake continues to drain into the two rivers.

The largest lake in the world to drain naturally into two different oceans is also situated in Saskatchewan: Wollaston Lake is the source of Fond du Lac River draining into the Arctic Ocean and of Cochrane River draining into Hudson Bay, part of the Atlantic Ocean.

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Biogeomorphology

Biogeomorphology and **ecogeomorphology** are the study of interactions between organisms and the development of landforms, and are thus fields of study within geomorphology and ichnology. Organisms affect geomorphic processes in a variety of ways. For example, trees can reduce landslide potential where their roots penetrate to underlying rock, plants and their litter inhibit soil erosion, biochemicals produced by plants accelerate the chemical weathering of bedrock and regolith, and marine animals cause the bioerosion of coral. The study of the interactions between marine biota and coastal landform processes is called coastal biogeomorphology.

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External links

- Biogeomorphology Platform at Delft University of Technology [2]

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[1] http://water.usgs.gov/osw/techniques/workshop/osterkamp.html

[2] http://www.citg.tudelft.nl/live/pagina.jsp?id=30a1ff5a-a497-4c28-a4a2-ab37c9d8d1a9&lang=en

Blockfield

A **blockfield** or **felsenmeer** is a surface covered by block-sized angular rocks usually associated alpine and subpolar climates and periglaciation. Blockfields differ from screes and talus slope in that blockfields does not apparently originate from mass movements.

Most known blockfields are located in the northern hemisphere, examples can be found can be found in Abisko National Park in Sweden, Snowdonia National Park in Wales, River of Rocks, Hickory Run Boulder Field in the Appalachians of United States. All examples except the first one are outside present day subpolar climate areas, and have thus traditionally been seen as relict landforms from past times when these areas were under periglaciation.

The term "felsenmeer" comes from the German meaning 'sea of rock'. In a felsenmeer (also known as a block field), freeze-thaw weathering has broken up the top layer of the rock, covering the underlying rock formation with jagged, angular boulders. Freeze-thaw weathering occurs when water that is trapped along microcracks in rock expands and contracts due to fluctuations in temperature above and below the freezing point. Felsenmeers are formed *in situ*, meaning that they are not transported during or after their creation.

Characteristics

Surface

Felsenmeers only form on slopes of 25° or lower. A steeper angle results in transport of the blocks due to gravity. This creates a talus slope, rather than a felsenmeer.[1] Crude sorting with boulder imbrication can occasionally be seen on the surface of felsenmeers.

Profile

The depth of the boulder field depends on the slope angle, rock types, age, and erosional history. However, a reasonable average for felsenmeer depth is approximately 1m. Ballantyne (1998) [2] defines three types of felsenmeer profiles: Type 1 consists of boulders overlying a matrix of fines at some depth below the surface. Type 2 consists of boulders supported by a cohesionless sandy matrix that continues from the surface down through the profile. Type 3 also consists of boulders supported by a matrix, but differs from Type 2 in that the matrix consists of silt and/or clay rather than sand.

Occurrence

Felsenmeers are most often found in high mountain periglacial regions near the Arctic Circle, especially in Iceland, the Canadian arctic and Norway. Due to the slope requirements they are most commonly found on plateaus. Basalt and sedimentary rocks often produce larger, more numerous felsenmeers than other types of rock.

Age

Felsenmeers are, typically, relatively young geomorphological features. Most felsenmeers formed during or since last ice age (approximately 20,000 years ago). Their specific age can be determined using surface exposure dating, a technique that works best on materials which have been exposed to cosmic rays with little interference from trees or soils.

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Bradyseism

Bradyseism is the gradual uplift (positive bradyseism) or descent (negative bradyseism) of part of the Earth's surface caused by the filling or emptying of an underground magma chamber and/or hydrothermal activity, particularly in volcanic calderas. It can persist for millennia in between eruptions and is normally accompanied by thousands of small tremors and sometimes larger earthquakes.

The Serapium of Pozzuoli

Phlegraean Fields

The area around the Phlegraean Fields (Campi Flegrei) caldera near Naples, which includes the dormant Solfatara volcano, is especially noted for bradyseismic uplift and subsidence. The inflation and deflation of this caldera is especially well documented due to its seaside location and a long history of habitation and construction in the area.

In particular, the town of Pozzuoli contains three marble columns (in the Roman Temple to Serapis) which have boreholes made by marine molluscs. These occur up to 7 metres up the columns, showing how bradyseism in the area lowered the land to at least this depth under the sea and subsequently raised it again.

More recently, between 1968 and 1972, the town suffered an episode of positive bradyseism and rose by 1.7 metres. Another rise of 1.8 metres occurred between 1982 and 1984. This correlated with a shallow (4 km deep) earthquake, on 4 October 1983, which left around 30,000 people homeless.

References

Braid bar

Braid Bars, or mid-channel bars, are landforms in a river that begin to form when the discharge is low and the river is forced to take the route of less resistance by means of flowing in locations of lowest elevation. Over time, the river begins to erode the outer edges of the bar, causing it to become a higher elevation than the surrounding areas. The water level decreases even more as the river laterally erodes the less cohesive bank material resulting in a widening of the river and a further exposure of the braid bar. As the discharge increases, material may deposit about the braid bar since it is an area in the river of low velocity due to its increased elevation than the surrounding areas. During times of extremely high flow, the bars may become covered; only to resurface when the flow decreases. Most braid bars do not remain stable or in one location. However, vegetation succession on braid bars can increase the stability of the landform. [1] They are commonly composed of sand or gravel and typically occur in braided rivers. A braid bar is a perfect place for a picnic during levels of low-discharge.

References

[1] http://www3.interscience.wiley.com/cgi-bin/fulltext/8385/PDFSTART

Braided river

Not to be confused with the River Braid, Ballymena, Northern Ireland. For other uses see Braid (disambiguation).

The Waimakariri River in the South Island of New Zealand.

A **braided river** is one of a number of channel types and has a channel that consists of a network of small channels separated by small and often temporary islands called braid bars or, in British usage, *aits* or *eyots*. Braided streams occur in rivers with high slope and/or large sediment load (Schumm and Kahn 1972). Braided channels are also typical of environments that dramatically decrease channel depth, and consequently channel velocity, such as river deltas, alluvial fans and peneplains.

Braided rivers, as distinct from meandering rivers, occur when a threshold level of sediment load or slope is reached. Geologically speaking an increase in sediment load will over time increase the slope of the river, so these two conditions can be considered synonymous and consequently a variation of slope can model a variation in sediment load. A threshold slope was experimentally determined to be 0.016 (ft/ft) for a 0.15 cu ft/s (0.0042 m^3/s) stream with poorly sorted coarse sand (Schumm and Kahn 1972). Any slope over this threshold created a braided stream, and under the threshold created a meandering stream or for very low slopes a straight channel. So the main controlling factor on river development is the amount of sediment that the river carries, once a given system crosses a threshold value for sediment load it will convert from a meandering system to a braided system. Also important to channel development is the proportion of suspended load sediment to bed load. An increase in suspended sediment allowed for the deposition of fine erosion resistant material on the inside of a curve which accentuated the curve and in some

instances caused a river to shift from a braided to a meandering profile (Schumm and Kahn 1972).

The channels and braid bars are usually highly mobile, with the river layout often changing significantly during flood events (Hickin and Sichingabula 1988). Channels move sideways via differential velocity: On the outside of a curve, deeper, swift water picks up sediment (usually gravel or larger stones), which is re-deposited in slow-moving water on the inside of a bend.

The braided channels may flow within an area defined by relatively stable banks or may occupy an entire valley floor. The Rakaia River in Canterbury, New Zealand has cut a channel 100 metres deep into the surrounding plains.

Conditions which promote braided channel formation are:

- an abundant supply of sediment
- high stream gradient
- rapid and frequent variations in water discharge
- erodible banks
- a steep channel gradient

Locations

Extensive braided river systems are found in only a few regions worldwide:

- Alaska
- Canada
- New Zealand's South Island
- the Himalayas

All these regions contain young, rapidly eroding mountains.

The enormous Brahmaputra-Jamuna River is a classic example of a braided river.[1]

Europe contains two braided rivers: the Narew, in Poland and Belarus, and the Tagliamento in Northeastern Italy.

A notable example of a large braided stream in the contiguous United States is the Platte River in central and western Nebraska. The sediment of the arid Great Plains is augmented by the presence of the nearby Sandhills region north of the river.

The upper third of the lower Yellow River takes a braided form.

The Sewanee Conglomerate, a Pennsylvanian coarse sandstone covering the Cumberland Plateau near the University of the South, is thought to have been an ancient braided river that once covered the eastern United States.

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British Society for Geomorphology

The **British Society for Geomorphology (BSG)**, formerly the **British Geomorphological Research Group** (**BGRG**), is the professional association for geomorphologists in the United Kingdom. According to the society:

> *The BSG promotes the field of geomorphology, encouraging interests in: earth surface process, and the erosion, deposition and formation of landforms and sediments. Foci include the physical geography of our river, valley, glacier, mountain, hill, slope, coast, desert and estuary environments; alongside responses to Holocene, Pleistocene or Quaternary environmental change. These pages outline BSG activities, and include details of:- forthcoming meetings, conferences and field excursions; publications (the* Geophemera *newsletter and the academic journal* Earth Surface Processes and Landforms); *research funding; educational resources for schools; and membership details.*[1]

References

[1] http://bgrg.org/

External links

- Official website (http://www.geomorphology.org.uk)

Kirk Bryan (geologist)

Kirk Bryan	
 Kirk Bryan	
Born	22 July 1888Albuquerque, New Mexico
Died	22 August 1950Cody, Wyoming
Nationality	American
Fields	geology
Alma mater	Yale University
Doctoral students	Luna Leopold

Kirk Bryan (22 July 1888 in Albuquerque, New Mexico - 22 August 1950 in Cody, Wyoming) was the son of R.W.D. Bryan(Astronomer Under Hall in the Polaris expedition) an American geologist on the faculty of Harvard University from 1925 until his death in 1950.

Bryan received his undergraduate education at the University of New Mexico and later obtained a Ph.D. from Yale University.[1]

A geomorphologist, he worked primarily in arid regions, and was one of the pioneers in explaining the forces that formed landmasses in those areas.

According to Luna Leopold, one of his students, Bryan was influential as a teacher. In 2004, Leopold wrote:[2]

> His students made important advances in a variety of subjects, including alluvial chronology, periglacial and glacial geology, wind action, soil and vegetative effects on landscape development, and archaeology. His influence is indicated by the fact that of the four geologists who have received the National Medal of Science, three were students of Kirk Bryan.[3]

The Geological Society of America's Kirk Bryan Award is named in his honour. It is awarded annually in recognition of a publication of distinction advancing the science of geomorphology or Quaternary geology[4] , which were Bryan's areas of specialization.

Publications

Bryan was a prolific writer. This is a partial list of his scientific contributions:

- 1925. Date of channel trenching (arroyo cutting) in the arid Southwest. *Science* 62(1607): 338–344.
- 1927. Channel erosion of the Rio Salado, Socorro County, New Mexico. *U.S. Geological Survey Bulletin* 79: 15–19.
- 1928. Historic evidence on changes in the channel of Rio Puerco, a tributary of the Rio Grande in New Mexico. *Journal of Geology* 36(3): 265–282.
- 1928. Change in plant associations by change in ground water level. *Ecology* 9(4): 474–478.
- 1929. Flood-water farming. *Geographical Review* 19:444–456.
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- 1938. Prehistoric quarries and implements of pre-Amerindian aspect in New Mexico. *Science* (new series) 87 (229): 343–346.
- 1941. Geologic antiquity of man in America. *Science* 93 (2422): 505-514.
- K. Bryan and C.C. Albritton. 1943. Soil phenomena as evidence of climate changes. *American Journal of Science* 241: 469-490.
- 1950. The Place of Geomorphology in the Geographic Sciences. *Annals of the Association of American Geographers*, Vol. 40, No. 3 (Sep., 1950), pp. 196–208

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[2] Geomorphology: A Sliver Off the Corpus of Science (http://eps.berkeley.edu/people/lunaleopold/(181) Geomorphology - A Sliver Off the Corpus of Science.pdf), Luna B. Leopold, Annu. Rev. Earth Planet. Sci. 2004. 32:l-12

[3] Leopold did not provide a list of the National Medal of Science winners to whom he referred, and his meaning is not apparent. Earth scientists in addition to Leopold who had received the National Medal of Science at the time of this statement include geochemist Wallace S. Broecker, oceanographer Walter Munk, geophysicist Frank Press, oceanographer Roger Revelle, geologist William Rubey, planetary geologist Eugene Shoemaker, meteorologist Verner Suomi, geophysicist George Wetherill, and geographer Gilbert F. White. None of these men's biographies (other than Leopold's) suggest that they ever studied formally under Bryan, although several may have collaborated with him.

[4] Kirk Bryan Award (http://rock.geosociety.org/qgg/KBA.html), Geological Society of America website

[[eo:Kirk Bryan]

Channel pattern

Fluvial processes form several **channel patterns**, including:

- Straight, which are found in the most tectonically incised/active areas. This is more of a hypothetical end-member, and are not often found in nature. Straight-type channels can be found at alluvial fans.
- Braided rivers, which form in (tectonically active) areas that have a larger sedimentary load than the discharge of the river and a high gradient.
- Meandering rivers, which form a sinuous path in a usually low-gradient plain toward the end of a fluvial system.
- Anastomosed river is a rare case of a relatively straight, complicated vertical sequence of river deposits with banks held together by dense vegetation.

References

- Prothero, D. R. and Schwab, F., 1996, Sedimentary Geology, pg. 137-167, ISBN 0-7167-2726-9

Channel types

A wide variety of river and stream **channel types** exist in limnology. All these can be divided into two groups by using the water-flow gradient as either *low gradient channels* for streams or rivers with less than two percent (2%) flow gradient, or *high gradient channels* for those with greater than a 2% gradient.

Low gradient channels

Low gradient channels of rivers and streams can be divided into braided rivers, wandering rivers, single thread sinuous rivers (meandering), and anastomosing rivers. The channel type developed depends on stream gradient, riparian vegetation and sediment supply. Braided rivers tend to occur on steeper gradients where there is a large supply of sediment for braid bars, while single thread sinous channels occur where there is a lower sediment supply for point bars. Anastomosing channels are multithreaded, but are much more stable than braided channels and commonly have thick clay and silt banks and occur at lower gradients of stream bed. Wandering rivers fall between sinuous single thread and braided streams and are relatively stable multi-channel gravel bed rivers.

High gradient channels

High gradient channels of rivers and streams have been divided into riffle-pool (which can cover all of the low gradient channel morphologies discussed above), rapid/plane bed, step-pool and cascade unit morphologies.

- Riffle-pool sequence channels are composed of migrating pools and transfers bars called riffles and occur on gradients less than 1-2 percent.
- Rapids (also called plane bed, but not to be confused with the plane beds described in sand bed rivers) lack distinct pools and bars but commonly have stone cells or clusters and occur on gradients in the range of 1-5 percent, and have "whitewater".
- Step-pools are composed of channel-spanning pools and boulder/cobble steps that cause subcritical flow in the pool and supercritical flow over the steps. They occur in gradients in the range of 5 and 20%.
- Cascade units exist at steeper gradients (approx > 10–15 percent) where the channel is dominated by boulders and cobbles and channel spanning pools do not exist. Pocket pools are common. In all four channel types large woody debris may strongly influence the channel type.

References and further reading

- See Church (1992) for more details on low gradient streams and Grant et al. (1990) and Buffington and Montgomery (1997) for more details regarding high gradient streams.

- Buffington, J. M., and D. R. Montgomery (1997), A systematic analysis of eight decades of incipient motion studies, with special reference to gravel-bedded rivers, Water Resources Research, 33, 1993-2029.
- Church, M. (1992), Channel morphology and topology, in The River Handbook, edited by P. Calow and G. E. Petts, pp. 126-143, Blackwell.
- Grant, G. E., F. J. Swanson, and M. G. Wolman (1990), Pattern and origin of stepped-bed morphology in high gradient streams, western Cascades, Oregon, Geological Society of America, Bulletin, 102, 340-352.

Claypan

In geology, a **claypan** is a dense, compact, slowly permeable layer in the subsoil having a much higher clay content than the overlying material, from which it is separated by a sharply defined boundary. Claypans are usually hard when dry, and plastic and sticky when wet. They limit or slow the downward movement of water through the soil.

Coastal biogeomorphology

Over the past two decades, biogeomorphology has developed as an established research field examining the interrelationship between organisms and geomorphic processes in a variety of environments, both marine, and terrestrial (Naylor, Larissa A. 2005). Coastal biogeomorphology looks at the interaction between marine organisms, and coastal geomorphic processes (Reed, D.J. 2000). Biogeomorphology is a subdisclipline of Geomorphology.

Photo of a coastline in Lane County, OR. Obtained from Wikicommons images (11/30/2008).

This can include not only microorganisms and plants, but animals as well. These interactions are very important factors in the development of certain environments like salt marsh, mangrove and other types of coastal wetlands as well as influencing coastal and shoreline stability (Reed, D.J. 2000). There are three main processes related to biogeomorphology; bioerosion, bioprotection, and bioconstruction (Naylor, Larissa A. 2005). Bioerosion refers to the erosion of ocean substrates by living organisms. Bioprotection refers to the protection of substrate from various forms erosion by the presence of organisms, and the structures they create (i.e. coral reefs). Finally bioconstruction refers to the physical construction of biological structures on ocean substrate (Naylor, Larissa A. 2005). Marine biota interact with landform processes by building structures, accumulating carbonate sediments, accelerating erosion by boring or bioturbation, and marine plant life contribute to shoreline stability, especially in marsh and wetland environments (Bernal P., and P.M. Holligan 1992). The interaction between marine biota and geologic processes is very important to shoreline stability, especially in soft sedimentary environments where sediments are more likely to erode away. Benthic, and planktonic organisms, as well as Shellfish filter, package, and even bind fine sediments together in tidal regions. This action reduces turbidity in the area by solidifying and protecting loose, soft sediments, and thus allowing for more colonization by other organisms. If disturbance of these soft sediments occurs, particularly through human interaction like shellfish harvesting, dredging, or the introduction of toxins the environment may drastically change. If this occurs, and marine biota are removed from the environment, erosion can occur, or increase, especially in regions prone to wave action and tidal resuspension (Bernal P., and P.M. Holligan 1992).

References

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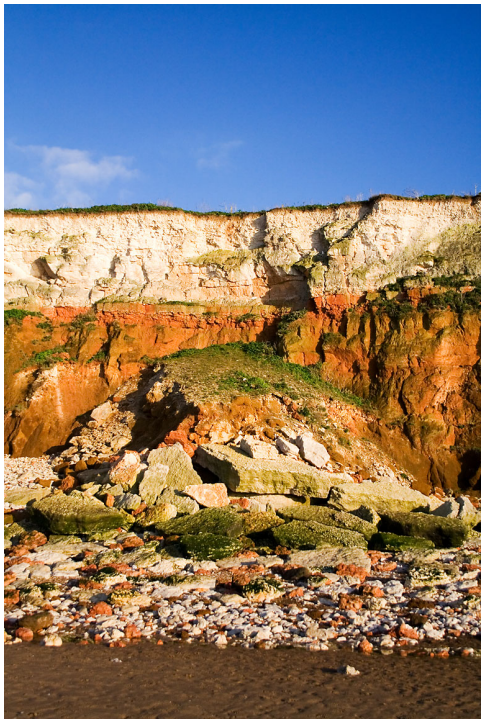
Coastal erosion

Coastal erosion is the wearing away of land and the removal of beach or dune sediments by wave action, tidal currents, wave currents, or drainage (see also beach evolution). Waves, generated by storms, wind, or fast moving motor craft, cause coastal erosion, which may take the form of long-term losses of sediment and rocks, or merely the temporary redistribution of coastal sediments; erosion in one location may result in accretion nearby. The study of erosion and sediment redistribution is called 'coastal morphodynamics'. It may be caused by hydraulic action, abrasion, impact and corrosion.



Many stretches of the East Anglia, England coastline are prone to heavy levels of erosion, such as this, the collapsed section of cliffs at Hunstanton, Norfolk.

On non-rocky coasts, coastal erosion results in dramatic (or non-dramatic) rock formations in areas where the coastline contains rock layers or fracture zones with varying resistance to erosion. Softer areas become eroded much faster than harder ones, which typically result in landforms such as tunnels, bridges, columns, and pillars.

An example of coastline erosion is in north Wales where over years of the sea beating at the cliffs the houses on top have begun collapsing into the sea. With some of them you can even see inside as the entire backs of some of the houses have come off and have been launched over the clifftop that has been torn through by the ferocious sea.

Dunwich, the capital of the English medieval wool trade, disappeared over the period of a few centuries due to redistribution of sediment by waves. Human interference can also increase coastal erosion: Hallsands in Devon, England, was a coastal village that washed away overnight, an event possibly exacerbated by dredging of shingle in the bay in front of it.

The California coast, which has soft cliffs of sedimentary rock and is heavily populated, regularly has incidents of housing damage as cliffs erode. Damage in Pacifica is shown at left. Devil's Slide, Santa Barbara and Malibu are regularly affected.

The Holderness coastline on the east coast of England, just north of the Humber Estuary, is the fastest eroding coastline in Europe due to its soft clay cliffs and powerful waves. Groynes and other artificial measures to keep it under control has only accelerated the process further down the coast, because longshore drift starves the beaches of

sand, leaving them more exposed. The white cliffs of dover have also been affected.

Wave action

Hydraulic action

Hydraulic action occurs when waves striking a cliff face compress air in cracks on the cliff face. This exerts pressure on the surrounding rock, and can progressively splinter and remove pieces. Over time, the cracks can grow, sometimes forming a cave. The splinters fall to the sea bed where they are subjected to further wave action.

Attrition

Attrition occurs when waves causes loose pieces of rock debris (scree) to collide with each other, grinding and chipping each other, progressively becoming smaller, smoother and rounder. Scree also collides with the base of the cliff face, chipping small pieces of rock from the cliff or have a corrasion (abrasion) effect, similar to sandpapering.

Corrasion

Corrasion (abrasion) occurs when waves break on cliff faces and slowly erode it. As the sea pounds cliff faces it also uses the scree from other wave actions to batter and break off pieces of rock from higher up the cliff face which can be used for this same wave action and attrition.

Corrosion

Corrosion or solution/chemical weathering occurs when the sea's pH (anything below pH 7.0) corrodes rocks on a cliff face. Limestone cliff faces, which have a high pH, are particularly affected in this way. Wave action also increases the rate of reaction by removing the reacted material.

Factors that influence erosion rates

Primary factors

The ability of waves to cause erosion of the cliff face depends on many factors.

The hardness or ‘erodibility’ of sea-facing rocks is controlled by the rock strength and the presence of fissures, fractures, and beds of non-cohesive materials such as silt and fine sand.

The rate at which cliff fall debris is removed from the foreshore depends on the power of the waves crossing the beach. This energy must reach a critical level to remove material from the debris lobe. Debris lobes can be very persistent and can take many years to completely disappear.

Beaches dissipate wave energy on the foreshore and provide a measure of protection to the adjoining land.

The stability of the foreshore, or its resistance to lowering. Once stable, the foreshore should widen and become more effective at dissipating the wave energy, so that fewer and less powerful waves reach beyond it. The provision of updrift material coming onto the foreshore beneath the cliff helps ensure a stable beach.

The adjacent bathymetry controls the wave energy arriving at the coast, and can have an important influence on the rate of cliff erosion.

Coastal Erosion

Pacifica, California coast after major storms in 1997 destroyed the houses shown above.

Beach erosion at Cabrillo National Monument, California.

Large-scale coastal erosion at Torrey Pines State Reserve, California.

Coastal erosion at Torrey Pines State Reserve, California, resulted in the necessary relocation of a scenic overlook.

Secondary factors

- Weathering and transport slope processes
- Slope hydrology
- Vegetation
- Cliff foot erosion
- Cliff foot sediment accumulation
- Resistance of cliff foot sediment to attrition and transport

Tertiary factors

- Resource extraction
- Coastal management

External links

- Sustainable coastal erosion management in Europe [1]
- Coastal Erosion Information from the Coastal Ocean Institute [2], Woods Hole Oceanographic Institution
- Environment Agency guide to coastal erosion [3]
- Wave Erosion [4]
- Time-lapse movie of beach erosion in Australia [5]
- Examine an example of wave erosion [6]
- Erosion & Flooding in the Parish of Easington [7]
- Some interesting teaching resources [8]
- Examples of coastal landforms [9]
- US Economic Costs of Coastal Erosion & Inundation [10] NOAA Economics
- British Geological Survey coastal erosion and landslides case studies [11]

Images:

- Work to reduce coastal erosion at Lyme Regis in Dorset 2006 [12]
- Images of Coastal features [13]

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[1] http://www.eurosion.org
[2] http://www.whoi.edu/page.do?pid=11914
[3] http://www.environment-agency.gov.uk/homeandleisure/107495.aspx
[4] http://cse.cosm.sc.edu/erth_sci/Coasts/Erode.htm
[5] http://www.youtube.com/watch?v=LN_0LM1XtbU
[6] http://www.classzone.com/books/earth_science/terc/content/visualizations/es1606/es1606page01.cfm?chapter_no=visualization
[7] http://www.hull.ac.uk/coastalobs/easington/erosionandflooding/
[8] http://www.geolsoc.org.uk/template.cfm?name=resources
[9] http://www.fettes.com/caithness/coastal%20erosion.htm
[10] http://www.economics.noaa.gov/?goal=weather&file=events/erosion/
[11] http://www.bgs.ac.uk/research/climatechange/environment/coastal/caseStudies.html
[12] http://www.malconet.me.uk/lymebeach
[13] http://www.earthscienceworld.org/images/search/results.html?Keyword=Sea%20Stacks#null

Coastal sediment supply

Coastal sediment supply is the transport of sediment to the beach environment by both fluvial and aeolian transport. While aeolian transport plays a role in the overall sedimentary budget for the coastal environment, it is paled in comparison to the fluvial supply which makes up 95% of sediment entering the ocean.[1] When sediment reaches the coast it is then entrained by longshore drift and littoral cells until it is accreted upon the beach or dunes.

While it is acknowledged that storm systems are the driver behind coastal erosion. There is a general consensus that human activity, mainly dam and reservoir impoundments on rivers are the cause of indirect human related coastal erosion, along with other local scale effects such as: land use change, irrigation, gravel extraction and river re-alignment.

Rate of supply

Worldwide, rivers discharge approximately $35x10^3$ km^3 of freshwater into the ocean annually. Transported in this freshwater is 15 to 20 x 10^9 tons of sediment.[2] This sediment load is not proportionally distributed across the worlds rivers, with Asian and Oceanic regions being among those most significantly affected by changing sediment regimes, as they account for 75% of this global sediment budget.

These changing rates of supply/replenishment from the fluvial environment are a dominant factor in controlling the rate of coastal erosion. While sediment supply is actually increasing, due to increased erosion rates, the supply of this sediment to the coastal environment is decreasing.

Factors that influence sediment supply

Fluvial systems are key elements for operating Earth surface change because they convey most of the global fluxes of water and sediment from land to oceans. Human activities can affect the discharge of water and sediment from a river to the coastal environment in many ways. Deforestation and agriculture, as well as urbanization can increase the erosion of a river basin by as much as an order of magnitude. Freshly exposed soil is much less likely to resist erosion by rainfall or moving water, especially in areas where land is often used for agriculture and precipitation is high.

Since the 1950s the number of dams in the world has increased more than sevenfold.[2] The creation of reservoirs has significantly reduced the sediment yield of many rivers as sediment that was entrained in the flow is stopped by a manmade barrier and the energy required to transport the material is lost, the sediment is no longer entrained as there is no flow or the flow is to slow.

Removal of water for irrigation reduces river flow and also plays its part in reducing the sediment carrying capacity of a river. Agricultural and farming practices often require intensive irrigation systems to achieve appropriate production levels. This creates a high demand on waterways as water is diverted and used to irrigate crops and pasture. This decreases the flow rate within the river system, which in turn lowers the sediment carrying capacity of the river as the energy within is less.[3] Sediment is deposited along the reach of the river and takes much longer to reach the coastal zone if at all.

Effects on the coast

This changing coastal sediment supply regime leads to predominantly erosional outcomes but it is a case by case, river by river scenario. There are areas where the coastal sediment flux has increased and accretion of the shoreline has been evident. The effects of changing sediment flux can be very localised but pronounced, below are examples within the Bohai Sea. The Yellow River delta is undergoing an accretion phase while 200 across the sea the Laun River area has experienced increased erosion rates along the coastline as a result of the changing sediment input.

Accretion

The Yellow River transports an order of magnitude more sediment than it did prior to widespread cultivation of the loess plateaus in northern China, about 2400 years ago. One implication of this large increase in the sediment discharge of Asian rivers has been the increased shoreward accretion of some deltaic areas over the past several millennia.[2] The Yellow River Delta has accreted 100s of km^2 over the past few decades. Building the coastline at a rate greater than sea level rise and depositing sediment faster than erosional processes can remove it. Mankind in Asia is occupying land areas that may not have existed if not for the increased upstream erosion and delivery of the sediment to the coastal environment.[4]

Erosion

Coastal erosion/retreat has wide-ranging implications for human habitat. With 45% of the world's population living within 100 km of a coastline. The decline of sediment supply to the coast generally results in increased rates of erosion as there is no nourishment of the beach profile. Over time as storm systems 'attack' the coastline removing sediment to offshore bars or from the system altogether a real issue develops in how to slow the advancing ocean and protect coastal developments.

Qinhuangadao coast

Since the completion of construction of two large dams on the Luan River in 1979, its annual sediment delivery to the Bohai Sea has been cut from 20.2 million tons to an annual sediment flux of only 1.9 million tons. This sharp reduction in sediment discharge has been accompanied by phase shift of the Luan River Delta into para-abandonment. This drop in sediment yield has inevitably altered the longshore transport equilibrium in the local coastal area. With prevailing northward winds, shoreline retreat rates north of the Luan River have increased from 1 m/y to 3.7 m/y over twenty year period since dam construction, rapidly changing the morphology and[5] beach profile via positive feedback until a new equilibrium was reached, at which the present retreat is back at its original 1 m/y. With a longshore drift equilibrium was reached within a new state.

Mississippi Delta

The effects of changing sediment flux were a definite compounding factor in the havoc brought upon New Orleans in 2005 by Hurricane Katrina. The Mississippi River Delta is slowly sinking due natural compaction and its sediment supply from up river being greatly diminished by up to 50%, due to dam construction in the Mississippi Basin.[6] The loss of sediment supply has resulted in subsidence of the delta and wetland reduction. Fresh sediment is not deposited at a rate fast enough for vegetation to grow on as sea level rises.[7] The brackish conditions that are essential for vegetation growth on the delta are no longer. These coastal wetlands are vital for the diverse wildlife habitat that lives among them, and for protecting developed areas from storm surges, like the one experienced during Katrina.

Solutions

Beach nourishment

This is a short term fix for a long term problem. It treats the immediate symptoms of coastal erosion by dumping of sand either just off shore or on the berm itself, It can be a costly and time consuming process as it requires upkeep on regular bases. While it may look aesthetically pleasing it does not fix the problem at hand, the beach has lost its source of natural nourishment. Artificial nourishment is an appropriate short term solution on small scale restoration projects.

Management

Humans are simultaneously increasing the availability of sediment for fluvial transportation through activities and practices that increase soil erosion, and decreasing this flux to the coastal environment through retention of sediment behind reservoir walls and decreasing river discharge rates. The net result is a global reduction in the overall sediment flux.[8] This impact on coastal erosion will be further accelerated as the sea level rises, which is anticipated because of climate change. Given the modern levels of fluvial sediment loads, over 100 billion tons of sediment have been sequestered behind human-made reservoirs. This gives reason for the effects of changes in the upstream fluvial environment to be included into the Integrated coastal zone management framework. Planners and decision makers must consider what the impacts of upstream development will have on the coastal environment. The management of the coastal zone must account for both the effect of human activities as well as the impacts resulting from corresponding changes in the coastal zone.

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Colluvium

Colluvium is the name for loose bodies of sediment that have been deposited or built up at the bottom of a low-grade slope or against a barrier on that slope, transported by gravity. The deposits that collect at the foot of a steep slope or cliff are also known by the same name. Colluvium often outerfingers with alluvium (deposits transported downslope by water). Coarse deposits due to rockfall at a cliff base are called talus (scree) and if lithified are talus breccias. Avalanches, mudslides, and landslides are processes that deposit colluvium. This build-up process is called **colluviation**.

Colluvium normally forms humps at the base of mountains or fan-shaped deposits similar in shape to alluvial fans that cover former ground surfaces. This process is an important phenomenon in the fields of archaeology and soil science.

Many colluvial soils tend to have a fragipan associated with them that are a brittle subsoil layer typically high in clay. One theory of fragipan formation is the smearing of soil during the colluvial process causing the clays to seal the surface between the moving portion of soil and the stationary soil on which it slides. Ancient sites can be preserved beneath colluvium if later changes in the landscape such as deforestation encourage a downward movement of material.

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Community Surface Dynamics Modeling System

The **Community Surface Dynamics Modeling System** (CSDMS) deals with the Earth's surface and the observable and projected changes constantly taking place. Based on the campus of the University of Colorado at Boulder, the CSDMS project involves a diverse community of experts promoting the modeling of earth surface processes by working with and developing integrated software modules that predict the erosion, transport, and deposition of sediment and solutes in landscapes and sedimentary basins.

In early 2007 James Syvitski, formerly the director of INSTAAR [1] (Institute of Arctic and Alpine Research, Boulder CO) and currently a professor at the University of Colorado in the Department of Geological Sciences, was awarded a multimillion-dollar cooperative agreement from the National Science Foundation (NSF) to coordinate this national effort and develop the CSDMS project.

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External links

- Official page [3]
- NSF Award page [4]

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Complex response

Complex Response: An environmental reaction to change that occurs at multiple levels to multiple objects, and can induce a chain reaction of responses to a single initial change.

The reaction to a change at multiple, and possibly unforeseen, levels. This could include a chain reaction of responses to a single initial change, resulting in a complex set of results, which in turn, could lead to more, and again possibly unforeseen, change. Succinctly, it is akin to the butterfly effect: one small event (change) can cascade through a given system creating new agents of change, and operating at several levels.

The term complex response in most commonly used in fluvial geomorphology, or the study of river systems and changes within those systems.

Cosmogenic radionuclide dating

Cosmogenic radionuclide dating is the use of certain cosmogenic radionuclides to date how long a particular surface has been exposed, how long a certain piece of material has been buried, or how quickly a location or drainage basin is eroding. The basic principle is that these radionuclides are produced at a known rate, and also decay at a known rate.[1]

Cosmogenic nuclides such as these are produced by chains of spallation reactions. The production rate for a particular nuclide is a function of latitude, the amount of sky that can be seen from the point that is sampled, elevation, sample depth, and density of the material in which the sample is embedded. Decay rates are given by the decay constants of the nuclides. These equations can be combined to give the total concentration of cosmogenic radionuclides in a sample as a function of age.

Common radionuclides used in geomorphology include beryllium-10,[2] aluminium-26,[2] and chlorine-36.[3] ^{10}Be and ^{26}Al are produced when a portion of a quartz crystal (SiO_2) is bombarded by a spallation product: oxygen of the quartz is transformed into ^{10}Be and the silicon is transformed into ^{26}Al. Each of these nuclides is produced at a different rate. Both can be used individually to date how long the material has been exposed at the surface. Because there are two radionuclides decaying, the ratio of concentrations of these two nuclides can be used without any other knowledge to determine an age at which the sample was buried past the production depth (typically 2–10 meters).

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Cryosuction

Cryosuction is the process in freezing soils whereby water migrates through soil pores to the freezing zone (through capillary action).[1] [2] In periglacial environments, this mechanism is highly significant. It is the predominant process in ice lens formation.[3]

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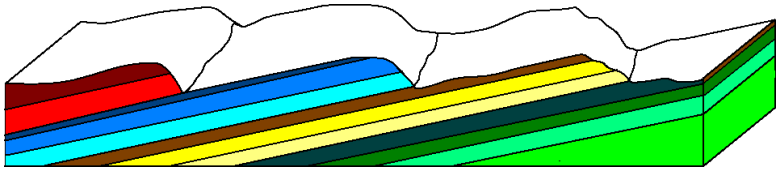
Cuesta

In structural geology and geomorphology, a **cuesta** (from Spanish: "slope") is a ridge formed by gently tilted sedimentary rock strata in a homoclinal structure.[1] [2] Cuestas have a steep slope, where the rock layers are exposed on their edges, called an escarpment or, if more steep, a cliff. Usually an erosion-resistant rock layer also has a more gentle slope on the other side of the ridge called a dip slope. The steeper slopes face inside anticlines and outside eroded synclines.[3]

Escarpment face of a cuesta broken by a fault.
Cumberland Plateau, Tennessee.



Schematic cross section of three cuestas, dip slopes facing left, and harder rock layers in darker colors than softer ones

Examples of cuestas

Two well-known cuestas in western New York and southern Ontario are the Onondaga escarpment and the Niagara escarpment, respectively. The dip of the Onondaga is about 40 feet per mile (about 7.6 m/km) to the south. The escarpment edge faces north and, in its most populated section, runs roughly parallel to the southern Lake Ontario shoreline.

The Gulf Coastal Plain in Texas is punctuated by a series of cuestas that parallel the coast, as are most coastal plains.[4] The Reynosa Plateau is the most coast-ward cuesta, which sees surface expression with the Bordes-Oakville escarpment, on the northwest side and a low ridge on the eastern boundary, called the Reynosa cuesta, where the deposits dip below later Pliocene-Pleistocene deposits of the Willis and Lissie Formation.

Cuesta in Crimea

Cuestas have less dramatic expression in the United Kingdom, with two notable examples being the northwest-facing escarpment of the Jurassic chalk White Horse Hills and the similarly-aligned escarpment of the Cotswolds, sometimes called the Cotswold Edge.

In continental Europe, the Swabian Alb offers particularly good views of cuestas in Jurassic rock. In France, the term for a cuesta is the same as for a coastline: "côte". Notable French cuestas are the wine-growing regions of Côte d'Or and Côtes du Rhône.

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External links

- Escarpment geology (http://www.hamiltonnature.org/habitats/escarpment/escarpment_geology.htm)

Cut bank

A **cut bank**, also known as a **river cliff**, is an erosional feature of streams. Cut banks are found in abundance along mature or meandering streams, they are located on the *outside* of a stream bend, known as a meander. They are shaped much like a small cliff, and are formed by the erosion of soil as the stream collides with the river bank. As opposed to a point bar which is an area of deposition, a cut bank is an area of erosion.

Typically, cut banks are nearly vertical and often expose the roots of nearby plant life. Often, particularly during periods of high rainfall and higher-than average water levels, trees and poorly placed buildings can fall into the stream due to mass wasting events. Given enough time, the combination of erosion along cut banks and deposition along point bars can lead to the formation of an oxbow lake.

Not only are cut banks steep and unstable, they are also the area of a stream where the water is flowing the fastest and the deepest, making them rather dangerous. Geologically speaking, this is known as an area of *high-energy*.

Material eroded here is deposited downstream in point bars.

Cut bank erosion and point bar deposition as seen on the Powder River in Montana.

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- Photo illustration of a cut bank [1]

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Cycle of erosion

The **cycle of erosion** was a model for stream erosion and landscape development proposed by William Morris Davis in the late 19th century. Davis' *Stages in the fluvial cycle of erosion* published in 1909 defined a *young, mature, and old* sequence in the development of river valleys and the landscape the rivers were eroding. The concept of peneplanation was a part of his model.

The model developed by Davis, though important in historical context, is currently considered only a *first approximation*. Developments in the sciences of geology and geomorphology, especially the plate tectonics revolution of the 1960s and 70s, have confirmed the preliminary nature of the model.

External links

- Fluvial cycle of erosion [1]

References

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Debris flow

Scars formed by debris flow in great Los Angeles during the winter of 1968-1969. The photograph was taken within several months of the debris flows occurring.

A **debris flow** is a fast moving, liquefied landslide of unconsolidated, saturated debris that looks like flowing concrete. It is differentiated from a mudflow in terms of the viscosity and textural properties of the flow. Flows can carry material ranging in size from clay to boulders, and may contain a large amount of woody debris such as logs and tree stumps. Flows can be triggered by intense rainfall, glacial melt, or a combination of the two. Speed of debris flows can vary from 5 km/h to up to 80 km/h in extreme cases. Volumes of material delivered by single events vary from less than 100 to more than 100,000 cubic meters. Variables considered important in debris flow initiation include slope angle, available loose sediment, and degree of land disturbance by activities such as forest harvesting. Debris flows are often more frequent following forest and brush fires, as experience in southern California clearly demonstrates. Debris flows are extremely destructive to life and property, and claim thousands of lives world-wide in any given year. They are a particular problem in steep mountainous areas subjected to intense rainstorms, and have received particular attention from researchers in Japan, Western USA, Western Canada, New Zealand, the European Alps, and Kazakhstan.[1]

Features and behavior

Debris flows generally form when unconsolidated material becomes saturated and unstable, either on a hillslope or in a stream channel. Flows are accelerated downhill by gravity and tend to follow steep mountain channels. The front, or 'head' of debris flow often contains a great deal of coarser material such as boulders and logs. Trailing behind this frontal lobe is the less viscous, main part of the flow that contains sand, silt and clay. Debris flows eventually become 'thinner', or less viscous, muddy flood waters as they deposit their coarser components in areas of reduced gradient. Debris flows tend to move in pulses, or discrete surges, as friction or other barriers are overcome during the flow. Sometimes earlier pulses or previous debris flow deposits form levees which confine the flow until they are breached by later, larger flows. The presence of older levees (a.k.a. lateral deposits) provides some idea of the magnitudes of previous debris flows in a particular area, and through dating of trees growing on such deposits, may indicate the approximate frequency of destructive debris flows. This is important information for land development in areas where debris flows deposit material, known as debris fans and alluvial fans.

Almaty, Kazakhstan, after the catastrophic debris flow of 1921. A number of facilities, including the Medeu Dam, have been built since to prevent flows of this kind from reaching the city.[1]

Ancient debris flow deposit, Resting Springs Pass, California.

Types

Lahar

A lahar is a debris flow related in some way to volcanic activity, either directly as a result of an eruption, or indirectly by the collapse of loose material from the flanks of a recently active volcano. A variety of factors may trigger a lahar, including melting of glacial ice due to volcanic activity or pyroclastic flow, intense rainfall on loose pyroclastic material, or the out bursting of a lake that was previously dammed by pyroclastic or glacial material. The word lahar is of Indonesian origin, but is now routinely used by geologists world-wide to describe volcanogenic debris flows.

Jökulhlaup

A jökulhlaup is a debris flow that originates from a glacial outburst flood. Jökulhlaup is an Icelandic word which refers specifically to floods having a glacial trigger. In the case of Iceland, many such floods are triggered by sub-glacial volcanic eruptions, since Iceland sits atop the Mid-Atlantic Ridge. Elsewhere, a more common cause of jökulhlaups is the breaching of ice-dammed or moraine-dammed lakes. Such breaching events are often caused by the sudden calving of glacier ice into a lake, which then causes a displacement wave to breach a moraine or ice dam. Downvalley of the breach point, a jökulhlaup may increase greatly in size through entrainment of loose sediment and water from the valley through which it travels. Travel distances may exceed 100 km.

Theories and models of debris flows

Debris flows as mud flows

- Rheologically based models that apply to mud flows that are treated as a homogeneous liquid (Examples include: Bingham, visco-plastic, thixotropic, etc.)
- The mixture theory of Iverson[2]
- Dam break wave e.g. Hunt,[3] Chanson et al.[4]
- Roll wave Takahashi,[5] Davies[6]

Unsaturated "rocky" or "stony" debris flows

- Progressive wave-Hungr[7]
- A type of translating rock dam-Coleman[8]

Topographic effects in debris flows

- Curved and twisted channel: "flow over-banking"-Pudasaini et al.[9]

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External links

- Mass Movements. Section of the information platform "Natural hazards in Switzerland" (http://www.naturgefahren.ch/index.php?userhash=82419776&l=e&nav=4,472,472,472,472)
- Washington State information about Debris flows, and related material (http://vulcan.wr.usgs.gov/Glossary/Lahars/description_lahars.html)

Degradation (geology)

In geology, **degradation** refers to the lowering of a fluvial surface, such as a stream bed or floodplain, through erosional processes.[1] [2] It is the opposite of aggradation. Degradation is characteristic of channel networks in which either bedrock erosion is taking place, or in systems that are sediment-starved and are therefore entraining more material than is being deposited. When a stream degrades, it leaves behind a fluvial terrace. This can be further classified as a strath terrace—a bedrock terrace that may have a thin mantle of alluvium—if the river is incising through bedrock. These terraces may often be dated with methods such as cosmogenic radionuclide dating, OSL dating, and paleomagnetic dating (using reversals in the Earth's magnetic field to constrain the timing of events) to find when a river was at a particular level and how quickly it is downcutting.

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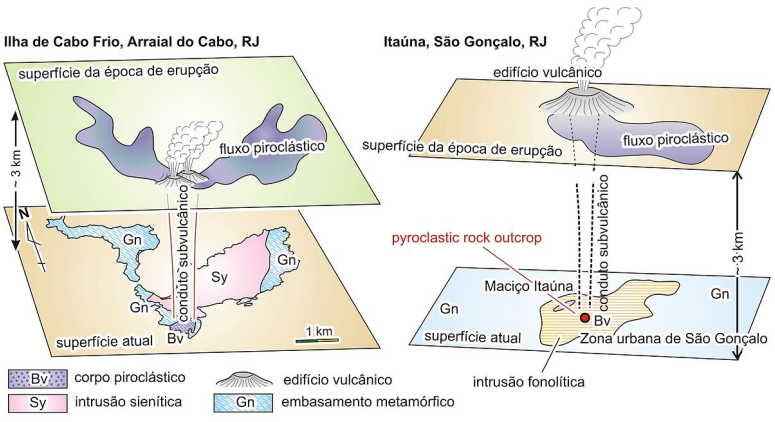
Denudation

In geology, **denudation** is the long-term sum of processes that cause the wearing away of the earth's surface leading to a reduction in elevation and relief of landforms and landscapes. Endogenetic processes such as volcanoes, earthquakes, and plate tectonics uplift and expose continental crust to the exogenetic denudation processes of weathering, erosion, and mass wasting.



Schematic illustration of regional denudation for felsic alkaline intrusive rock bodies of the State of Rio de Janeiro, Brazil: Cabo Frio Island and Itaúna Body.

Processes

Denudation incorporates mechanical, biological and chemical processes of erosion, weathering and mass wasting. Denudation can involve the removal of both solid particles and dissolved material. These include sub-processes of cryofracture, insolation weathering, slaking, salt weathering, bioturbation and anthropogenic impacts.[1]

Factors affecting denudation include:

- Surface topography
- Geology
- Climate (most directly in chemical weathering)
- Tectonic activity

- Biosphere (fauna and flora)
- Anthropogenic activity

Rates

Modern denudation estimates are usually based on stream load measurements taken at gauging stations. Suspended load, bed load, and dissolved load are included in measurements. The weight of the load is converted to volumetric units and the load volume is divided by the area of the watershed above the gaging station. The result is an estimate of the wearing down of the Earth's surface in inches or centimeters per 1000 years.[2] In most cases no adjustments are made for human impact, which causes the measurements to be inflated.[3]

Denudation rates are usually much lower than the rates of uplift. The only areas at which there could be equal rates of denudation and uplift are active plate margins with an extended period of continuous deformation.[4]

Proposed cycles

Early studies prompted the formation of denudation cycle hypotheses to describe land formations. Although at present they are mostly discounted, many of these models are enduring due to their simplicity and seemingly obvious assumptions.

In the 1890s W. M. Davis proposed a cycle of 'wearing down' in which so called 'young' landscapes had high gradients and elevations, and waning, low elevation topography through middle age to old age. Landscapes of Britain and Wales were thought to reflect these multiple peneplanation and rejuvenation cycles, such as the 3,000-foot remnant summit plateau in North Wales. A number of assumptions of fluvial and glacial dynamics in temperate areas were made in the formation of this model.

Such theories were proposed before tectonic theory was largely understood, and therefore are now largely discredited.

Volcanic landforms

A) Villarica Volcano, Chile, a volcano without effects of erosion and denudationB) Chachahén Volcano, Mendoza, Argentina, a volcano with strong effect of erosion but no denudationC) Cardiel Lake, Santa Cruz, Argentina, a volcanic area under strong effect of **denudation**, exposing subvolcanic rock body.[5]

Denudation exposes deep sub-volcanic structures on the present surface of the area where volcanic activity once occurred. Sub-volcanic structures such as neck and dyke (volcanic vent) are exposed by denudation.

Medical use

In medicine, denudation refers to the loss of surface layers, such as the epithelium.

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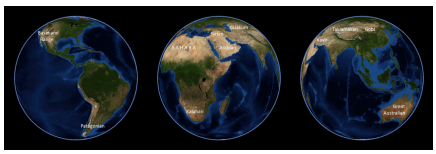
Desert

A **desert** is a landscape or region that receives an extremely low amount of precipitation, less than enough to support growth of most plants. Deserts are defined as areas with an average annual precipitation of less than 250 millimetres (10 in) per year,[1] [2] or as areas where more water is lost by evapotranspiration than falls as precipitation.[3] In the Köppen climate classification system, deserts are classed as *BWh* (hot desert) or *BWk* (temperate desert). In the Thornthwaite climate classification system, deserts would be classified as arid megathermal climates.[4] [5]

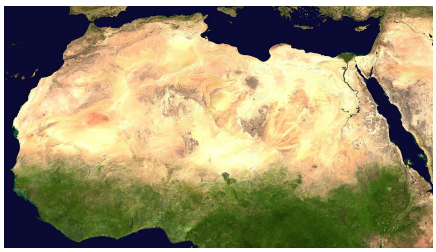


Largest non-polar deserts

Hills in the Judean desert

Geography

Deserts are part of a wide classification of regions that, on an average annual basis, have a moisture deficit (i.e. they can potentially lose more than is received). Deserts are located where vegetation cover is sparse to almost nonexistent.[1] [6] Deserts take up about one fifth (20%) of the Earth's land surface.[1] Hot deserts usually have a large diurnal and seasonal temperature range, with high daytime temperatures, and low nighttime temperatures (due to extremely low humidity). In hot deserts the temperature in the daytime can reach 45 °C/113 °F or higher in the summer, and dip to 0 °C/32 °F or lower at nighttime in the winter. Water vapor in the atmosphere acts to trap long



A satellite image of the Sahara, the world's largest hot desert.

wave infrared radiation from the ground, and dry desert air is incapable of blocking sunlight during the day (due to absence of clouds) or trapping heat during the night. Thus, during daylight most of the sun's heat reaches the ground, and as soon as the sun sets the desert cools quickly by radiating its heat into space. Urban areas in deserts lack large (more than 14 °C/25 °F) daily temperature variations, partially due to the urban heat island effect.

The snow surface at Dome C Station in Antarctica is representative of the majority of the continent's surface.

Many deserts are formed by rain shadows; mountains blocking the path of precipitation to the desert (on the lee side of the mountain). Deserts are often composed of sand and rocky surfaces. Sand dunes called ergs and stony surfaces called hamada surfaces compose a minority of desert surfaces. Exposures of rocky terrain are typical, and reflect minimal soil development and sparseness of vegetation. The soil is rocky because of the low chemical weathering, and the relative absence of a humus fraction.

Bottomlands may be salt-covered flats. Eolian processes are major factors in shaping desert landscapes. Polar deserts (also seen as "cold deserts") have similar features, except the main form of precipitation is snow rather than rain. Antarctica is the world's largest cold desert (composed of about 98% thick continental ice sheet and 2% barren rock). Some of the barren rock is to be found in the so-called Dry Valleys of Antarctica that almost never get snow, which can have ice-encrusted saline lakes that suggest evaporation far greater than the rare snowfall due to the strong katabatic winds that evaporate even ice.

The largest hot desert is the Sahara in northern Africa, covering 9 million square kilometres and 12 countries.

Deserts sometimes contain valuable mineral deposits that were formed in the arid environment or that were exposed by erosion. Due to extreme and consistent dryness, some deserts are ideal places for natural preservation of artifacts and fossils.

The ten largest deserts

Rank	Desert	Area (km²)	Area (mi²)
1	**Antarctic Desert** (Antarctica)	13,829,430	5,339,573
2	**Sahara Desert** (Africa)	9,100,000+	3,320,000+
3	**Arctic Desert** (Arctic)	2,600,000+	1,003,600+
4	**Arabian Desert** (Middle East)	2,330,000	900,000
5	**Gobi Desert** (Asia)	1,300,000	500,000
6	**Kalahari Desert** (Africa)	900,000	360,000
7	**Patagonian Desert** (South America)	670,000	260,000
8	**Great Victoria Desert** (Australia)	647,000	250,000
9	**Syrian Desert** (Middle East)	520,000	200,000
10	**Great Basin Desert** (North America)	492,000	190,000

Etymology

The Thar Desert near Jaisalmer, India.

English *desert* and its Romance cognates (including Italian and Portuguese *deserto*, French *désert* and Spanish *desierto*) all come from the ecclesiastical Latin *dēsertum* (originally "an abandoned place"), a participle of *dēserere*, "to abandon." (See desertion.) The correlation between aridity and sparse population is complex and dynamic, varying by culture, era, and technologies; thus the use of the word *desert* can cause confusion. In English prior to the 20th century, *desert* was often used in the sense of "unpopulated area", without specific reference to aridity; but today the word is most often used in its climate-science sense (an area of low precipitation)—and a desert may be quite heavily populated, with millions of inhabitants. Phrases such as "desert island" and "Great American Desert" in previous centuries did not necessarily imply sand or aridity; their focus was the sparse population. However, the connotation of a hot, parched, and sandy place often influences today's popular interpretation of those phrases.

Classification

Tadrart Acacus desert in western Libya, part of the Sahara.

In 1961, Peveril Meigs divided desert regions on Earth into three categories according to the amount of precipitation they received. In this now widely accepted system, extremely arid lands have at least 12 consecutive months without rainfall, arid lands have less than 250 mm (10 in) of annual rainfall, and semiarid lands have a mean annual precipitation of between 250 and 500 mm (10–20 in). Arid and extremely arid lands are deserts, and semiarid areas are generally referred to as steppes.[1]

Definition

Measurement of rainfall alone cannot provide an accurate definition of what a desert is because being arid also depends on evaporation, which depends in part on temperature. For example, Phoenix, Arizona receives less than 250 millimeters (10 in) of precipitation per year, and is immediately recognized as being located in a desert due to its arid adapted plants. The North Slope of Alaska's Brooks Range also receives less than 250 millimeters (10 in) of precipitation per year and is often classified as a cold desert.[7] Other regions of the world have cold deserts, including areas of the Himalayas[8] and other high altitude areas in other parts of the world.[9] Polar deserts cover much of the ice free areas of the arctic and Antarctic.[10] [11]

Potential evapotranspiration supplements the measurement of rainfall in providing a scientific measurement-based definition of a desert. The water budget of an area can be calculated using the formula $P - PE \pm S$, wherein P is precipitation, PE is potential evapotranspiration rates and S is amount of surface storage of water. Evapotranspiration is the combination of water loss through atmospheric evaporation and through the life processes of plants. Potential evapotranspiration, then, is the amount of water that *could* evaporate in any given region. As an example, Tucson, Arizona receives about 300 millimeters (12 in) of rain per year, however about 2500 millimeters (100 in) of water could evaporate over the course of a year. In other words, about 8 times more water could evaporate from the region than actually falls. Rates of evapotranspiration in cold regions such as Alaska are much lower because of the lack of heat to aid in the evaporation process.

There are different forms of deserts. Cold deserts can be covered in snow or ice; frozen water unavailable to plant life. These are more commonly referred to as tundra if a short season of above-freezing temperatures is experienced,

or as an ice cap if the temperature remains below freezing year-round, rendering the land almost completely lifeless.

Most non-polar deserts are hot in the day and chilly at night (for the latitude) because of the lack of the moderating effect of water. In some parts of the world, deserts are created by a rain shadow effect in which air masses lose much of their moisture as they move over a mountain range; other areas are arid by virtue of being very far from the nearest available sources of moisture.

Deserts are also classified by their geographical location and dominant weather pattern as trade wind, mid-latitude, rain shadow, coastal, monsoon, or polar deserts. Former desert areas presently in non-arid environments are paleodeserts.

The Agasthiyamalai hills cut off Tirunelveli in India from the monsoons, creating a rainshadow region.

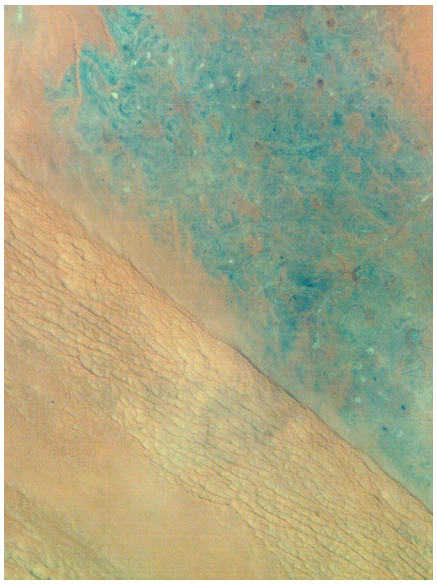
Montane deserts are arid places with a very high altitude; the most prominent example is found north of the Himalayas, especially in Ladakh region of Jammu and Kashmir, in parts of the Kunlun Mountains and the Tibetan Plateau. Many locations within this category have elevations exceeding 3,000 meters (10,000 ft) and the thermal regime can be hemiboreal. These places owe their profound aridity (the average annual precipitation is often less than 40 mm or 1.5 in) to being very far from the nearest available sources of moisture. Montane deserts are normally cold.

Rain shadow deserts form when tall mountain ranges block clouds from reaching areas in the direction the wind is going. As the air moves over the mountains, it cools and moisture condenses, causing precipitation on the windward side. When that air reaches the leeward side, it is dry because it has lost the majority of its moisture, resulting in a desert. The air then warms, expands, and blows across the desert. The warm, desiccated air takes with it any remaining moisture in the desert.

Desert features

Sand covers only about 20% of Earth's deserts. Most of the sand is in sand sheets and sand seas—vast regions of undulating dunes resembling ocean waves "frozen" in an instant of time. In general, there are five forms of deserts:

- Mountain and basin deserts
- Hamada deserts, which consist of plateau landforms
- Regs, which consist of rock pavements
- Ergs, which are formed by sand seas
- Intermontane Basins



Satellite view of Al-Dahna desert in Saudi Arabia showing different depositional features

Nearly all desert surfaces are plains where eolian deflation—removal of fine-grained material by the wind—has exposed loose gravels consisting predominantly of pebbles but with occasional cobbles.

The remaining surfaces of arid lands are composed of exposed bedrock outcrops, desert soils, and fluvial deposits including alluvial fans, playas, desert lakes, and oases. Bedrock outcrops occur as small mountains surrounded by extensive erosional plains.

Several different types of dunes exist. Barchan dunes are produced by strong winds blowing across a level surface and are crescent-shaped. Longitudinal or seif dunes are dunes that are parallel to a strong wind that blows in one

general direction. Transverse dunes run at a right angle to the constant wind direction. Star dunes are star-shaped and have several ridges that spread out around a point.

Oases are vegetated areas moistened by springs, wells, or by irrigation. Many are artificial. Oases are often the only places in deserts that support crops and permanent habitation.

Fauna and flora

Prickly pear flower

Camel Thorn Tree (Acacia erioloba) in the Namib Desert

Saguaro cacti in the Sonoran Desert of Arizona.

Deserts have a reputation for supporting very little life, but in reality deserts often have high biodiversity, including animals that remain hidden during daylight hours to control body temperature or to limit moisture needs. Some fauna includes the kangaroo rat, coyote, jack rabbit, and many lizards. These animals adapted to live in deserts are called xerocoles. Many desert animals (and plants) show especially clear evolutionary adaptations for water conservation or heat tolerance, and so are often studied in comparative physiology, ecophysiology, and evolutionary physiology. One well-studied example is the specializations of mammalian kidneys shown by desert-inhabiting species.[12] Many examples of convergent evolution have been identified in desert organisms, including between cacti and Euphorbia, kangaroo rats and jerboas, *Phrynosoma* and *Moloch* lizards.

Some flora includes shrubs, Prickly Pears, Desert Holly, and the Brittlebush. Most desert plants are drought- or salt-tolerant, such as xerophytes. Some store water in their leaves, roots, and stems. Other desert plants have long taproots that penetrate to the water table if present, or have adapted to the weather by having wide-spreading roots to absorb water from a greater area of the ground. Another adaptation is the development of small, spiny leaves which shed less moisture than deciduous leaves with greater surface areas. The stems and leaves of some plants lower the surface velocity of sand-carrying winds and protect the ground from erosion. Even small fungi and microscopic plant organisms found on the soil surface (so-called *cryptobiotic soil*) can be a vital link in preventing erosion and providing support for other living organisms.

Deserts typically have a plant cover that is sparse but enormously diverse. The giant saguaro cacti of the Sonoran Desert provide nests for desert birds and serve as "trees" of the desert. Saguaro grow slowly but may live up to 200 years. When 9 years old, they are about 15 centimeters (6 in) high. After about 75 years, the cacti develop their first branches. When fully grown, saguaro cacti are 15 meters (50 ft) tall and weigh as much as 10 tons. They dot the Sonoran and reinforce the general impression of deserts as cactus-rich land.

Although cacti are often thought of as characteristic desert plants, other types of plants have adapted well to the arid environment. They include the pea and sunflower families. Cold deserts have grasses and shrubs as dominant vegetation.

Flora of Baja California Desert, Cataviña region, Mexico

Water

Atacama, the world's driest desert[13]

Atacama is the driest place on Earth[13] [14] [15] [16] and is virtually sterile because it is blocked from moisture on both sides by the Andes mountains and by the Chilean Coast Range. The cold Humboldt Current and the anticyclone of the Pacific are essential to keep the dry climate of the Atacama. The average rainfall in the Chilean region of Antofagasta is just 1 mm per year. Some weather stations in the Atacama have never received rain. Evidence suggests that the Atacama may not have had any significant rainfall from 1570 to 1971. It is so arid that mountains that reach as high as 6,885 meters (22,590 feet) are completely free of glaciers and, in the southern part from 25°S to 27°S, may have been glacier-free throughout the Quaternary, though permafrost extends down to an altitude of 4,400 meters and is continuous above 5,600 meters.

Rain *does* fall occasionally in deserts, and desert storms are often violent. A record 44 millimeters (1.7 in) of rain once fell within 3 hours in the Sahara. Large Saharan storms may deliver up to 1 millimeter per minute. Normally dry stream channels, called arroyos or wadis, can quickly fill after heavy rains, and flash floods make these channels dangerous.

A thunderstorm hits Wah Wah Valley, Utah

A flash flood in the Gobi

Though little rain falls in deserts, deserts receive runoff from ephemeral, or short-lived, streams fed considerable quantities of sediment for a day or two. Although most deserts are in basins with closed or interior drainage, a few deserts are crossed by 'exotic' rivers that derive their water from outside the desert. Such rivers infiltrate soils and evaporate large amounts of water on their journeys through the deserts, but their volumes are such that they maintain their continuity. The Nile River, the Colorado River, and the Yellow River are exotic rivers that flow through deserts to deliver their sediments to the sea. Deserts may also have underground springs, rivers, or reservoirs that lie close to the surface, or deep underground. Plants that have not completely adapted to sporadic rainfalls in a desert environment may tap into underground water sources that do not exceed the reach of their root systems.

While deserts are well-known for their lack of water, some groups have adapted ways to find water in this harsh environment. The Bedouin, for example, turn over half-buried stones just before dawn so dew forms on them.[17]

Lakes form where rainfall or meltwater in interior drainage basins is sufficient. Desert lakes are generally shallow, temporary, and salty. Because these lakes are shallow and have a low bottom gradient, wind stress may cause the lake waters to move over many square kilometers. When small lakes dry up, they leave a salt crust or hardpan. The flat area of clay, silt, or sand encrusted with salt that forms is known as a playa or a sink. There are more than a hundred playas in North American deserts. Most are relics of large lakes that existed during the last ice age about 12,000 years ago. Lake Bonneville was a 52,000-square-kilometer (20,000 mi²) lake almost 300 meters (1000 ft) deep in Utah, Nevada, and Idaho during the Ice Age. Today the remnants of Lake Bonneville include Utah's Great Salt Lake, Utah Lake, and Sevier Lake. Because playas are arid landforms from a wetter past, they contain useful clues to climatic change.

When the occasional precipitation does occur, it erodes the desert rocks quickly.

The flat terrains of hardpans and playas make them excellent racetracks and natural runways for airplanes and spacecraft. Ground-vehicle speed records have been established on the flat lakebeds of the Black Rock Desert in Nevada and Bonneville Speedway in Utah. Space shuttles and flight-test aircraft land on Rogers Lake Playa at Edwards Air Force Base in California.

Formation of hot deserts

There are four main, interlinked causes of hot deserts:

- The formation of the subtropical high-pressure cell.
- The rain shadow effect in the belt of easterly trade winds.
- The effect of the cold currents off the west coast of the continents at these latitudes.
- The depositing sands of a desert along its border into the fertile land

Hot deserts (like cold deserts) may result in average temperature cooling[18] because they reflect more of the incoming light (their albedo is higher than that of water or forests).

Mineral resources

A mining plant near Jodhpur, India

Deserts may contain great amounts of mineral resources over their entire surface. This occurrence in minerals also determines the color. For example, the red color of many sand deserts is a result of the occurrence of laterite.[19]

Some mineral deposits are formed, improved, or preserved by geologic processes that occur in arid lands as a consequence of climate. Ground water leaches ore minerals and redeposits them in zones near the water table. This leaching process concentrates these minerals as ore that can be mined.

Evaporation in arid lands enriches mineral accumulation in their lakes. Lake beds known as playas may be sources of mineral deposits formed by evaporation. Water evaporating in closed basins precipitates minerals such as gypsum, salts (including sodium nitrate and sodium chloride), and borates. The minerals formed in these evaporite deposits depend on the composition and temperature of the saline waters at the time of deposition.

Significant evaporite resources occur in the Great Basin Desert of the United States, mineral deposits made famous by the "20-mule teams" that once hauled borax-laden wagons from Death Valley to the railroad. Boron, from borax and borate evaporites, is an essential ingredient in the manufacture of glass, enamel, agricultural chemicals, water softeners, and pharmaceuticals. Borates are mined from evaporite deposits at Searles Lake, California, and other desert locations. The total value of chemicals that have been produced from Searles Lake substantially exceeds US$1 billion.

The Atacama Desert of Chile is unique among the deserts of the world in its great abundance of saline minerals. Sodium nitrate has been mined for explosives and fertilizer in the Atacama since the middle of the 19th century. Nearly 3 million metric tons were mined during World War I.

Valuable minerals located in arid lands include copper in the United States, Chile, Peru, and Iran; iron and lead-zinc ore in Australia; and gold, silver, and uranium deposits in Australia and the United States. Nonmetallic mineral resources and rocks such as beryllium, mica, lithium, clays, pumice, and scoria also occur in arid regions. Sodium carbonate, sulfate, borate, nitrate, lithium, bromine, iodine, calcium, and strontium compounds come from sediments and near-surface brines formed by evaporation of inland bodies of water, often during geologically recent times.

The Green River Formation of Colorado, Wyoming, and Utah contains alluvial fan deposits and playa evaporites created in a huge lake whose level fluctuated for millions of years. Economically significant deposits of trona, a major source of sodium compounds, and thick layers of oil shale were created in the arid environment.

Some of the more productive petroleum areas on Earth are found in arid and semiarid regions of Africa and the Mideast, although the oil fields were originally formed in shallow marine environments. Recent climate change has placed these reservoirs in an arid environment. It's noteworthy that Ghawar, the world's largest and most productive oilfield is mostly under the Empty Quarter and Al-Dahna deserts.

Other oil reservoirs, however, are presumed to be eolian in origin and are presently found in humid environments. The Rotliegendes, a hydrocarbon reservoir in the North Sea, is associated with extensive evaporite deposits. Many of the major U.S. hydrocarbon resources may come from eolian sands. Ancient alluvial fan sequences may also be hydrocarbon reservoirs.

Solar energy resources

Deserts are increasingly seen as sources for solar energy. The Negev Desert and the surrounding area, including the Arava Valley, are the sunniest parts of Israel and little of this land is arable, which is why it has become the center of the Israeli solar industry.[20] David Faiman, a world expert on solar energy, feels the energy needs of a country like Israel could be met by building solar energy plants in the Negev.[21] Faiman also feels the technology now exists to supply all of the world's electricity needs with 10% of the Sahara.[21] Solel has nine fields of solar collectors in the Mojave Desert of California.[22] It recently signed a contract to build the Mojave Solar Park, which will be the world's largest solar generating plant.[23] [24]

Human life in deserts

A desert is a hostile, potentially deadly environment for unprepared humans. In hot deserts, high temperatures cause rapid loss of water due to sweating, and the absence of water sources with which to replenish it can result in dehydration and death within a few days. In addition, unprotected humans are also at risk from heatstroke. Humans may also have to adapt to sandstorms in some deserts, not just in their adverse effects on respiratory systems and eyes, but also in their potentially harmful effects on equipment such as filters, vehicles and communication equipment. Sandstorms can last for hours, sometimes even days. This makes surviving in the desert quite difficult for humans.

Mahktesh Gadol, an erosional basin in the Negev Desert of southern Israel

Cooking in a desert

Despite this, some cultures have made hot deserts their home for thousands of years, including the Bedouin, Tuareg and Pueblo people. Modern technology, including advanced irrigation systems, desalinization and air conditioning have made deserts much more hospitable. In the United States and Australia for example, desert farming has found extensive use. In cold deserts, hypothermia and frostbite are the chief hazards, as well as dehydration in the absence of a source of heat to melt ice for drinking. Falling through pack-ice or surface ice layers into freezing water is a particular danger requiring emergency action to prevent rapid hypothermia. Starvation is also a hazard; in low temperatures the body requires much more food energy to maintain body heat and to move. As with hot deserts, some people such as the Inuit have adapted to the harsh conditions of cold deserts. Most traditional human life in deserts is nomadic. It depends in hot deserts on finding water, and on following infrequent rains to obtain grazing for livestock. In cold deserts, it depends on finding good hunting and fishing grounds, on sheltering from blizzards and winter extremes, and on storing enough food for winter. Permanent settlement in both kinds of deserts requires permanent water and food sources and adequate shelter, or the technology and energy sources to provide it.

Many deserts are flat and featureless, lacking landmarks, or composed of repeating landforms such as sand dunes or the jumbled ice-fields of glaciers. Advanced skills or devices are required to navigate through such landscapes and inexperienced travellers may perish when supplies run out after becoming lost. In addition sandstorms or blizzards may cause disorientation in severely reduced visibility.

Kolob Canyon, part of Zion National Park, Utah, United States is part of the larger desert the Colorado Plateau.

The danger represented by wild animals in deserts has been featured in explorers' accounts but does not cause higher rates of death than in other environments such as rain forests or savanna woodland, and generally does not by itself affect human distribution. Defense against polar bears may be advisable in some areas of the Arctic, as may precautions against venomous snakes and scorpions in choosing sites at which to camp in some hot deserts.

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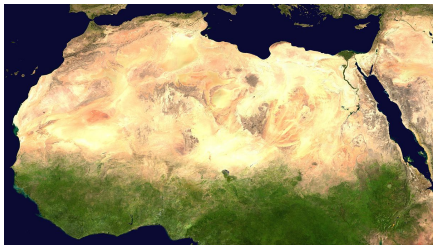
- "The Desert Biome" (http://www.ucmp.berkeley.edu/glossary/gloss5/biome/deserts.html). University of California Museum of Paleontology. 1996.
- "Global Deserts Outlook" (http://www.unep.org/geo/gdoutlook/). United Nations Environment Programme (UNEP). 2006., a report in the Global Environment Outlook (GEO) series.
- Map with biodiversity scenarios for desert areas, from the Global Deserts Outlook (http://maps.grida.no/go/graphic/relative_biodiversity_scenarios_for_deserts_2000_2050).
- Finding Water in the Desert (http://www.wikihow.com/Find-Water-in-the-Desert) - wikiHow page

Desert greening

Desert greening is activated to greening deserts with different methods.



A satellite image of the Sahara; the world's largest hot desert and third largest desert after Antarctica and the Arctic.

Methods

- Planting trees and plants and resistant plants such as Salicornia and Halophyte
- Artificial rain
- Flood and water distribution
- Balance to protect livestock and pasture vegetation
- The advantage of efficient methods of rain water accumulate
- Regeneration salt Desert
- Greenhouse agriculture like the Integrated biotectural system

Countering desertification

The soil of the Thar Desert in India remains dry for much of the year and is prone to wind erosion. High velocity winds blow soil from the desert, depositing some on neighboring fertile lands, and causing shifting sand dunes within the desert, which bury fences and block roads and railway tracks. Permanent solution to this problem of shifting sand dunes can be provided by fixation of the shifting sand dunes with suitable plant species and planting windbreaks and shelterbelts. They also provide protection from hot or cold and desiccating winds and the invasion of sand. The Rajasthan Canal system is the major irrigation scheme of the Thar Desert and is conceived to reclaim it and also to check spreading of the desert to fertile areas.

Checking of shifting sand dunes through plantations of Acacia tortilis near Laxmangarh town. There are few local tree species suitable for planting in the desert region and these are slow growing. The introduction of exotic tree species in the desert for plantation has become necessary. Many species of Eucalyptus, Acacia, Cassia and other genera from Israel, Australia, US, Russia, Zimbabwe, Chile, Peru, and Sudan have been tried in Thar Desert. Acacia tortilis has proved to be the most promising species for desert afforestation and the jojoba is another promising

species of economic value found suitable for planting in these areas.

External links

- http://permaculture.org.au/
- http://www.greeningthedesert.com/
- http://permaculture.org.au/2009/12/11/greening-the-desert-ii-final/
- http://www.desert-greening.com

Differential weathering

Differential weathering is the difference in degree of discoloration, disintegration, etc., of rocks of different kinds exposed to the same environment. Quartz deposits in basaltic flows will weather slower than the surrounding rock, while being exposed to the same forces of weathering.

Differential weathering occurs when a some parts of a rock weathers at different rates than others.[1]

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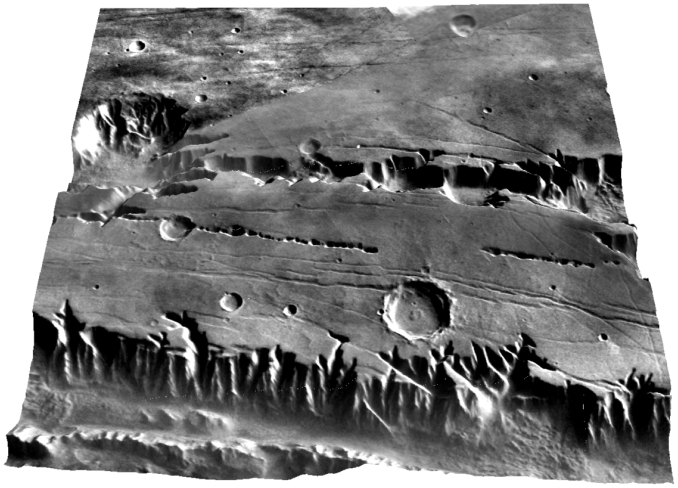
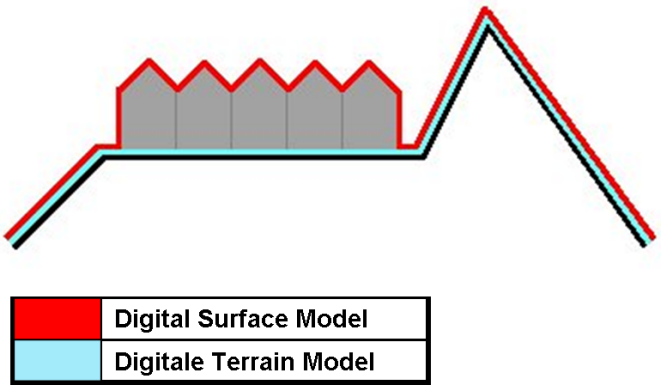
Digital elevation model

A **digital elevation model** is a digital model or 3-D representation of a terrain's surface — commonly for a planet (including Earth), moon, or asteroid — created from terrain elevation data.

There is no common usage of the terms **digital elevation model (DEM)**, **digital terrain model (DTM)** and **digital surface model (DSM)** in scientific literature. In the most cases the term **digital surface model** represents the earth's surface and includes all objects on it. In contrast to a DSM, the **digital terrain model** represents the bare ground surface without any objects like plants and buildings (see Figure on the right).[1] [2]



3D rendering of a DEM of Tithonium Chasma on Mars



Surfaces represented by a Digital Surface Model and Digital Terrain Model

The term Digital Elevation Model is often used as a generic term for DSMs and DTMs, only representing height information without any further definition about the surface[3] . Other definitions equalise the terms DEM and DTM[4] , or define the DEM as a subset of the DTM, which is also representing other morphological elements[5] . There are also definitions which equalise the terms DEM and DSM[6] . In the Web definitions can be found which define the DEM as a digital regularly spaced GRID and a DTM as a real three-dimensional model (TIN)[7] . Most of the data providers (USGS, ERSDAC, CGIAR) use the term DEM as a generic term for DSMs and DTMs. All datasets which are captured with satellites, airplanes or other flying platforms are originally DSMs (like SRTM or the ASTER GDEM). It is possible to compute a DTM from high resolution DSM datasets with complex algotithms (Li et al. (2005). In the following the term DEM is used as a generic term for DSMs and DTMs.

A DEM can be represented as a raster (a grid of squares, also known as a heightmap when representing elevation) or as a triangular irregular network (TIN). The TIN DEM dataset is also referred as a primary (measured) DEM, whereas the Raster DEM is referred as a secondary (computed) DEM[8] . DEMs are commonly built using remote sensing techniques, but they may also be built from land surveying. DEMs are used often in geographic information systems, and are the most common basis for digitally-produced relief maps. The DEM could be acquired through techniques such as photogrammetry, LiDAR, IfSAR, land surveying, etc. (Li et al. 2005). While a DSM may be useful for landscape modeling, city modeling and visualization applications, a DTM is often required for flood or drainage modeling, land-use studies, geological applications, and much more.[9]

Production

Relief map Sierra Nevada

Mappers may prepare digital elevation models in a number of ways, but they frequently use remote sensing rather than direct survey data. One powerful technique for generating digital elevation models is interferometric synthetic aperture radar: two passes of a radar satellite (such as RADARSAT-1 or TerraSAR-X), or a single pass if the satellite is equipped with two antennas (like the SRTM instrumentation), suffice to generate a digital elevation map tens of kilometers on a side with a resolution of around ten meters . Alternatively, other kinds of stereoscopic pairs can be employed using the digital image correlation method, where two optical images acquired with different angles taken from the same pass of an airplane or an Earth Observation Satellite (such as the HRS instrument of SPOT5 or the VNIR band of ASTER).[10]

In 1986, the SPOT 1 satellite provided the first usable elevation data for a sizeable portion of the planet's landmass, using two-passes stereoscopic correlation. Later, further data were provided by the European Remote-Sensing Satellite (ERS) using the same method, the Shuttle Radar Topography Mission using single-pass SAR and the ASTER instrumentation on the Terra satellite using double-pass stereo pairs.[10]

Older methods of generating DEMs often involve interpolating digital contour maps that may have been produced by direct survey of the land surface; this method is still used in mountain areas, where interferometry is not always satisfactory. Note that the contour line data or any other sampled elevation datasets (by GPS or ground survey) are not DEMs, but may be considered digital terrain models. A DEM implies that elevation is available continuously at each location in the study area.

The quality of a DEM is a measure of how accurate elevation is at each pixel (absolute accuracy) and how accurately is the morphology presented (relative accuracy). Several factors play an important role for quality of DEM-derived products:

- terrain roughness;
- sampling density (elevation data collection method);
- grid resolution or pixel size;
- interpolation algorithm;
- vertical resolution;
- terrain analysis algorithm;

Methods for obtaining elevation data used to create DEMs

- LIDAR
- Stereo photogrammetry from aerial surveys
- Real Time Kinematic GPS
- Topographic maps
- Theodolite or total station
- Doppler radar
- Focus variation
- Inertial surveys

Uses

Common uses of DEMs include:

- Extracting terrain parameters
- Modeling water flow or mass movement (for example avalanches and landslides)
- Creation of relief maps
- Rendering of 3D visualizations.
- 3d flight planning
- Creation of physical models (including raised-relief maps)
- Rectification of aerial photography or satellite imagery.
- Reduction (terrain correction) of gravity measurements (gravimetry, physical geodesy).
- Terrain analyses in geomorphology and physical geography
- Geographic Information Systems (GIS)
- Engineering and infrastructure design
- Global positioning systems (GPS)
- Line-of-sight analysis
- Base mapping
- Flight simulation
- Precision farming and forestry

Bezmiechowa airfield 3D Digital Surface Model obtained using Pteryx UAV flying 200m above hilltop

- Surface analysis
- Intelligent transportation systems (ITS)
- Auto safety / Advanced Driver Assistance Systems (ADAS)

Digital Surface Model of motorway interchange construction site. Note that tunnels are closed.

Sources

A free DEM of the whole world called GTOPO30 (30 arcsecond resolution, approx. 1 km) is available, but its quality is variable and in some areas it is very poor. A much higher quality DEM from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument of the Terra satellite is also freely available for 99% of the globe, and represents elevation at a 30 meter resolution. A similarly high resolution was previously only available for the United States territory under the Shuttle Radar Topography Mission (SRTM) data, while most of the rest of the planet was only covered in a 3 arc-second resolution (around 90 meters). The limitation with the GTOPO30 and SRTM datasets is that they cover continental landmasses only, and SRTM does not cover the polar regions and has mountain and desert no data (void) areas. SRTM data, being derived from radar, represents the elevation of the first-reflected surface — quite often tree tops. So, the data are not necessarily representative of the ground surface, but the top of whatever is first encountered by the radar. Submarine elevation (known as bathymetry) data is generated using ship-mounted depth soundings. The SRTM30Plus dataset (used in NASA World Wind) attempts to combine GTOPO30, SRTM and bathymetric data to produce a truly global elevation model.[11] A novel global DEM of postings lower than 12m and a height accuracy of less than 2m is expected being generated by the TanDEM-X satellite mission which started in July 2010.

The most usual grid (raster) is between 50 and 500 meters. In gravimetry e.g., the primary grid may be 50 m, but is switched to 100 or 500 meters in distances of about 5 or 10 kilometers.

Many national mapping agencies produce their own DEMs, often of a higher resolution and quality, but frequently these have to be purchased, and the cost is usually prohibitive to all except public authorities and large corporations. DEMs are often a product of National LIDAR Dataset programs.

Free DEMs are also available for Mars: the MEGDR, or Mission Experiment Gridded Data Record, from the Mars Global Surveyor's Mars Orbiter Laser Altimeter (MOLA) instrument; and NASA's Mars Digital Terrain Model (DTM).[12]

United States

The US Geological Survey produces the National Elevation Dataset, a seamless DEM for the contiguous United States, Hawaii and Puerto Rico based on 7.5' topographic mapping. As of the beginning of 2006, this replaces the earlier DEM tiled format (one DEM per USGS topographic map).[13] [14]

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[13] http://eros.usgs.gov/DEMNotice.html

[14] see Herbert Glarner's paper on using USGS data, http://herbert.gandraxa.com/herbert/dem.asp

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DEM file formats

- USGS DEM
- SDTS DEM
- DTED
- DIMAP (http://www.spotimage.fr/web/en/235-the-dimap-format.php,)

External links

- Maps-For-Free.com (http://www.maps-for-free.com) Free global relief maps
- Geo-Spatial Data Acquisition Homepage (http://www.emrl.byu.edu/gsda)
- GTOPO30 Homepage (http://edcdaac.usgs.gov/gtopo30/gtopo30.html)
- GTOPO30 FTP Server (ftp://edcftp.cr.usgs.gov/pub/data/gtopo30/global/)
- SRTM Homepage (http://srtm.usgs.gov/)
- SRTM30 Plus Homepage (http://topex.ucsd.edu/WWW_html/srtm30_plus.html)
- Terrainmap Homepage (http://www.terrainmap.com/)
- More information about available DEM data (http://www.vterrain.org/Elevation/index.html)
- More information about DEM by Spot Image (http://www.spotimage.fr/web/en/807-spot-3d.php)
- DEMs with TanDEM-X (http://www.terrasar.de/tandem-x_dem)
- TanDEM-X Science Home (http://www.dlr.de/HR/tdmx)

Diluvium

Diluvium is a term in geology for superficial deposits formed by flood-like operations of water, and so contrasted with alluvium or alluvial deposits formed by slow and steady aqueous agencies. The term was formerly given to the boulder clay deposits, supposed to have been caused by the Noachian deluge.

In the late 20th century Russian geologist Alexei Rudoy proposed the term "**diluvium**" for description of deposits created as a result of catastrophic outbursts of Pleistocene giant glacier-dammed lakes in intermontane basins of the Altai.[1] The largest of these lakes - Chuya and Kuray, had a volume of water in hundreds of cubic kilometers, and their discharge in peak hydrograph flow rate exceeded the maximum rates of the well-known Pleistocene Lake Missoula in North America. The term "diluvium" in the meaning of A. N. Rudoy has become accepted, and the process of diluvial morpholithogenesis can be found in modern textbooks.

Diluvial terrases on Katun River Altai Scabland, Altai Republic

Giant current ripples in the Kuray Basin, Altai, Russia

Flood deposits of the Altai region

Nearly all intermountain depressions in southern Siberia and northern Mongolia hosted glacier-dammed lakes during the Pleistocene ice ages. Climatic changes and hydrostatic alterations of the ice dams were followed by repeated fillings and releases of the basin lakes. The lake outbursts had a cataclysmic character. In accordance with climatic conditions, the glaciers would protrude again into the main drainage valleys immediately after dam deformations and lake outbursts and would again dam the basins.

The greatest of the lakes (Lakes Chuya, Kuray, Uymon, Darkhat and others) achieved volumes up to hundreds of cubic kilometres, while the discharges of the outburst floods reached millions of cubic metres per second. These floods transformed the drainage valleys, repeatedly building new sediment deposits. The dating of the latter proves the occurrence of large-scale floods in the Chuya and the Katun River valleys in the interval between 23 and 7 thousand years ago. During that period there were at least five large-scale flooding events. Enormous water masses were drained simultaneously and repeatedly towards the south of West Siberia. The total water volume out of the Altai basins only used to reach 10 thousand cubic kilometres. With some periodicity, all of the basins of South

Siberia were able to deliver northwards about 60 thousand cubic kilometres of flood waters.

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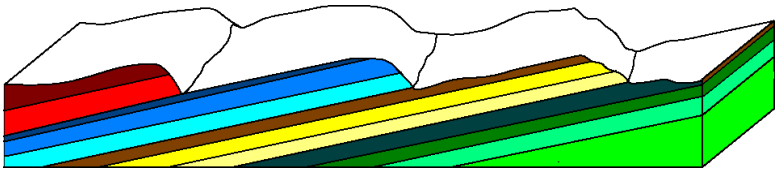
- Athabasca-video in large Scale (http://video.mail.ru/mail/larisaterehova1953/8614/8949.html?liked=1)
- Alexei Rudoy. Giant gravel bars - дилювиально-аккумулятивные валы ("высокие террасы"). (http://knol.google.com/k/alexei-rudoy/Ð´Ð¸Ð»ÑÐ²Ð¸Ð°Ð»ÑÐ½Ð¾-Ð°ÐºÐºÑÐ¼ÑÐ»ÑÑÐ¸Ð²Ð½ÑÐµ-Ð²Ð°Ð»Ñ-Ð²ÑÑÐ¾ÐºÐ¸Ðµ/2mjmwx6ls3hzt/46#view)
- А. Н. Рудой. Study diluvium: general provisions. Общие положения учения о дилювии. (http://ice.tsu.ru/index.php?option=com_content&view=category&layout=blog&id=1&Itemid=22)

Dip slope

A **dip slope** is a geological formation often created by erosion of tilted strata.[1] Dip slopes are found on homoclinal ridges with one side that is steep and irregular (an escarpment) and another side, the dip slope, that is generally planar with a dip parallel to the bedding.[2] The orientation of the dip slope is referred to as the strike.



Schematic cross section of a cuesta, dip slopes facing left and harder rock layers in darker colors than softer ones

Formation

Some rocks (usually softer ones) erode more rapidly than others. For example, shale most frequently erodes faster than limestone. In situations like this, an entire layer of the easily erodible rock can be weathered away while a layer of a more durable rock will remain largely unchanged. This results in a nearly flat surface created by the top of the more durable layer. When this happens to beds that are not tilted mesas are formed. With tilted beds, structures called cuestas and hogbacks are formed. Mesas will have a flat top, while cuestas and hogbacks will look like ridges, with one side that is a dip slope and a steeper escarpment on the other.

Dip slopes can also be formed by igneous structures such as sills. Any generally planar geological structure can form dip slopes, when it is tilted away from horizontal.

Landslides

Dip slopes are quite prone to landslides, due to the dipping flat erosional surface. Large sheets of rock have a tendency to slide down dip slopes.

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Downhill creep

Downhill creep, or commonly just **creep**, is the slow downward progression of rock and soil down a low grade slope; it can also refer to slow deformation of such materials as a result of prolonged pressure and stress. Creep may appear to an observer to be continuous, but it really is the sum of numerous minute, discrete movements of slope material caused by the force of gravity. Friction being the primary force to resist gravity is produced when one body of material slides past another offering a mechanical resistance between the two which acts on holding objects (or slopes) in place. As slope on a hill increases, the gravitational force that is perpendicular to the slope decreases and results in less friction between the material that could cause the slope to slide.

Overview

Trees showing the effect of creep.

The rate of soil creep down a slope depends on the steepness (gradient) of the slope, water absorption and content, type of sediment and material, and lastly vegetation. The rate of creep will take into account all of these factors to decide whether or not the hillside will progress downward. Creep is what is responsible for the rounded shape of hillsides.

Water is a very important factor when discussing soil deformation and movement. For instance, a sandcastle will only stand up when it is made with damp sand. The water offers cohesion to the sand which binds the sand particles together. However, pouring water over the sandcastle destroys it. This is because the presence of too much water fills the pores between the grains with water creating a slip plane between the particles and offering no cohesion causing them to slip and slide away. This holds true for hillsides and creep as well. The presence of water may help the hillside stay put and give it cohesion, but in a very wet environment or during or after a large amount of precipitation the pores between the grains can become saturated with water and cause the ground to slide along the slip plane it creates.

Creep can also be caused by the expansion of materials such as clay when they are exposed to water. Clay expands when wet, then contracts after drying. The expansion portion pushes downhill, then the contraction results in consolidation at the new offset.

Vegetation plays a role with slope stability and creep. When a hillside contains many trees, ferns, and shrubs their roots create an interlocking network that can strengthen unconsolidated material. They also aid in absorbing the excess water in the soil to help keep the slope stable. However, they do add to the weight of the slope giving gravity that much more of a driving force to act on in pushing the slope downward. In general, though, slopes without vegetation have a greater chance of movement.

Design engineers sometimes need to guard against downhill creep during their planning to prevent building foundations from being undermined. Pilings are planted sufficiently deep into the surface material to guard against this behavior.

Creep over a sidewalk.

Modeling regolith diffusion

For shallow to moderate slopes, diffusional sediment flux is modeled linearly as (Culling, 1960; McKean et al., 1993)

$$q_s = k_d S$$

where k_d is the diffusion constant, and S is slope. For steep slopes, diffusional sediment flux is more appropriately modeled as a non-linear function of slope (Roering et al., 1999)

$$q_s = \frac{k_d S}{1 - (S/S_c)^2}$$

where S_c is the critical gradient for sliding of dry soil.

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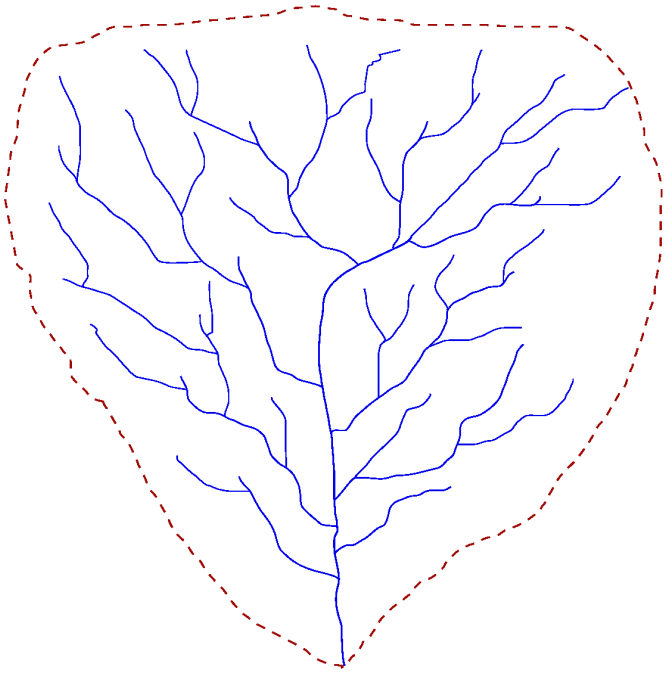
Drainage basin

A **drainage basin** is an extent or an area of land where surface water from rain and melting snow or ice converges to a single point, usually the exit of the basin, where the waters join another waterbody, such as a river, lake, reservoir, estuary, wetland, sea, or ocean. In closed drainage basins the water converges to a single point inside the basin, known as a sink, which may be a permanent lake, dry lake, or a point where surface water is lost underground.[1] The drainage basin includes both the streams and rivers that convey the water as well as the land surfaces from which water drains into those channels, and is separated from adjacent basins by a drainage divide.[2]



Example of a drainage basin. The dashed line is the main water divide of the hydrographic basin

The drainage basin acts as a funnel by collecting all the water within the area covered by the basin and channelling it to a single point. Each drainage basin is separated topographically from adjacent basins by a geographical barrier such as a ridge, hill or mountain.

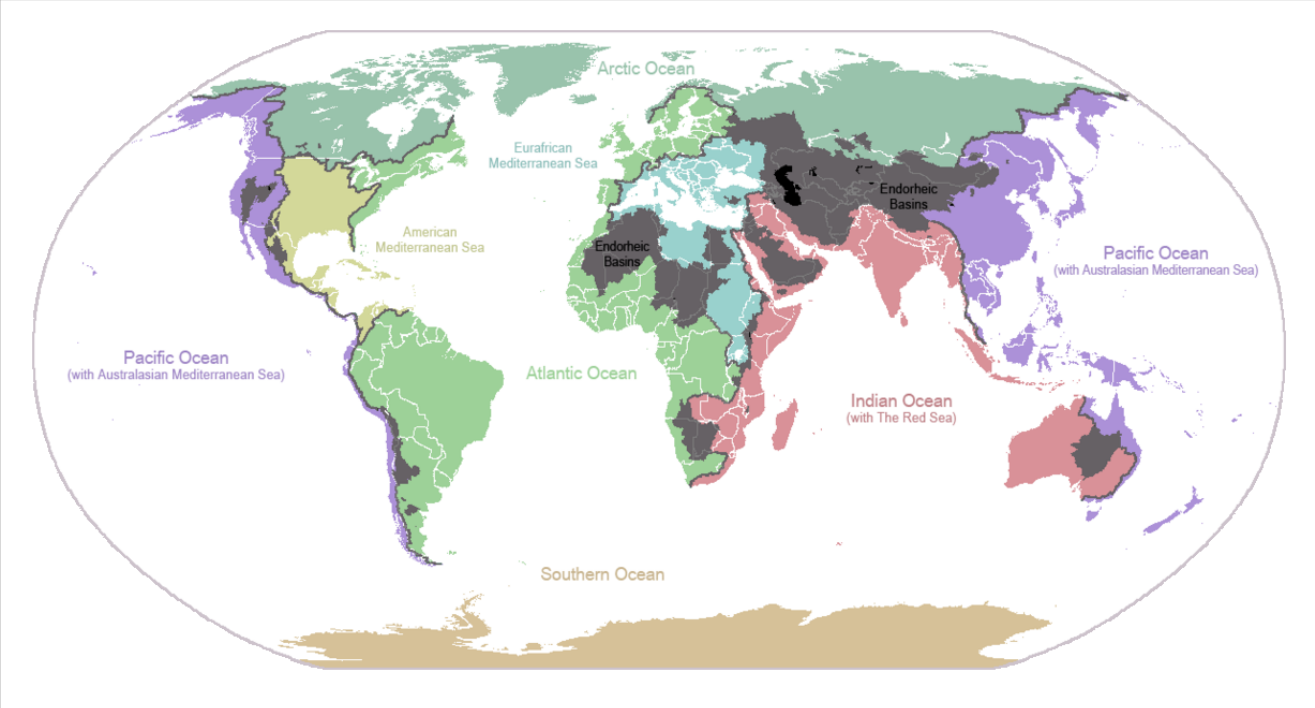
Other terms that are used to describe a drainage basin are **catchment**, **catchment area**, **catchment basin**, **drainage area**, **river basin**, **water basin** and **watershed**.[3] In the technical sense, a watershed refers to a divide that separates one drainage area from another drainage area.[4] However, in the United States and Canada, the term is often used to mean a drainage basin or catchment area itself. Drainage basins drain into other drainage basins in a hierarchical pattern, with smaller **sub-drainage basins** combining into larger drainage basins.[5]

Drainage basins are similar but not identical to hydrologic units, which are drainage areas delineated so as to nest into a multi-level hierarchical drainage system. Hydrologic units are designed to allow multiple inlets, outlets, or sinks. In a strict sense, all drainage basins are hydrologic units but not all hydrologic units are drainage basins.[1]

The United States Environmental Protection Agency launched the website Watershed Central for the US public to exchange information and locate resources needed to restore local drainage basins in that country.

Major drainage basins of the world

Map



Drainage basins of the principal oceans and seas of the world. Grey areas are endorheic basins that do not drain to the ocean.

Ocean basins

There are 354 drainage basins throughout the world in all sorts of places. The following is a list of some of the major ones:

- About 47% of all land in the world drains to the Atlantic Ocean. In North America, surface water drains to the Atlantic via the Saint Lawrence River and Great Lakes basins, the Eastern Seaboard of the United States, the Canadian Maritimes, and most of Newfoundland and Labrador. Nearly all of South America east of the Andes also drains to the Atlantic, as does most of Western and Central Europe, and the greatest portion of western Sub-Saharan Africa. The three major mediterranean seas of the world also flow to the Atlantic:
  - The American Mediterranean Sea (the Caribbean Sea and Gulf of Mexico) basin includes most of the American interior between the Appalachian and Rocky Mountain ranges, a small part of the Canadian provinces of Alberta and Saskatchewan, eastern Central America, the islands of the Caribbean and the Gulf, and a small part of northern South America.
  - The European Mediterranean Sea basin includes much of northern Africa, east-central Africa (through the Nile), southern, central, and eastern Europe, Turkey, and the coastal areas of Israel, Lebanon, and Syria.
  - The Arctic Ocean basin drains most of Western and Northern Canada east of the Continental Divide, the north shore of Alaska and parts of North Dakota, South Dakota, Minnesota, and Montana in the United States, the north shore of the Scandinavian peninsula in Europe, and much of central and northern Russia.
- Just over 13% of the land in the world drains to the Pacific Ocean. Its basin includes much of China, southeastern Russia, Japan, Korea, most of Indonesia and Malaysia, the Philippines, all of the Pacific Islands, the northeast coast of Australia, and the western parts of Canada, the United States (including most of Alaska), Central America, and South America.

- The Indian Ocean's drainage basin also comprises about 13% of Earth's land. It drains the eastern coast of Africa, the coasts of the Red Sea and the Persian Gulf, the Indian subcontinent, Burma, and most of Australia.
- The Southern Ocean drains Antarctica. Antarctica comprises approximately eight percent of the Earth's land.

Largest river basins

The three largest river basins (by area), from largest to smallest, are the Amazon basin, the Congo basin, and the Mississippi basin.[6] The three rivers that drain the most water, from most to least, are the Amazon, Congo, and Ganges Rivers.[7]

Endorheic drainage basins

Endorheic drainage basins are inland basins that do not drain to an ocean. Around 18% of all land drains to endorheic lakes or seas or sinks. The largest of these consists of much of the interior of Asia, and drains into the Caspian Sea and the Aral Sea. Other endorheic regions include the Great Basin in the United States, much of the Sahara Desert, the watershed of the Okavango River (Kalahari Basin), highlands near the African Great Lakes, the interiors of Australia and the Arabian Peninsula, and parts in Mexico and the Andes. Some of these, such as the Great Basin, are not single drainage basins but collections of separate, adjacent closed basins.

In endorheic bodies of standing water where evaporation is the primary means of water loss, the water is typically more saline than the oceans. An extreme example is the Dead Sea.

Endorheic basin in Central Asia

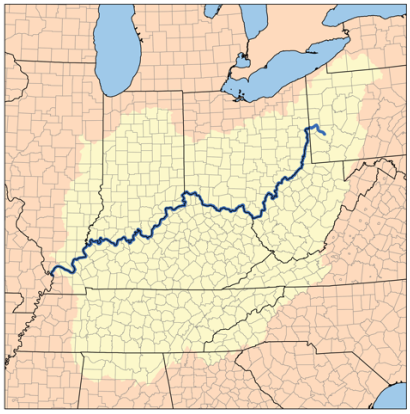
Importance of drainage basins

Geopolitical boundaries

Drainage basins have been historically important for determining territorial boundaries, particularly in regions where trade by water has been important. For example, the English crown gave the Hudson's Bay Company a monopoly on the fur trade in the entire Hudson Bay basin, an area called Rupert's Land. Today, bioregional democracy can include agreements of states in a particular drainage basin to defend it. One example of this is the Great Lakes Commission.

Hydrology

In hydrology, the drainage basin is a logical unit of focus for studying the movement of water within the hydrological cycle, because the majority of water that discharges from the basin outlet originated as precipitation falling on the basin. A portion of the water that enters the groundwater system beneath the drainage basin may flow towards the outlet of another drainage basin because groundwater flow directions do not always match those of their overlying drainage network. Measurement of the discharge of water from a basin may be made by a stream gauge located at the basin's outlet.



Drainage basin of the Ohio River, part of the Mississippi River drainage basin.

Rain gauge data is used to measure total precipitation over a drainage basin, and there are different ways to interpret that data. If the gauges are many and evenly distributed over an area of uniform precipitation, using the arithmetic mean method will give good results. In the Thiessen polygon method, the watershed is divided into polygons with the rain gauge in the middle of each polygon assumed to be representative for the rainfall on the area of land included in its polygon. These polygons are made by drawing lines between gauges, then making perpendicular bisectors of those lines form the polygons. The isohyetal method involves contours of equal precipitation are drawn over the gauges on a map. Calculating the area between these curves and adding up the volume of water is time consuming.

Geomorphology

Drainage basins are the principal hydrologic unit considered in fluvial geomorphology. A drainage basin is the source for water and sediment that moves through the river system and reshapes the channel.

Ecology

Drainage basins are important elements to consider also in ecology. As water flows over the ground and along rivers it can pick up nutrients, sediment, and pollutants. Like the water, they get transported towards the outlet of the basin, and can affect the ecological processes along the way as well as in the receiving water source.

Modern usage of artificial fertilizers, containing nitrogen, phosphorus, and potassium, has affected the mouths of watersheds. The minerals will be carried by the watershed to the mouth and accumulate there, disturbing the natural mineral balance. This can cause eutrophication where plant growth is accelerated by the additional material.

The Mississippi River drains the largest area of any U.S. river, much of it agricultural regions. Agricultural runoff and other water pollution that flows to the outlet is the cause of the dead zone in the Gulf of Mexico.

Resource management

Because drainage basins are coherent entities in a hydrological sense, it has become common to manage water resources on the basis of individual basins. In the U.S. state of Minnesota, governmental entities that perform this function are called watershed districts. In New Zealand, they are called catchment boards. Comparable community groups based in Ontario, Canada, are called conservation authorities. In North America this function is referred to as watershed management. In Brazil, the National Policy of Water Resources, regulated by Act n° 9.433 of 1997, establishes the drainage basin as territorial division of Brazilian water management.

Catchment factors

The catchment is the most significant factor determining the amount or likelihood of flooding.

Catchment factors are: topography, shape, size, soil type and land use (paved or roofed areas). Catchment topography and shape determine the time taken for rain to reach the river, while catchment size, soil type and development determine the amount of water to reach the river.

Topography

Topography determines the speed with which the runoff will reach a river. Clearly rain that falls in steep mountainous areas will reach the river faster than flat or gently sloping areas.

Shape

Shape will contribute to the speed with which the runoff reaches a river. A long thin catchment will take longer to drain than a circular catchment.

Size

Size will help determine the amount of water reaching the river, as the larger the catchment the greater the potential for flooding.

Soil type

Soil type will help determine how much water reaches the river. Certain soil types such as sandy soils are very free draining and rainfall on sandy soil is likely to be absorbed by the ground. However, soils containing clay can be almost impermeable and therefore rainfall on clay soils will run off and contribute to flood volumes. After prolonged rainfall even free draining soils can become saturated, meaning that any further rainfall will reach the river rather than being absorbed by the ground.

Land use

Land use can contribute to the volume of water reaching the river, in a similar way to clay soils. For example, rainfall on roofs, pavements and roads will be collected by rivers with almost no absorption into the groundwater.

Footnotes

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[2] "drainage basin" (http://www.uwsp.edu/geo/faculty/ritter/glossary/a_d/drainage_basin.html). www.uwsp.edu. . Retrieved 2008-02-21.

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[7] Encarta Encyclopedia articles on Amazon River, Congo River, and Ganges Published by Microsoft in computers.

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External links

- Science week catchment factsheet (http://www.abc.net.au/science/catchmentdetox/factsheet/)
- Catchment Modelling Toolkit (http://www.toolkit.net.au/)
- Water Evaluation And Planning System (WEAP) - modeling hydrologic processes in a drainage basin (http://www.weap21.org/)
- eWater CRC (http://www.ewatercrc.com.au/)
- New Mexico State University - Water Task Force (http://spectre.nmsu.edu/watertaskforce/aboutus.lasso?t=31&v=Watershed Management)
- Recommended Watershed Terminology (http://watershed.org/news/fall_94/terminology.html)
- A detailed map of watersheds in North America (http://www.cec.org/naatlas/watersheds.cfm?varlan=english)
- *Science in Your Watershed* (http://water.usgs.gov/wsc), USGS
- *Studying Watersheds: A Confluence of Important Ideas* (http://www.ericdigests.org/2003-1/ideas.htm)

- *Water Sustainability Project* Sustainable water management through demand management and ecological governance, with the POLIS Project at the University of Victoria (http://waterdsm.org/)
- Map of the Earth's primary watersheds (http://earthtrends.wri.org/maps_spatial/maps_detail_static.cfm?map_select=274&theme=2), WRI
- What is a watershed and why should I care? (http://www.wr.udel.edu/cb/whatwhycare.html)
- Cycleau - A project looking at approaches to managing catchments in North West Europe (http://www.cycleau.com/index.asp)
- American Water Resources Association (http://www.awra.org/)
- flash animation of how rain falling on to the landscape will drain into a river depending on the terrain (http://techalive.mtu.edu/meec/module01/whatiswatershed.htm)
- StarHydro – software tool that covers concepts of fluvial geomorphology and watershed hydrology (http://web.mit.edu/star/hydro)
- EPA Surf your watershed (http://cfpub.epa.gov/surf/locate/index.cfm)
- Florida Watersheds and River Basins - Florida DEP (http://www.protectingourwater.org/watersheds/map/)

Drainage density

Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. It is a measure of how well or how poorly a watershed is drained by stream channels. It is equal to the reciprocal of the constant of channel maintenance and equal to the reciprocal of two times the length of overland flow.

Drainage density depends upon both climate and physical characteristics of the drainage basin. Soil permeability (infiltration difficulty) and underlying rock type affect the runoff in a watershed; impermeable ground or exposed bedrock will lead to an increase in surface water runoff and therefore to more frequent streams. Rugged regions or those with high relief will also have a higher drainage density than other drainage basins if the other characteristics of the basin are the same.

Drainage density can affect the shape of a river's hydrograph during a rain storm. Rivers that have a high drainage density will often have a more 'flashy' hydrograph with a steep falling limb. High densities can also indicate a greater flood risk.

High drainage densities also mean a high bifurcation ratio.

External links

- Drainage Basin at the Learning Channel [1]

References

[1] http://www.learn.co.za/content/grade12/Geography/geomorphology/density/Unit1/

Drainage divide

A **drainage divide**, **water divide**, **divide** or (outside North America) **watershed** is the line separating neighbouring drainage basins (catchments). In hilly country, the divide lies along topographical peaks and ridges, and may be in the form of a single range of hills or mountains (known as a *Dividing range*), but in flat country (especially where the ground is marshy) the divide may be invisible – just a more or less notional line on the ground on either side of which falling raindrops will start a journey to different rivers, and even to different sides of a region or continent.

Drainage divides are important geographical, and often also political boundaries. Roads (such as ridgeways) and rail tracks often follow divides to minimise grades (gradients), and to avoid marshes and rivers.

Main European drainage divides (red lines) separating drainage basins (gray regions)

A divide is also known as:

- A *watershed*, the line between drainage basins – *shedding* is an old term for splitting or dividing, so it is the line which divides the water (however in North America "watershed" has come to mean the drainage basin itself);
- a *water parting*;
- a *height of land* (in Canada).

A *valley floor divide* is a low drainage divide running across a valley, sometimes created by deposition or stream capture.

Types

Drainage divides can be grouped in three types:

- Continental divide

  A divide in which the waters on each side flow to different oceans (example: the Nile and Congo divide, Lunghin Pass triple divide)

- Major drainage divide

  The waters on each side of the divide never meet again, but do flow into the same ocean (example: the divide between the Yellow River basin and the Yangtze)

- Minor drainage divide

  The waters part but eventually join again at a river confluence (example: the Mississippi and Missouri divide)

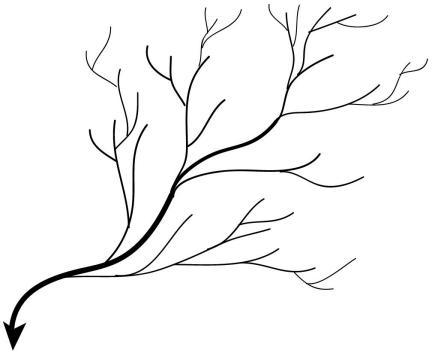
Drainage divides are a hindrance to river navigation. In pre-industrial times water divides were crossed at portages. Later, canals were built to connect the adjoining drainage basins.

Drainage system (geomorphology)

In geomorphology, a **drainage system** is the pattern formed by the streams, rivers, and lakes in a particular drainage basin. They are governed by the topography of the land, whether a particular region is dominated by hard or soft rocks, and the gradient of the land. Geomorphologists and hydrologists often view streams as being part of drainage basins. A drainage basin is the topographic region from which a stream receives runoff, throughflow, and groundwater flow. Drainage basins are divided from each other by topographic barriers called a watershed. A watershed represents all of the stream tributaries that flow to some location along the stream channel. The number, size, and shape of the drainage basins found in an area varies and the larger the topographic map, the more information on the drainage basin is available.[1]

Types of drainage system

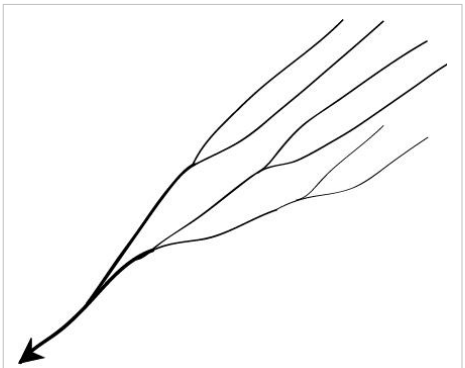
Drainage systems can fall into one of several categories, depending on the topography and geology of the land:



Dendritic drainage pattern.

Dendritic drainage system

Dendritic drainage systems (from Greek δενδρίτης, *dendrites*, "of or pertaining to a tree") are the most common form of drainage system. In a dendritic system, there are many contributing streams (analogous to the twigs of a tree), which are then joined together into the tributaries of the main river (the branches and the trunk of the tree, respectively). They develop where the river channel follows the slope of the terrain. Dendritic systems form in V-shaped valleys; as a result, the rock types must be impervious and non-porous.[2]



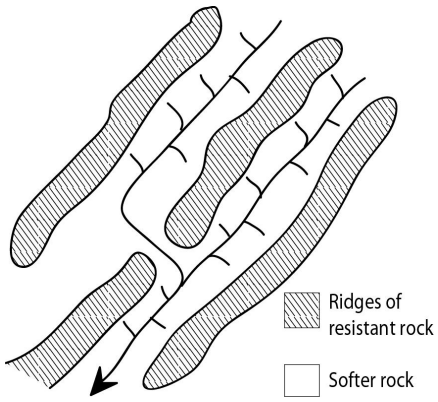
Parallel drainage pattern.

Parallel drainage system

A parallel drainage system is a pattern of rivers caused by steep slopes with some relief. Because of the steep slopes, the streams are swift and straight, with very few tributaries, and all flow in the same direction. This system forms on uniformly sloping surfaces, for example, rivers flowing southeast from the Aberdare Mountains in Kenya.

Trellis drainage system

The geometry of a trellis drainage system is similar to that of a common garden trellis used to grow vines. As the river flows along a strike valley, smaller tributaries feed into it from the steep slopes on the sides of mountains. These tributaries enter the main river at approximately 90 degree angles, causing a trellis-like appearance of the drainage system. Trellis drainage is characteristic of folded mountains, such as the Appalachian Mountains in North America.[3]



Trellis drainage pattern.

Rectangular drainage system

Rectangular drainage develops on rocks that are of approximately uniform resistance to erosion, but which have two directions of jointing at approximately right angles. The joints are usually less resistant to erosion than the bulk rock so erosion tends to preferentially open the joints and streams eventually develop along the joints. The result is a stream system in which streams consist mainly of straight line segments with right angle bends, and tributaries join larger streams at right angles.[3]

Radial drainage system

In a radial drainage system the streams radiate outwards from a central high point. Volcanos usually display excellent radial drainage. Other geological features on which radial drainage commonly develops are domes and laccoliths. On these features the drainage may exhibit a combination of radial and annular patterns.[3]

Deranged drainage system

A deranged drainage system is a drainage system in drainage basins where there is no coherent pattern to the rivers and lakes. It happens in areas where there has been much geological disruption. The classic example is the Canadian Shield. During the last ice age, the topsoil was scraped off, leaving mostly bare rock. The melting of the glaciers left land with many irregularities of elevation, and a great deal of water to collect in the low points, explaining the large number of lakes which are found in Canada. The watersheds are young and are still sorting themselves out. Eventually the system will stabilize.[1]

Annular drainage pattern

In an annular drainage pattern streams follow a roughly circular or concentric path along a belt of weak rock, resembling in plan a ringlike pattern. It is best displayed by streams draining a maturely dissected structural dome or basin where erosion has exposed rimming sedimentary strata of greatly varying degrees of hardness, as in the Red Valley, which nearly encircles the domal structure of the Black Hills of South Dakota.

Footnotes

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[2] Lambert, David (1998). *The Field Guide to Geology*. Checkmark Books. pp. 130–131. ISBN 0-8160-3823-6.

[3] Ritter, Michael E. The Physical Environment: an Introduction to Physical Geography. 2006. Date visited. http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/title_page.html

External links

- StarHydro – software tool that covers concepts of fluvial geomorphology and watershed hydrology (http://web.mit.edu/star/hydro/)

Dreikanter

Dreikanters typically form in desert or periglacial environments from the action of wind erosion. [1]

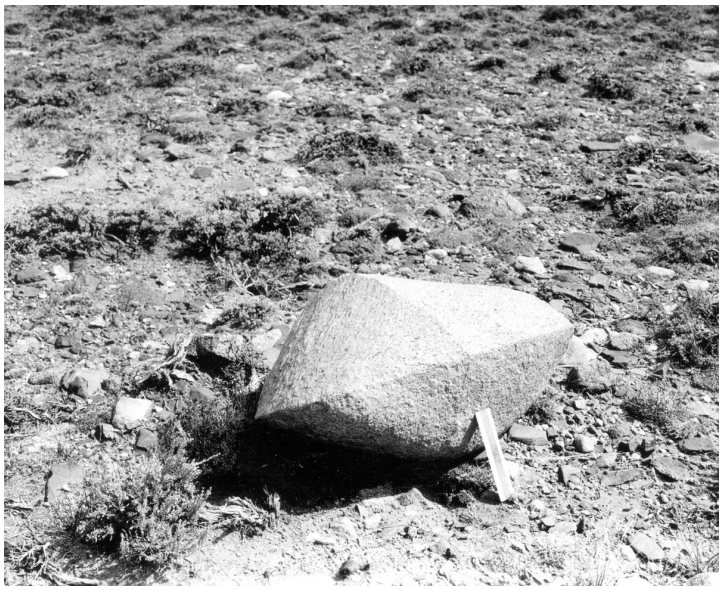
A **Dreikanter** is a ventifact that exhibits a characteristic three-faced pyramidal shape. The word *Dreikanter* is a German word meaning "a three-sider." [2]

References

[1] Wade, A. 1910. On the formation of dreikanter in desert regions. The Geological Magazine, Decade V, 7(9):394-398.

[2] WeatherTalk - Jargon (http://climate.umn.edu/cawap/mpr/jargon.htm)

[3] U.S. Geological Survey Photographic Library (http://libraryphoto.cr.usgs.gov/)



Unusually large dreikanter of granite, Sweetwater County, Wyoming. This dreikanter measures 71 cm by 46 cm deep and 37 cm wide. Photo by Bradley, W.H., USGS (1930).[3]

External links

- An image of a Dreikanter (http://www.uwgb.edu/dutchs/EarthSC202Slides/windslid.htm)
- Glossary of Meteorology (http://amsglossary.allenpress.com/glossary/search?id=dreikanter1)
- The Bibliography of Aeolian Research (http://www.lbk.ars.usda.gov/wewc/biblio/bar.htm)

Electromechanical disintegration

Electromechanical disintegration is a process in geomorphology in which lightning interacts in erosion and weathering.[1]

An excellent example of this phenomenon is fracturing in the quartz formations of the Espinaço mountains of Brazil. For many years, itinerant miners in these mountains have reported the appearance of broken boulders and fissures along the ground after lightning storms.

The Espinaço Range represents a typical site for orographic thunderstorms, which develop from the ascent of air along mountain ranges. These storms have the highest rate of lightning occurrence and are therefore useful for studying the effects of such atmospheric discharges.

These discharges have peculiar features: velocities of 160000 m/s (ft/s) and plasma temperatures of 30000 °C (54000 °F) are achieved in nanoseconds in lightning channels.

Evidences of the effect of lightning on rock are the presence of beta-quartz (T > 573 °C (1060 °F), called "flashstones" by local diggers), melted barbed wires (T > 1500 °C or 2730 °F); furrows in soils and colluvium up to 120-metre (394 ft) long with the presence of cristobalite, the high-temperature modification of quartz (1713–18 °C or 3115–64 °F). In permeable Precambrian quartzites, the instantaneous shock rise of temperature from 15 to 1500 °C (59 to 2700 °F), or higher, results in an extremely severe explosion-like expansion of water, leading to the formation of fissures and widening of other systems. The evidence points to lightning action, since quartz can change its modification from α to β and back again without cracking, as long as the temperature change is less than 1 °C (1.8 °F) per minute. For this reason, cracks caused by solar radiation or fire can be ruled out.

An enormous pressure of about 35.00 bar (508 psi) can be estimated by the presence of coesite relicts, the rare high-pressure polymorph of quartz.

This lightning-induced weathering is one of the more important starting mechanisms for other weathering processes. Because of the increase in surface area, chemical weathering can attack each newly made fragment from all sides and can go deeper into bedrock as new cracks are formed or older ones extended. Thus, *electromechanical disintegration* is a new term for a type of weathering as old as the planet's lithosphere, and it represents an important exogenic process for the beginning of erosion and the formation of soils.

Notes

[1] Karfunkel, 2001 (see: References).

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Emergent coastline

Emergent coastlines are stretches along the coast that have been exposed by the sea due to a relative fall in sea levels. This occurs due to either isostacy or eustacy.

Emergent coastline are the opposite of submergent coastlines which have experienced a relative rise in sea-levels.

The specific landform of an emergent coastline may be:

- Raised beach or machair
- Wave cut platform
- Sea cave such as King's Cave, Isle of Arran

The Scottish Gaelic word machair or machar refers to a fertile low-lying raised beach found on the some of the coastlines of Ireland and Scotland, in particular the Outer Hebrides.

Hudson Bay, in Canada's north, is an example of an emergent coastline. Currently it is still emerging by as much as one cm/year.

Entrenched river

An **entrenched river** is a river that is confined to a canyon or gorge, usually with a relatively narrow width and little or no flood plain, and often with meanders worn into the landscape. Such rivers form when the base level of erosion is rapidly lowered, so that the river begins downcutting into its channel faster than it can change course (which rivers normally do on a constant basis). This may occur due to tectonic uplift of the region, a lowering of the oceans, the collapse of a moraine-dammed lake downstream, or by capture of the river by another. Meanders established before the lowering of the base level of erosion may be preserved as the river channel deepens subsequently. Examples of entrenched meanders may be seen in the Snake River Canyon in southern Idaho, and in many canyons of the Colorado Plateau.

Entrenched meanders of the Virgin River at the upper end of Zion Canyon, Zion National Park, Utah.

Entrenched meanders of the San Juan River at Goosenecks State Park, Utah.

Epirogenetic

Epirogenetic or **epeirogenetic** movements are simultaneous rising and falling movements of continents, which maintain isostasy.

Erosion and tectonics

The interplay between **erosion and tectonics** has been a matter of debate since the early 1990s. While tectonic effects on surface processes such as erosion (for example, the river entrainment subsequent to a tectonic rock uplift) have been long recognized, the reverse (the effects of erosion on tectonic deformation) has only recently been addressed thanks to the availability of computer modelling techniques.[1]

Tectonics modify erosion because it modifies the surface topography, which is the most important parameter controlling surface processes of mass transport. Erosion might be reduced on a flat landscape before a normal fault generates a topographic gradient for example. Landforms are generally considered as the result of the interaction between the tectonic and isostatic uplift and the response of surface erosion.

The way the tectonic deformation is influenced by erosion is more subtle and is produced by the weight of the mass removed (eroded) from the surface and the weight of the deposited sediments, which in some circumstances can become relevant enough as to modify the state of stress at depth and the pattern of tectonic deformation.

Although originally proposed for continental collision settings, presently the effects of erosion on tectonic deformation have been extended to a diversity of tectonic settings including continental margins, plate subduction, and high plateaus.

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Erosion prediction

There are dozens of **erosion prediction** models. Most have been developed for agricultural areas and are design to compare predicted annual rates of soil loss from broad areas under various cropland and rangeland management techniques. Some are purely statistical models, others mechanistic. Two of the more widely used methods in North America are the Revised Universal Soil Loss Equation (RUSLE) and Water Erosion Prediction Project erosion model (WEPP). Much of the research on erosion rates is directed towards supporting or fitting these competing models. In particular much of the mineland erosion literature is solely focused on fitting or improving RUSLE parameters. Aside from a few new deterministic gully erosion models, these models do not consider gully erosion – mostly due to difficulties in modelling, and partly because gullies are often repaired in agricultural, forestry, or mining environments.

Because there is a wide discrepancy between predicted and observed erosion rates, models are better as research tools than as public policy and regulatory instruments or for prescriptive design measures for constructed landforms. But some models may provide useful guidance for the design engineer if adequately calibrated and verified for local conditions and if the design accounts for the uncertainty.

Most erosion modelling is applied to existing sites of known topography and material properties to guide land management activities. Designers of constructed landforms, however, have considerable control over the topography, cover soil placement, initial revegetation, and to a lesser extent the substrate properties – flexibility that is generally uneconomical for farmers and ranchers and most users of erosion models. On the other hand, miners have little input into post-closure land use practices and management.

Methods to estimate erosion rates include:

- purely statistical models
- subjectively determined erosion rates using expert judgement combined with a database of erosion rates of natural and reclaimed sites (natural and industrial analogs)
- surveying of existing erosional or depositional features of known age (or as determined by dating of deposits) to determine average erosion rates. Analysis of historical aerial photographs is often employed.
- site-specific empirical models that relate slope, watershed size, and rainfall
- empirical and semi-empirical or deterministic models based on laboratory and field flume measurements of erosion under simulated rainfall or flow conditions
- physically based gully erosion models
- landform and landscape scale models, often GIS-based, that apply erosion mechanics or statistical relationships to predict changes in topography and erosion rates
- sediment-budget models based on watershed monitoring.

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External links

- "About the Universal Soil Loss Equation" [1] - US Department of Agriculture

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European Watershed

The **European Watershed** is the line which divides the drainage basins of the major rivers of Germany: the Rhine, which originates in the Swiss Alps and empties into the North Sea via the Netherlands, and the Danube, which originates in the Black Forest and flows eastward emptying into the Black Sea.

The watershed is not a clearly defined divide. Tectonics, especially in the area that is now the Upper Rhine Plain, created River Rhine. As its headward erosion is much stronger than that of the much older River Danube (see the upper river geology) (due to the Rhine's gravity on its much shorter way to the North Sea), the Rhine and its tributaries intrude deeper into phreatic zones of the Swabian Karst and even capture the upper Danube and its surface tributaries.

Main European drainage divides (red lines) separating catchments (grey regions).

It is expected that the Danube's upper course will one day disappear entirely in favour of the Rhine ("stream capture").

Exhumed river channel

An **exhumed river channel** is a ridge of sandstone that remains when the softer flood plain mudstone is eroded away. The process begins with the deposition of sand within a river channel (typically a meandering river) and mud on the adjacent floodplain. Eventually the channel is abandoned and over time becomes buried by flood deposits from other channels. Because the sand is porous (grain-to-grain contact leaves spaces between), groundwater flows more easily through the sand than through the mud of the floodplain deposits.

An exhumed rived channel (red arrow) in the Cedar Mountain Formation near Green River, Utah.

Exhumed river channels were once the site of a river system. Sand was deposited in the channel and mud on the adjacent floodplain as seen with this meandering river in western South Dakota.

Minerals (typically calcium carbonate) can cement the grains together converting the loose sand into sandstone. Meanwhile, pressure from overlying sediments compresses the floodplain mud converting it to mudstone. Millions of years later, erosion can remove the softer, less cemented mudstone and leave the more resistant sandstone as a sinuous ridge. Thus, the local landscape where these occur is an inverted topography: what was previously low is now high, and vice versa. Exhumed channels are important indicators for ancient stream flow direction.

Some of the best examples of exhumed river channels occur in the Ruby Ranch Member of the Cretaceous Cedar Mountain Formation southwest of Green River, Utah. Within the Cedar Mountain Formation in this part of Utah, fluvial sandstones filling paleochannels within it are cemented by calcium carbonate. Because of this cementation, the sandtone filling these paleochannels are considerably more resistant to erosion than the shale and mudstone that enclose them. As a result, differential erosion preferentially removes the shale and mudstone and exposes these paleochannels as ridges.[1] [2] .

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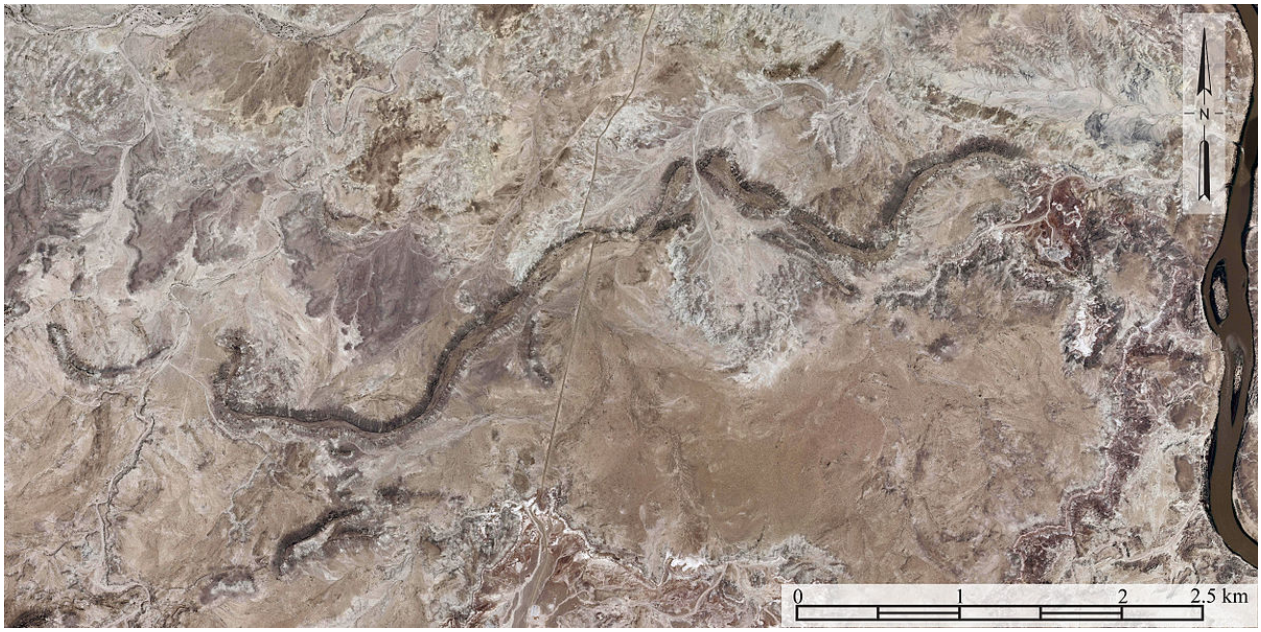
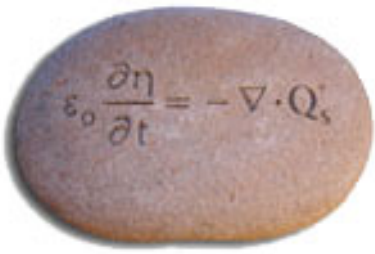
Emery County, Utah



Aerial view of exhumed river channel, Emery County, Utah.

Exner equation

The **Exner equation** is a statement of conservation of mass that applies to sediment in a fluvial system such as a river.[1] It was developed by the Austrian meteorologist and sedimentologist Felix Maria Exner, from whom it derives its name.[2]



This rock belonging to University of Minnesota Professor of Geology Chris Paola is inscribed with the Exner equation.

The equation

The Exner equation describes conservation of mass between sediment in the bed of a channel and sediment that is being transported. It states that bed elevation increases (the bed aggrades) proportionally to the amount of sediment that drops out of transport, and conversely decreases (the bed degrades) proportionally to the amount of sediment that becomes entrained by the flow.

Basic equation

The equation states that the change in bed elevation, η, over time, t, is equal to one over the grain packing density, ε_o, times the negative divergence of sediment flux, q_s.

$$\frac{\partial \eta}{\partial t} = -\frac{1}{\varepsilon_o} \nabla \cdot \mathbf{q_s}$$

Note that ε_o can also be expressed as $(1 - \lambda_p)$, where λ_p equals the bed porosity.

Good values of ε_o for natural systems range from 0.45 to 0.75.[3] A typical good value for spherical grains is 0.64, as given by random close packing. An upper bound for close-packed spherical grains is 0.74048. (See sphere packing for more details); this degree of packing is extremely improbable in natural systems, making random close packing the more realistic upper bound on grain packing density.

Often, for reasons of computational convenience and/or lack of data, the Exner equation is used in its one-dimensional form. This is generally done with respect to the down-stream direction x, as one is typically interested in the down-stream distribution of erosion and deposition though a river reach.

$$\frac{\partial \eta}{\partial t} = -\frac{1}{\varepsilon_o} \frac{\partial \mathbf{q_s}}{\partial x}$$

Including external changes in elevation

An additional form of the Exner equation adds a subsidence term, σ, to the mass-balance. This allows the absolute elevation of the bed η to be tracked over time in a situation in which it is being changed by outside influences, such as tectonic or compression-related subsidence (isostatic compression or rebound). In the convention of the following equation, σ is positive with an increase in elevation over time and is negative with a decrease in elevation over time.

$$\frac{\partial \eta}{\partial t} = -\frac{1}{\varepsilon_o} \nabla \cdot \mathbf{q_s} + \sigma$$

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Falesia

In Italy, **falesia** is a vertical rock sheer on the sea. A climbing route. Rock Climbing wall.

Fall line

A **fall line** (or **fall zone**) is a geomorphologic unconformity (e.g., monoclinal faulting and/or flexing)[1] between an upland region of relatively hard crystalline basement rock and a coastal plain of softer sedimentary rock.[2] A fall line is typically prominent when crossed by a river, for there will often be rapids or waterfalls. Many times a fall line will recede upstream as the river cuts out the uphill dense material, often forming “c”-shaped waterfalls. Because of these features riverboats typically cannot travel any farther inland without portaging, unless locks are built there. On the other hand, the rapid change in elevation of the water, and the resulting energy release, makes the fall line a good location for water mills, grist mills, and sawmills. Because of the need for a river port leading to the ocean, and a ready supply of water power, settlements often develop where rivers cross a fall line.

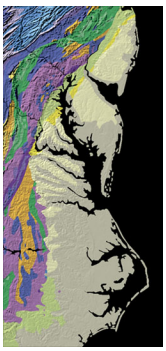
Fall lines of the United States

The slope of fall zones on rivers played a role in settlement patterns. For example, fall lines proved useful for hydroelectric dams such as at Rochester, New York (on the Niagara Escarpment) and Columbia, South Carolina (on the Atlantic Seaboard fall line). Other cities along fall lines of the United States include:

- New England fall line:
  - Lowell, Massachusetts (Merrimack River).
  - Hartford, Connecticut (Connecticut River).
  - Fall River, Massachusetts (Quequechan River).
  - Bangor, Maine (Penobscot River).
- Onondaga fall line:
  - Albany, New York (Hudson River).
- Southern fall line:
  - Richmond, Virginia on the James River
  - Augusta, Georgia on the Savannah River.
  - Milledgeville, Georgia on the Oconee River.
  - Macon, Georgia on the Ocmulgee River.
  - Columbus, Georgia on the Chattahoochee River.[3]
  - Tallassee, Alabama on the Tallapoosa River.
  - Wetumpka, Alabama on the Coosa River.
- Other fall lines:
  - Montreal (St. Lawrence River).

Atlantic Seaboard fall line

Atlantic Seaboard fall line	
Fall line	
Nickname: *Piedmont—Coastal Plain fall line*	
Country	United States
North endpoint **South endpoint**	New Jersey Carolinas or Georgia [4] [3]
Length	900 mi (1400 km) [3]



Map showing part of the Eastern Seaboard Fall Line where the pale colored coastal plain meets the brightly colored Piedmont.

The **Atlantic Seaboard Fall Line**, or **Fall Zone**, is a 900-mile (1400 km) escarpment where the Piedmont and Atlantic coastal plain meet in the eastern United States.[3] Much of the Atlantic Seaboard fall line passes through areas where no evidence of faulting is present.

The fall line marks the geologic boundary of hard metamorphosed terrain—the product of the Taconic orogeny—and the sandy, relatively flat outwash plain of the upper continental shelf, formed of unconsolidated Cretaceous and Tertiary sediments. Examples of the Fall Zone include the Potomac River's Great Falls and the rapids in Richmond, Virginia, where the James River falls across a series of rapids down to the tidal estuary of the James River.

Before navigation improvements such as locks, the fall line was often the head of navigation on rivers due to rapids and waterfalls, such as the Great Falls of the Potomac River. Numerous cities were founded at the intersection of rivers and the fall line. U.S. Route 1 links many of the fall line cities. Some of the cities along the Piedmont—Coastal Plain fall line include, from north to south:

- Trenton, New Jersey on the Delaware River.[3]
- Philadelphia, Pennsylvania on the Schuylkill River.[5]
- Wilmington, Delaware on Brandywine Creek.[5]
- Newark, Delaware on the Christina River.
- Stanton, Delaware on the White Clay Creek.
- Baltimore, Maryland, on the Patapsco River.[5]
- Laurel, Maryland on the Patuxent River.
- Georgetown, District of Columbia on the Potomac River.[6]
- Occoquan, Virginia on the Occoquan River.
- Fredericksburg, Virginia on the Rappahannock River.[6]
- Richmond, Virginia on the James River.[7]
- Petersburg, Virginia on the Appomattox River.
- Roanoke Rapids, North Carolina on the Roanoke River.

- Smithfield, North Carolina on the Neuse River.
- Fayetteville, North Carolina on the Cape Fear River.
- Cheraw, South Carolina on the Pee Dee River.
- Camden, South Carolina on the Wateree River.
- Columbia, South Carolina on the Congaree River.[7]
- Augusta, Georgia on the Savannah River.
- Columbus, Georgia on the Chattahoochee River.[3]

This list is incomplete.

Atlantic Seaboard fall line, north-to-south

State	Point (crossing)	Elevation & coordinates	Fall zone: drop/width (slope)	Geomorphology Piedmont—Coastal plain
New Jersey	New Brunswick (Raritan River)	460 ft (140 m)40°29′18″N 74°26′52″W		
	Trenton (Delaware River)	40°13′18″N 74°45′22″W	8 ft	
Pennsylvania				
Delaware				
Maryland	Conowingo Dam (Susquehanna)			
	Ellicott City[8] (Patapsco)	39°16.044′N 76°47.573′W[9]		crystalline rock—unconsolidate marine sediments [10]
	Great Falls (Potomac River)	38°59′51″N 77°15′9″W	76 ft/<1 mi (>1.4%)	
Virginia	Fredericksburg (Rappahannock)	39°16.044′N 76°47.573′W[9]		[west of Interstate 95 bridge][11]
	Emporia (Meherrin River)[12]			

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[10] http://www.mde.maryland.gov/assets/document/Patapsco%20LNB%20Stressor%20ID%20Report_04-20-09.pdf
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Fault scarp

A **fault scarp** is the topographic expression of faulting attributed to the displacement of the land surface by movement along faults. They are exhibited either by differential movement and subsequent erosion along an old *inactive* geologic fault (a sort of old rupture), or by a movement on a recent active fault. Fault scarps often contain highly fractured rock of both hard and weak consistency. In many cases, bluffs form from the upthrown block and can be very steep. The height of the scarp formation is equal to the vertical displacement along the fault. Active scarps are usually formed by tectonic displacement, e.g. when an earthquake changes the elevation of the ground, and can be caused by any type of fault, including strike-slip faults, whose motion is primarily horizontal. This movement is usually episodic, with the height of the bluffs being the result of multiple movements over time. Displacement of around 5 to 10 meters per tectonic event is common.[1]

This fault scarp was created by the 1959 Hebgen Lake, Montana, earthquake. Photo taken August 19, 1959.

A reverse-motion, fault-line scarp from Mongolia.

Borah Peak and its fault scarp, formed in the 1983 Borah Peak earthquake.

A geology class takes a close look at the Wasatch Fault scarp, Utah

Due to the dramatic uplift along the fault, the fault scarp is very prone to erosion, especially if the material being uplifted consists of unconsolidated sediment. Weathering, mass wasting and water runoff can soon wear down these bluffs. Fault scarps may be only a few centimeters or many meters high. *Fault-line scarps* are coincident with faults, but are most typically formed by the erosion of weaker rocks that have been brought alongside more resistant ones by the movement along the fault. In the case of old eroded fault scarps, active erosion may have moved the physical cliff back away from the actual fault location which may be buried beneath a talus, alluvial fan or the valley fill.

Notable characteristics

The rapid erosion of these bluffs can create defined V-shaped valleys along runoff channels. Adjacent V-shaped valley formations give the remaining fault spurs a very triangular shape. This formation is known as a *triangular facet*; however, this landform is not limited to fault scarps.

Examples

The Teton Range in Wyoming is an example of an active fault scarp. The dramatic topography of the Tetons is due to the geologically recent activity on the Teton fault. The Hurricane Cliffs, west of Zion National Park in Utah is a prominent example of a fault scarp along an old, essentially inactive, fault. Other examples include the scarps bounding the East African Rift Valley and the Rio Grande Rift in New Mexico.

In other parts of the world, many fault scarps exist in the Eastern and Western Alps. In New Zealand a large scarp can be seen at Maruia Falls on the Shenandoah Highway, South Island. The 1929 Murchison earthquake raised the upstream side by about four metres, thereby creating a fault scarp and, as a result, also a waterfall.

New Zealand's Maruia Falls after a storm

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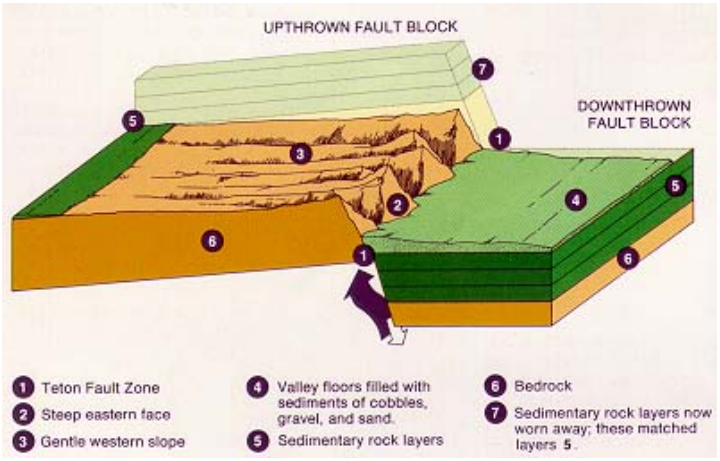
Fault-block mountain

Fault-block landforms (mountains, hills, ridges, etc.) are formed when large areas of bedrock are widely broken up by faults creating large vertical displacements of continental crust.

Vertical motion of the resulting blocks, sometimes accompanied by tilting, can then lead to high escarpments. These mountains are formed by the Earth's crust being stretched and extended by tensional forces. Fault block mountains commonly accompany rifting, another indicator of tensional tectonic forces.

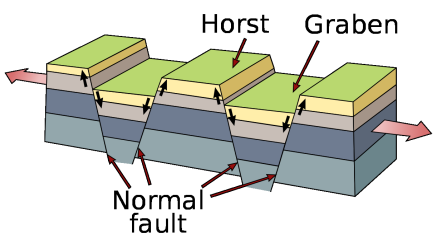


Fault block formation in the Teton Range

The uplifted blocks are called *block mountains* or *horsts*. The intervening dropped blocks are termed *graben*: these can be small or form extensive rift valley systems. This form of landscape can be seen in East Africa, the Vosges, the Basin and Range province of Western North America, in south-central New England, and the Rhine valley. These areas often occur when the regional stress is extensional and the crust is thinned.

Two types of block mountains are lifted and tilted. Tilted type block mountains have one gently sloping side and one steep side with an exposed scarp, and are common in the Basin and Range region of the western United States. Level blocks lead to the horst and graben terrain seen in northern Europe. Lifted type block mountains have two steep sides exposing both sides scarps.

The Hanging Hills of Connecticut (Metacomet Ridge range); upfaulting (horst) visible from right to left.



Fault-block geology

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External links

- http://www.universetoday.com/guide-to-space/earth/fault-block-mountains/
- http://science.jrank.org/pages/2667/Fault-Mountain-building-by-small-movements-along-faults.html Fault - Mountain-building By Small Movements Along Faults

Feeder bluff

A **feeder bluff** is a geomorphological term whose use is primarily restricted to the Puget Sound region. It is not a standard or widely-accepted geologic term. The concept of a feeder bluff was first developed at Western Washington University, and it has not been extensively researched. Specific criteria have not been developed that distinguish feeder bluffs from other types of bluffs. Quantities and rates of sediment supply to beaches and the littoral drift are unspecified and unknown. The overall contribution of "feeder bluffs" to beach processes, unlike the well-researched effects of sediment from rivers, is still undetermined.

Feeder Bluff located at Jefferson Beach in Kingston,WA

A feeder bluff is a coastal cliff or headland that feeds the beaches down current. As the waves approach the bluff, they erode away sediment which then gets carried along the coastline and deposited across other beaches. The majority of the wave energy is concentrated at the base of the bluff, where it is most accessible for the wave action.

The bluff will be more susceptible to erosion if the sediment is unconsolidated, and is found to be more resistant in crystalline rocks, like granite. The difference between the two is quite drastic, a difference of thousands of cm/year to less than 1 cm/year of retreat respectively. Rocks that are heavily fractured are also very likely to suffer from excess erosion because the water can flow between the cracks to speed up the process. The bluff will retreat towards land as the erosion processes continue.

Types

Evidence of erosion causing mass movement at Jefferson Beach in Kingston, Washington

There are two main types of feeder bluff erosion, defined by the patterns of wave energy. These patterns are also highly variable, even within themselves. The first type consists of erratic erosion patterns, light waves with intermittent large storms, those tend to be rocky slopes. The majority of the erosion that occurs happens during storms. The high energy storm waves have more power to take sediment away and deposit it along the coast with the long shore drift. The high energy of a single storm has the ability to take up to 5 to 30 m of the bluff into the water with it.

The second type of bluff is adding sediment at a rate nearly equal to the rate of erosion. In this case, the sediment load is balanced and between storms. There will almost always be a talus, mass of eroded material, at the base of the bluff. This talus will help protect the base of the cliff from further erosion as long as it is present.

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External links

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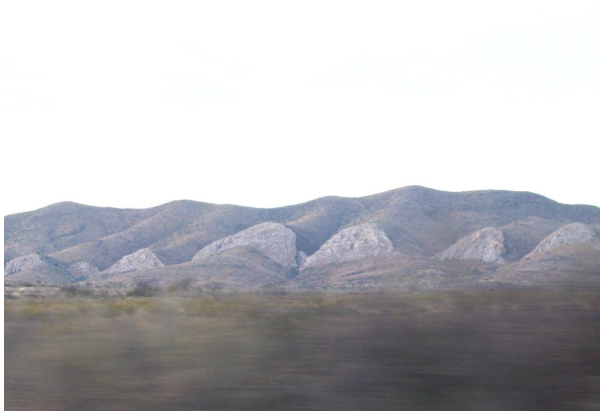
Flatiron (geomorphology)

A **flatiron** in geomorphology is a steeply sloping wedge-shaped landscape feature created by differential erosion of a resistant rock layer which is inclined in the same direction as, but at a steeper angle than the exposed mountain slope. Flatirons are associated with hogback ridges. The name *flatiron* was derived from the resemblance to an upended household flatiron.

The Flatirons near Boulder, Colorado, are a notable example of the landform. Other well developed flatirons are found in the eastern Uinta Mountains in northwestern Colorado[2] and on the flanks of the Marathon Uplift in west Texas.[1]

The Flatirons overlooking Boulder, Colorado



Novaculite flatirons on the flank of East Bourland Mountain in the Marathon Uplift of West Texas[1]

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Floodplain

A **floodplain**, or **flood plain**, is a flat or nearly flat land adjacent to a stream or river that stretches from the banks of its channel to the base of the enclosing valley walls and experiences flooding during periods of high discharge.[1] It includes the floodway, which consists of the stream channel and adjacent areas that carry flood flows, and the **flood fringe**, which are areas covered by the flood, but which do not experience a strong current. In other words, a floodplain is an area near a river or a stream which floods easily.

View of the flood plain following a 1 in 10 year flood on the Isle of Wight

Physical geography

Flood plains are made by a meander eroding sideways as it travels downstream. When a river breaks its banks and floods, it leaves behind layers of rock and mud. These gradually build up to create the floor of the flood plain. Floodplains generally contain unconsolidated sediments, often extending below the bed of the stream. These are accumulations of sand, gravel, loam, silt, and/or clay, and are often important aquifers, the water drawn from them being pre-filtered compared to the water in the stream.

Gravel floodplain of a glacial river near the Snow Mountains in Alaska, 1902

Geologically ancient floodplains are often represented in the landscape by fluvial terraces. These are old floodplains that remain relatively high above the present floodplain and indicate former courses of a stream.

Sections of the Missouri River floodplain taken by the United States Geological Survey show a great variety of material of varying coarseness, the stream bed having been scoured at one place and filled at another by currents and floods of varying swiftness, so that sometimes the deposits are of coarse gravel, sometimes of fine sand or of fine silt. It is probable that any section of such an alluvial plain would show deposits of a similar character.

Entrenched river: The Virgin River at the upper end of Zion Canyon, Zion National Park, Utah, has almost no floodplain at all.

The floodplain during its formation is marked by meandering or anastomotic streams, ox-bow lakes and bayous, marshes or stagnant pools, and is occasionally completely covered with water. When the drainage system has ceased to act or is entirely diverted for any reason, the floodplain may become a level area of great fertility, similar in appearance to the floor of an old lake. The floodplain differs, however, because it is not altogether flat. It has a gentle slope down-stream, and often, for a distance, from the side towards the center.

Ecology

Floodplains can support particularly rich ecosystems, both in quantity and diversity. They are a category of riparian zones or systems. A floodplain can contain 100 or even 1000 times as many species as a river. Wetting of the floodplain soil releases an immediate surge of nutrients: those left over from the last flood, and those that result from the rapid decomposition of organic matter that has accumulated since then. Microscopic organisms thrive and larger species enter a rapid breeding cycle. Opportunistic feeders (particularly birds) move in to take advantage. The production of nutrients peaks and falls away quickly; however the surge of new growth endures for some time. This makes floodplains particularly valuable for agriculture.

Aggradation and plantation: The Laramie River meanders across its floodplain in Albany County, Wyoming, 1949.

Interaction with society

Historically, many towns have been built on floodplain, where they are highly susceptible to flooding, for a number of reasons:

- access to fresh water;
- the fertility of floodplain land for farming;
- cheap transportation, via rivers and railroads, which often followed rivers;
- ease of development of flat land

The extent of floodplain inundation depends in part on the flood magnitude, defined by the return period.

Aggradational floodplain: This floodplain of a small meandering stream in La Plata County, Colorado, is underlain by silt deposited above a dam formed by a terminal moraine left by the Wisconsin Glacier.

In the United States the National Flood Insurance Program regulates development in mapped floodplains based on the 100-year flood (1% annual chance of a flood of this magnitude). The Flood Insurance Rate Maps, typically depict both the 100-year floodplain and the 500-year floodplains. Where a detailed study of a waterway has been done, the 100-year floodplain will also include the floodway, the critical portion of the floodplain which includes the stream channel and any adjacent areas that must be kept free of encroachments that might block flood flows or restrict storage of flood waters. When a floodway is shown on the Flood Insurance Rate Maps, the portion of the 100-year floodplain outside of the floodway is known as the flood fringe. Another commonly-encountered term is the Special Flood Hazard Area, which is any area subject to inundation by the 100-year flood.[2] A problem is that any alteration of the watershed upstream of the point in question can potentially affect the ability of the watershed to handle water, and thus potentially affects the levels of the periodic floods. A large shopping center and parking lot, for example, may raise the levels of the 5-year, 100-year, and other floods, but the maps are rarely adjusted, and are frequently rendered obsolete by subsequent development.

Riparian vegetation on the floodplain of the Lynches River near Johnsonville, South Carolina. These tupelo and cypress trees show the high water mark of flooding.

In order for flood-prone property to qualify for government-subsidized insurance, a local community must adopt an ordinance that protects the floodway and requires that new residential structures built in Special Flood Hazard Areas

be elevated to at least the level of the 100-year flood. Commercial structures can be elevated or floodproofed to or above this level. In some areas without detailed study information, structures may be required to be elevated to at least two feet above the surrounding grade.[3] Many State and local governments have, in addition, adopted floodplain construction regulations which are more restrictive than those mandated by the NFIP. The U.S. government also sponsors flood hazard mitigation efforts to reduce flood impacts. The Hazard Mitigation Program is one funding source for mitigation projects. A number of whole towns such as English, Indiana, have been completely relocated to remove them from the floodplain. Other smaller-scale mitigation efforts include acquiring and demolishing flood-prone buildings or flood-proofing them.

In some tropical floodplain areas such as the Inner Niger Delta of Mali, annual flooding events are a natural part of the local ecology and rural economy, allowing for the raising of crops through recessional agriculture. But in Bangladesh, which occupies the Ganges Delta, the advantages provided by the richness of the alluvial soil of floodplains are severely offset by frequent floods brought on by cyclones and annual monsoon rains, which cause severe economic disruption and loss of human life in this densely-populated region.

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[3] Code of Federal Regulations, Title 44, Section 60.3 - Flood plain management criteria for flood-prone areas (http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=5419b04fdcd492a8db45d92248c9e074&rgn=div8&view=text&node=44:1.0.1.2.27.1.25.3&idno=44)

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Fluvial

Fluvial is used in geography and Earth science to refer to the processes associated with rivers and streams and the deposits and landforms created by them. When the stream or rivers are associated with glaciers, ice sheets, or ice caps, the term **glaciofluvial** or **fluvioglacial** is used.[1] [2]

Deep, eroding glaciofluvial deposits alongside the Matanuska River, Alaska

Fluvial processes

Fluvial processes comprise the motion of sediment and erosion or deposition (geology) on the river bed.

Erosion by moving water can happen in two ways. Firstly, the movement of water across the bed exerts a shear stress directly onto the bed. If the cohesive strength of the substrate is lower than the shear exerted, or the bed is composed of loose sediment which can be mobilized by such stresses, then the bed will be lowered purely by clearwater flow. However, if the river carries significant quantities of sediment, this material can act as tools to enhance wear of the bed (abrasion). At the same time the fragments themselves are ground down, becoming smaller and more rounded (attrition).

Sediment in rivers is transported as either bedload (the coarser fragments which move close to the bed) or suspended load (finer fragments carried in the water). There is also a component carried as dissolved material.

For each grain size there is a specific velocity at which the grains start to move, called *entrainment velocity*. However the grains will continue to be transported even if the velocity falls below the entrainment velocity due to the reduced (or removed) friction between the grains and the river bed. Eventually the velocity will fall low enough for the grains to be deposited. This is shown by the Hjulstrøm curve.

A river is continually picking up and dropping solid particles of rock and soil from its bed throughout its length. Where the river flow is fast, more particles are picked up than dropped. Where the river flow is slow, more particles are dropped than picked up. Areas where more particles are dropped are called alluvial or flood plains, and the dropped particles are called alluvium.

Even small streams make alluvial deposits, but it is in the flood plains and deltas of large rivers that large, geologically-significant alluvial deposits are found.

The amount of matter carried by a large river is enormous. The names of many rivers derive from the color that the transported matter gives the water. For example, the Huang He in China is literally translated "Yellow River", and the Mississippi River in the United States is also called "the Big Muddy." It has been estimated that the Mississippi River annually carries 406 million tons of sediment to the sea,[3] the Huang He 796 million tons, and the Po River in Italy 67 million tons.[4]

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Fluvial landforms of streams

The fluvial landforms of streams, stream beds, and river valleys have various different landforms.

Classification

There are five generic classifications:

- **Consequent** streams are streams whose course is a direct consequence of the original slope of the surface[1] [2] upon which it developed, i.e., streams that follow slope of the land over which they originally formed.
- **Subsequent** streams are streams whose course has been determined by selective headward erosion along weak strata. These streams have generally developed after the original stream. Subsequent streams developed independently of the original relief of the land and generally follow paths determined by the weak rock belts.[3]
- **Resequent** streams are streams whose course follows the original relief, but at a lower level than the original slope (e.g., flows down a course determined by the underlying strata in the same direction). These streams develop later and are generally a tributary to a subsequent stream.
- **Obsequent** streams are streams flowing in the opposite direction of the consequent drainage.
- **Insequent** streams have an almost random drainage often forming dendritic patterns. These are typically tributaries and have developed by a headward erosion on a horizontally stratified belt or on homogeneous rocks. These streams follow courses that apparently were not controlled by the original slope of the surface, its structure or the type of rock.

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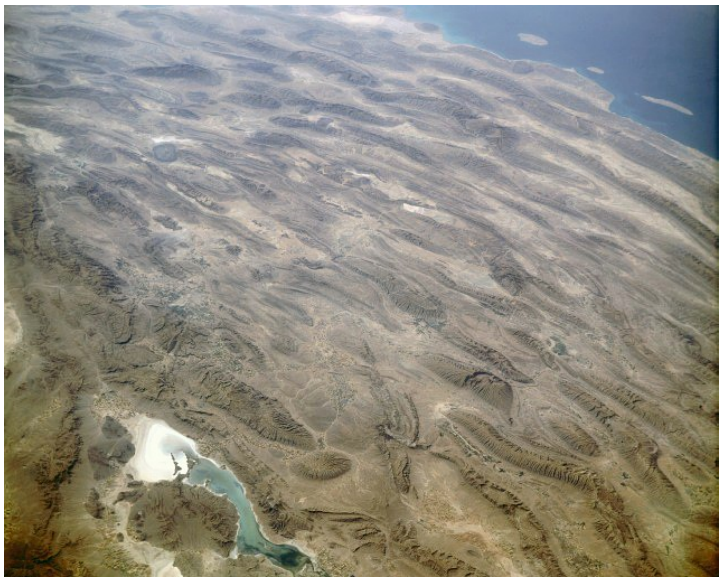
Fold mountain

Fold mountains are mountains formed mainly by the effects of folding on layers within the upper part of the Earth's crust. In the time before either plate tectonic theory developed, or the internal architecture of thrust belts became well understood, the term was used for most mountain belts, such as the Himalayas. The term is still fairly common in physical geography literature but has otherwise generally fallen out of use except as described below. The forces responsible for formation of the fold mountains are called orogenic movements. The term *orogenic* is derived from a Greek word meaning mountain building. These forces act at tangent to the surface of the earth and are primarily involved in plate tectonics.



Zagros mountain range, seen from space.

Formation

Fold mountains are formed when two plates move together (a compressional plate margin). This can be where two continental plates move towards each other or a continental and an oceanic plate. The movement of the two plates forces sedimentary rocks upwards into a series of folds. Fold mountains are usually formed from sedimentary rocks and are usually found along the edges continents. This is because the thickest deposits of sedimentary rock generally accumulate along the edges of continents. When plates and the continents riding on them collide, the accumulated layers of rock crumple and fold like a tablecloth that is pushed across a table.

There are two types of fold mountains: young fold mountains (10 to 25 million years of age, e.g. Rockies and Himalayas) and old fold mountains (over 200 million years of age, e.g. Urals and Appalachians of the USA).

Types

Alpine-Formed 30-35 million years ago. eg. Himalayas, Andes

Armorican-Formed about 250 million years ago. eg. Macgillycuddy reeks, Co. Kerry, Ireland

Caledonian- Formed about 500 million years ago. eg. Grampians, Scotland

Examples

- The Jura mountains - A series of sub-parallel mountainous ridges formed by folding over a Triassic evaporite decollement due to thrust movements in the foreland of the Alps.
- The Zagros mountains - A series of elongated anticlinal domes, mostly formed as fault bend folds over underlying thrusts in the foreland of the Zagros collisional belt

Forebulge

In geology, a **forebulge** is a flexural bulge in front of a load on the lithosphere. This load causes the lithosphere to flex by depressing the plate beneath it. Because of the flexural rigidity of the lithosphere, the area around the load is uplifted by a height that is 4% of that of the depression under the load. This load and resulting flexure place stress on the mantle, causing it to flow into the area around the loaded area. The subsidence of the area under the load and the uplift of the forebulge continue until the load is in isostatic equilibrium, a process which takes on the order of 10–20 thousand years. Because of the coupling with the mantle, the rate of forebulge formation and collapse is controlled by mantle viscosity.

Glacial

One cause for forebulge formation is loading of the continental lithosphere by ice sheets during continental glaciations. Because of the removal of the ice sheets, these formerly-glaciated areas are currently rising in a phenomenon known as post-glacial rebound. Because of the coupling of the mantle with the plates, data from post-glacial rebound are used as a direct probe of the viscosity of the upper mantle. As the ice melts and the land under it rises by isostatic recovery, the forebulge also subsides. Forebulge subsidence is the reason why the Netherlands and parts of southern England have been slowly sinking in the present day.[1]

One estimate [2] is that the centre of the North Sea rose by about 170m (558 feet) during the Ice Age because of forebulging.

Tectonic

Collisions between tectonic plates and island arcs lead to loading and flexure of the lithosphre. This flexure produces a significant forebulge that divides a forearc basin and a back arc basin.

Physics

The existence of a forebulge is predicted by the solution to the equations for the flexure of a thin elastic beam or plate (i.e., the lithosphere). The magnitude of the flexure goes as an exponentially decaying sinusoid. The lithosphere is therefore anomalously high at a flexural half-wavelength past the load; this flexural wavelength is determined in large part by the elastic thickness of the lithosphere.

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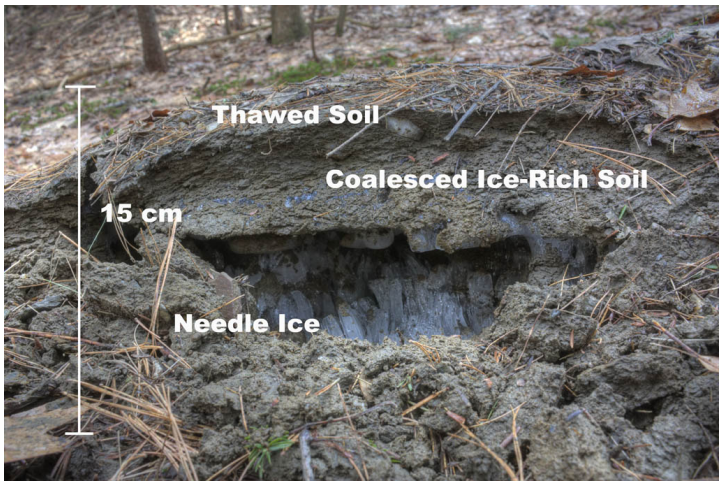
Frost heaving

Frost heaving (or a **frost heave**) results from ice forming beneath the surface of soil during freezing conditions in the atmosphere. The ice grows in the direction of heat loss (vertically toward the surface), starting at the freezing front or boundary in the soil. It requires a water supply to keep feeding the ice crystal growth; and the growing ice is restrained by overlying soil, which applies a load that limits its vertical growth and promotes the formation of a lens-shaped area of ice within the soil. Yet the force of one or more growing ice lenses is sufficient to lift a layer of soil, as much as 30 cm or more. The soil through which water passes to feed the formation of ice lenses must be sufficiently porous to allow capillary action, yet not so porous as to break capillary continuity. Such soil is referred to as "frost susceptible." The growth of ice lenses continually consumes the rising water at the freezing front.[1] [2] Differential frost heaving can crack pavements[3] and damage building foundations.[4]

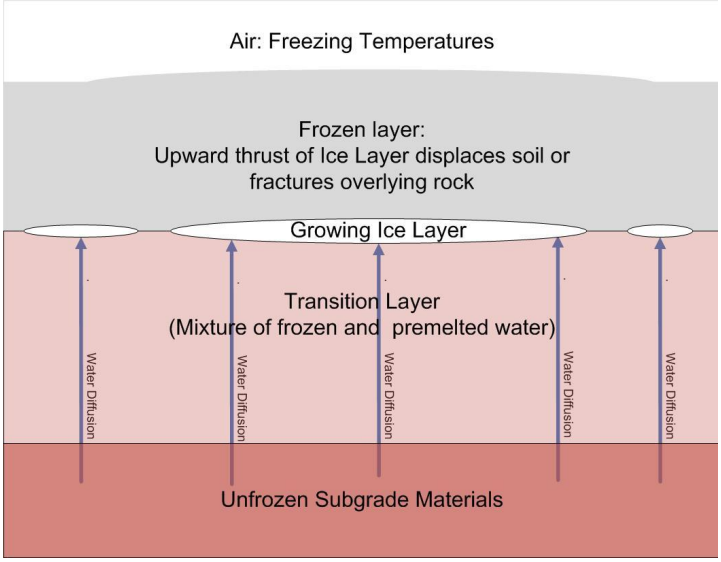


Anatomy of a frost heave during spring thaw. The side of a 6-inch (15-cm) heave with the soil removed to reveal (bottom to top):
· Needle ice, which has extruded up from the freezing front through porous soil from a water table below
· Coalesced ice-rich soil, which has been subject to freeze-thaw
· Thawed soil on top.
Photograph taken 21 March 2010 in Norwich, Vermont

Needle ice is essentially frost heaving that occurs at the beginning of the freezing season, before the freezing front has penetrated very far into the soil and there is no soil overburden to lift as a frost heave.[5]

Mechanisms

Historical understanding of frost heaving



Ice lens formation resulting in frost heave in cold climates.

According to Beskow, Urban Hiäme described frost effects in soil in 1694.[5] Taber disproved the hypothesis that frost heaving results from molar volume expansion with freezing of water already present in the soil prior to the onset of subzero temperatures, i.e. with little contribution from migration of water within the soil.

Since the molar volume of water expands by about 9% as it changes phase from water to ice at its bulk freezing point, 9% would be the maximum expansion possible owing to molar volume expansion, and even then only if the ice were rigidly constrained laterally in the soil so that the entire volume expansion had to be taken up vertically. Ice is unusual among compounds because it increases in molar volume from its liquid state, water. Most compounds decrease in volume when changing phase from liquid to solid. Taber showed that the vertical displacement of soil in frost heaving can be significantly greater than that due to molar volume expansion.[1]

Taber demonstrated that liquid water flows towards the freeze line within soil. He showed that other liquids, such as benzene, which contracts when it freezes, also produce frost heave.[6] This ruled out molar volume changes as the dominant mechanism for vertical displacement of freezing soil. His experiments further demonstrated the development of ice lenses inside columns of soil that were frozen by cooling the upper surface only, thereby establishing a temperature gradient[7] [8] [9]

Development of ice lenses

The dominant cause of soil displacement in frost heaving is the development of ice lenses. During frost heave, one or more soil-free ice lenses grow, and their growth displaces the soil above them. These grow with the continual addition of water from a groundwater source lower in the soil structure, below the freezing line in the soil. The presence of frost-susceptible soil with a pore structure that promotes capillary flow is essential to delivering water to the ice lenses, as they form.

Water can arrive at the forming ice lens at a temperature that is below the bulk freezing point, owing to the Gibbs-Thomson effect of confinement of liquids in pores. Very fine pores have a very high curvature, and this results in the liquid phase being thermodynamically stable in such media at temperatures sometimes several tens of degrees below the bulk freezing point.[10] Another water-transport effect is the preservation of a few atomic layers of liquid water on the surface of the ice lens, and between ice and soil particles. Faraday reported on the unfrozen layer of premelted water in 1860." [11] Ice premelts against its own vapor, and in contact with silica.[12]

Micro-scale processes

The same intermolecular forces that cause premelting at surfaces contribute to frost heaving at the particle scale on the bottom side of the forming ice lens. When ice surrounds a fine soil particle as it premelts, the soil particle will be displaced downward towards the warm direction within the thermal gradient due to melting and refreezing of the thin film of water that surrounds the particle. The thickness of such a film is temperature dependent and is thinner on the colder side of the particle.

Water has a lower free energy when in bulk ice than when in the supercooled liquid state. Therefore, there is a continuous replenishment of water flowing from the warm side to the cold side of the particle, and continuous melting to re-establish the thicker film on the warm side. The particle migrates downwards toward the warmer soil in a process that Faraday called "'thermal regelation."[11] This effect purifies the ice lenses as they form by repelling fine soil particles. Thus a 10-nanometer film of unfrozen water around each micrometre-sized soil particle can move it 10 micrometres/day in a thermal gradient of as low as 1°C km^{-1}.[12] As ice lenses grow, they lift the soil above, and segregate soil particles below, while drawing water to the freezing face of the ice lens via capillary action.

Frost-susceptible soils

Frost heaving requires a frost-susceptible soil, a continual supply of water below (a water table) and freezing temperatures, penetrating into the soil. Frost-susceptible soils are those with pore sizes between particles and particle surface area that promote capillary flow. Silty and loamy soil types, which contain fine particles, are examples of frost-susceptible soils. Many agencies classify materials as being frost susceptible if 10 percent or more constituent particles pass through a 0.075 mm (No. 200) sieve or 3 percent or more pass through a 0.02 mm (No. 635) sieve. Chamberlain reported other, more direct methods for measuring frost susceptibility.[13]

Partially melted and collapsed lithalsas (heaved mounds found in permafrost) have left ring-like structures on the Svalbard Archipelago

Non-frost-susceptible soils may be too dense to promote water flow (low hydraulic conductivity) or too open in porosity to promote capillary flow. Examples include dense clays with a small pore size and therefore a low hydraulic conductivity and clean sands and gravels, which contain small amounts of fine particles and whose pore sizes are too open to promote capillary flow.[14]

Structures created by frost heaving

Frost heaving creates raised-soil landforms in various geometries, including circles, polygons and stripes, which may be described as palsas in soils that are rich in organic matter, such as peat, or lithalsa[15] in more mineral-rich soils.[16] The stony lithalsa (heaved mounds) found on the archipelago of Svalbard are an example. Frost heaves occur in alpine regions, even near the equator, as illustrated by palsas on Mount Kenya.[17]

Palsas (heaving of organics-rich soils in discontinuous permafrost) may be found in alpine areas below Mugi Hill on Mount Kenya.

In Arctic permafrost regions, a related type of ground heaving over hundreds of years can create structures, as high as 60 metres, known as pingos, which are fed by an upwelling of ground water, instead of the capillary action that feeds the growth of frost heaves.

Polygonal forms apparently caused by frost heave have been observed in near-polar regions of Mars by the Mars Orbiter Camera (MOC) aboard the Mars Global Surveyor and the HiRISE camera on the Mars Reconnaissance Orbiter. In May 2008 the Mars Phoenix lander touched down on such a polygonal frost-heave landscape and quickly discovered ice a few centimetres below the surface.

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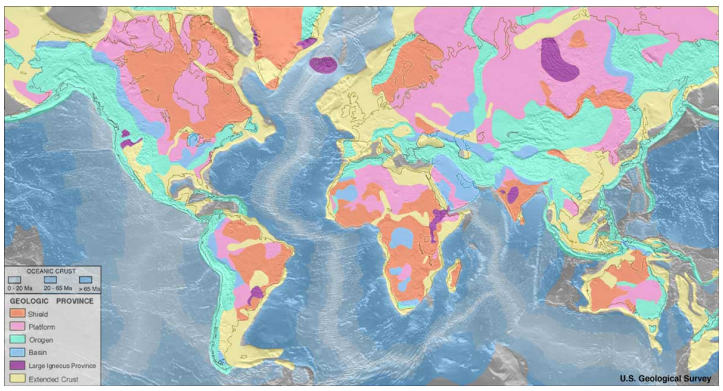
External links

- Presentation explaining mechanism and effects of frost heaving (http://www.youtube.com/watch?v=9jzycX380PA&feature=sub)
- ASTM D5918 - 06 Standard Test Methods for Frost Heave and Thaw Weakening Susceptibility of Soils (http://www.astm.org/Standards/D5918.htm)
- American Concrete Pavement Association (http://www.pavement.com/Concrete_Pavement/Technical/Fundamentals/Frost.asp) Frost Action and Frost Heave
- *Canadian Building Digest* article (http://www.nrc-cnrc.gc.ca/eng/ibp/irc/cbd/digest-index.html)
- National Research Council of Canada (http://www.nrc-cnrc.gc.ca/eng/ibp/irc/ci/volume-5-n2-1.html) Simple manhole innovation cuts frost heave in pavement
- American Institute of Physics pictures of frost heaving (http://www.aip.org/png/html/frost.htm)
- Stone Circles Explained (http://www.ucsc.edu/currents/02-03/01-20/patterns.html), about stone structures created by frost heaving

Geologic map

A **geologic map** or **geological map** is a special-purpose map made to show geological features. Rock units or geologic strata are shown by color or symbols to indicate where they are exposed at the surface. Bedding planes and structural features such as faults, folds, foliations, and lineations are shown with strike and dip or trend and plunge symbols which give these features' three-dimensional orientations.



Mapped global geologic provinces

Stratigraphic contour lines may be used to illustrate the surface of a selected stratum illustrating the subsurface topographic trends of the strata. Isopach maps detail the variations in thickness of stratigraphic units. It is not always possible to properly show this when the strata are extremely fractured, mixed, in some discontinuities, or where they are otherwise disturbed.

Symbology

Lithologies

Rock units are typically represented by colors. Instead of (or in addition to) colors, certain symbols can be used. Different geologic mapping agencies and authorities have different standards for the colors and symbols to be used for rocks of differing types and ages.

William Smith's geologic map

Orientations

Geologists take two major types of orientation measurements (using a hand compass like a Brunton compass): orientations of planes and orientations of lines. Orientations of planes are often measured as a "strike" and "dip", while orientations of lines are often measured as a "trend" and "plunge".

A standard Brunton Geo, used commonly by geologists

Strike and dip symbols consist of a long "strike" line, which is perpendicular to the direction of greatest slope along the surface of the bed, and a shorter "dip" line on side of the strike line where the bed is going downwards. The angle that the bed makes with the horizontal is along the dip direction is written next to the dip line. In the azimuthal system, strike and dip are often given as "STRIKE / DIP" (for example: 347/15, for a strike that is slightly West of North and a dip of 15 degrees below the horizontal).

Trend and plunge are used for linear features, and their symbol is a single arrow on the map. The arrow is oriented in the downgoing direction of the linear feature (the "trend") an at the end of the arrow, the number of degrees that the feature lies below the horizontal (the "plunge") is noted. Trend and plunge are often notated as PLUNGE → TREND (for example: 34 → 86 indicates a feature that is angled at 34 degrees below the horizontal at an angle that is just East of true South).

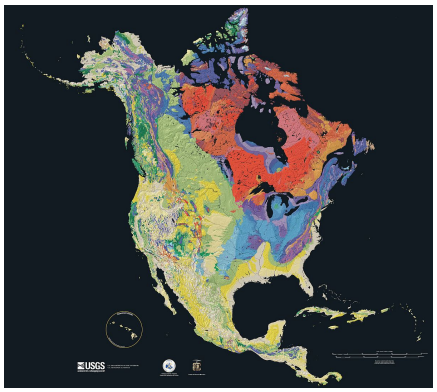
History

The oldest preserved geologic map is the Turin papyrus, made around 1150 BCE for gold deposits in Egypt.[1]

The first geologic map of Great Britain was created by William Smith in 1815.[2]

Maps and mapping across the globe

United States



Geologic map of North America superimposed on a shaded relief map

In the United States, geologic maps are usually superimposed over a topographic map (and at times over other base maps) with the addition of a color mask with letter symbols to represent the kind of geologic unit. The color mask denotes the exposure of the immediate bedrock, even if obscured by soil or other cover. Each area of color denotes a geologic unit or particular rock formation (as more information is gathered new geologic units may be defined). However, in areas where the bedrock is overlain by a significantly thick unconsolidated burden of till, terrace sedimentss, loess deposits, or other important feature, these are shown instead. Stratigraphic contour lines, fault lines, strike and dip symbols, are represented with various symbols as indicated by the map key. Whereas topographic maps are produced by the United States Geological Survey in conjunction with the states, geologic maps are usually produced by the individual states. There are almost no geologic map resources for some states, while a few states, such as Kentucky, are extensively mapped geologically.

United Kingdom

In the United Kingdom the term *geological map* is used. The UK and Isle of Man have been extensively mapped by the British Geological Survey since 1835; a separate Geological Survey of Northern Ireland (drawing on BGS staff) has operated since 1947.

Two 1:625,000 scale maps cover the basic geology for the UK. More detailed sheets are available at scales of 1:250,000, 1:50,000 and 1:10,000. The 1:625,000 and 1:250,000 scales show both onshore and offshore geology (the 1:250,000 series covers the entire UK continental shelf), whilst other scales generally cover exposures on land only.

Sheets of all scales (though not for all areas) fall into two categories:

> Superficial deposit maps (previously known as *solid and drift* maps) show both bedrock *and* the deposits on top of it.
>
> Bedrock maps (previously known as *solid* maps) show the underlying rock, without superficial deposits.

The maps are superimposed over a topographic map base produced by Ordnance Survey, and use symbols to represent fault lines, strike and dip or geological units, boreholes etc. Colors are used to represent different geological units. Explanatory booklets (memoirs) are produced for many sheets at the 1:50,000 scale.

Small scale thematic maps (1:1,000,000 to 1:100,000) are also produced covering geochemistry, gravity anomaly, magnetic anomaly, groundwater, etc.

Although BGS maps show the National Grid and employ an OS base map, sheet boundaries are not based on the grid. The 1:50,000 sheets originate from earlier 'one inch to the mile' (1:63,630) coverage utilising the pre-grid Ordnance Survey One Inch Third Edition as the base map. Current sheets are a mixture of modern field mapping at 1:10,000 redrawn at the 1:50,000 scale and older 1:63,630 maps reproduced on a modern base map at 1:50,000. In

both cases the original OS Third Edition sheet margins and numbers are retained. The 1:250,000 sheets are defined using lines of latitude and longitude, each extending 1° north-south and 2° east-west.

Singapore

The first geologic map of Singapore was produced in 1974, produced by the then Public Work Department. The publication include a locality map, 8 map sheets detailing the topography and geological units, and a sheet containing cross sections of the island.

Since 1974, for 30 years, there were many finding reported in various technical conferences on new found geology islandwide, but no new publication was produced. In 2006, Defence Science & Technology Agency, with their developments in underground space promptly started a re-publication of the Geology of Singapore, second edition. The new edition that was published in 2009, contains a 1:75,000 geology map of the island, 6 maps (1:25,000) containing topography, street directory and geology, a sheet of cross section and a locality map.

The difference found between the 1976 Geology of Singapore report include numerous formations found in literature between 1976 and 2009. These include the Fort Canning Boulder Beds and stretches of limestones.

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External links

- Geologic Maps (http://www2.nature.nps.gov/geology/usgsnps/gmap/gmap1.html) *from USGS National Park Service*
- USGS National Geologic Map Database (http://ngmdb.usgs.gov/)

Giant current ripples

Giant current ripples are active channel topographic forms up to 20 m high, which develop within near-talweg areas of the main outflow valleys crated by glacial lake outburst floods. Giant current ripple marks are morphologic and genetic macroanalogues of small current ripples formed in sandy stream sediments.

The giant current ripple marks are important depositional forms in diluvial plain and mountain scablands.[1]

Giant current ripples in the Kuray Basin, Altai Republic, Russia.

Short history of the research

J Harlen Bretz in 1949.

The history of the scabland studies has two distinct stages: the "*old*" one that began with the first works by J Harlen Bretz and Joseph Pardee in North America and lasted until the end of the 20th century that was crowned with the discovery of giant current ripple marks in Eurasia, and a "*new*" one. The latter is associated with heated debates concerning the genesis of the relief under study and which involved a lot of Russian geologists, geomorphologists and geographers. The discussion about the origin of the giant ripples dealt at least to a certain extent with every aspect of the diluvial theory, from the genesis of the lakes themselves, their existence duration, possibilities of their cataclysmic failures, etc. to the origin of the diluvial forms - the aspects that have been accepted by many scientists worldwide, including an increasing number of Russian scientists.

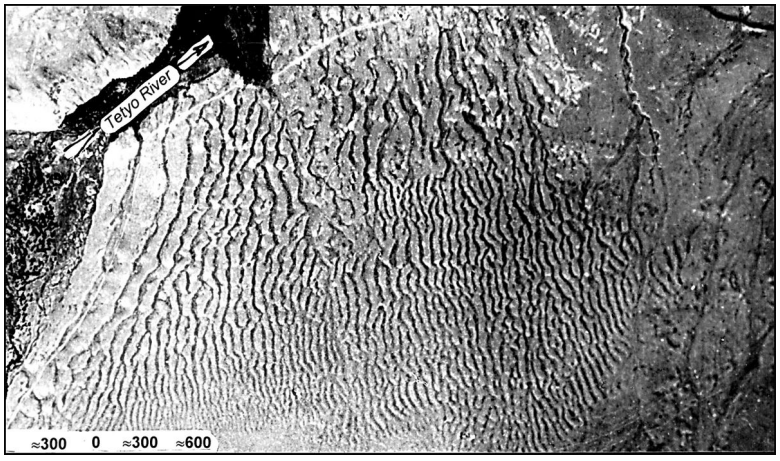
The state of the problem in the 20th century. "Old hypotheses"

J Harlen Bretz, the author of the hypothesis of the diluvial origin of the Channeled Scabland, considered mainly "giant gravel bars" (diluvial ramparts and terraces) among the diluvial-accumulative formations as a proof of his case along with the destructive forms of the scabland (gorges-coulees, waterfall cataracts – chains of erosional dry falls washed of loose sediments by the floods of diluvial farewell rocks).[2] [3] [4]

It was only after J. T. Pardee's report in Seattle at the Session of the American Association for the Advancement of Science in 1940[5] that the expression "giant current ripples" was introduced in the modern meaning. J. Pardee gave brief characteristics to the forms found by him already in the early 20th century while researching the Late Pleistocene lake Missoula.[6] J. Pardee, who was the discoverer of this lake and named it, had kept silent for over thirty years until his retirement about cataclysmic outbursts of the giant North-American ice-dammed lakes in the Pleistocene. As already mentioned, the "official" American geology represented by the United States Geological Survey, which strictly controlled all scientific studies, strongly objected to J H. Bretz's hypothesis in the early 20th century. J. Pardee was a member of this organization. Even the title "Ripple marks (?) in the glacial lake Missoula" of Pardee's report proves the great significance attached by Pardee to the relief he discovered a few decades ago as an instrument for the reconstruction of Late Quaternary diluvial palaeohydrology in North America. Thus, it is this scientist's name that we should associate with the discovery and correct genetic interpretation of the relief of giant current ripples. After Pardee's publication in 1942 the giant current ripples have been found practically everywhere on the territory of the basaltic Columbia Plateau (this was the direction of the cataclysmic outbursts of Missoula and other ice-dammed lakes).

A special study of the geomorphology and palaeohydrology of the American scabland was begun by Victor Baker.[7] It was Baker who mapped all main fields of giant current ripples known today in America, and it was he who made first attempts to gain chief hydraulic characteristics of the Missoula floods according to the multiple measurements of paired parameters of diluvial dunes and their mechanical composition.[8] Some other so far known means had certainly been used for the purpose as well since Bretz's times, in particular, the functional dependences by Schezi and Manning. However, those dependences estimated velocities and discharges of the floods at the channel line, and the data received, although imprecise, were tremendous. V. R. Baker calculated the palaeohydraulic data over the ripple fields, i.e. over the sites distanced from the channel line and (or) on wane of the floods, where the current velocities of the diluvial streams admittedly must have been less than maximum ones (all the same, they were hundreds of thousands of cubic kilometres per second).

For nearly sixty years the well known ice-dammed Lake Missoula (and other well-known North-American ice-dammed lakes) and its cataclysmic outbursts was considered as a unique one in the world's scientific literature. Special tourist routes were organised at most impressive sites of "giant vessels", canyons-coulees, vast fields of giant current ripples and others. Here professional guides tell the tourists about hydrospheric catastrophes which took place in the ice ages in America.



Giant current ripples in the Kuray Basin, Altai Republic, Russia

Current ripple marks in sand in modern stream in the Altai Republic, Russia

The discovery of the relief of giant current ripples in the Altai and Tuva and its correct diagnostics began a new stage in the paleogeographical research of the continents, a broad international cooperation and initiated new conclusions which have cleared up a lot of questions in the Quaternary geology and Paleohydrology of Pleistocene in Eurasia.

Along with the development of the ideas about enormous dimensions and a big role of Pleistocene glacier-dammed lakes and their cataclysmic outbursts, a new branch of the scientific research which was called by the British geologist P. A. Carling "flood deposit sedimentology"[9] is becoming more and more notable. In Russia in the middle 1990s the geological objects formed by the diluvial floods — floodstreams — were referred by the author to the research objects of Quaternary glaciohydrology based on the theory of the diluvial morpholithogenesis.[10]

The history of the scabland studies is distinctly divide into two stages: the "old" one that began with the first works by J H. Bretz and J. Pardee in North America and lasted until the end of the last century that was crowned with the discovery of giant current ripple marks discovered in Eurasia, and a "new" one. The latter is associated with heated debates concerning the genesis of the relief under study and which have involved a lot of Russian geologists, geomorphologists and geographers. The discussion about the origin of the giant ripples deals somehow or other with all the aspects of the diluvial theory, from the genesis of the lakes themselves, duration of their existence, possibilities of their cataclysmic failures, etc. to the origin of the diluvial forms that have already become doubtless for many scientists in other countries and an increasing number of the Russian scientists as well.

In Russia nobody had known anything about the regime of ice-dammed lakes until the 1980s and, of course, had not looked for any traces of their failures, either. Although some lake terraces of the basinal preglacial bodies of water in the mountains of South Siberia were mapped in the early 20th century (it was done incidentally during some geological and botanical investigations), the question of the evacuation mechanisms of these lakes did not even arise. As a matter of fact, this question was (and by someones is still) considered rhetorical: since there are strandlines on the sides of the depressions, then the lakes used to dry gradually and slowly. Moreover, in some authors' opinions, the lakes appeared in the depressions, in particular in the Altai, only once, at the most – twice. And when such lake terraces could be poorly distinguished, if any at all, in the depressions, then the question of the lakes did not arise: there were not any lakes.

Nevertheless, in the late 1950s G. F. Lungershausen and O. A. Rakovets[11] were the first to give a correct interpretation to a "mysterious" ridge-and-pading relief in Kuray intermountain depression. These scientists were the first to correctly define the genesis of the relief in the depression and to assume, according to the orientation of the diluvial dunes, the eastern direction of the runoff of the rivers, which is opposite to the contemporary one, at some moment in the history of the Altai. The genetic diagnostics of the giant ripples in the Kuray Basin had a general character and was essentially limited to the terminologically correct definition only (in fact, the purpose of the article of the authors mentioned was different). The article explained the origin of the direction of the water torrents proper by some neotectonic reasons.

New hypotheses of the origin of the giant current ripple marks

The notice made by G.F. Lungershausen and O.A. Rakovets about the diluvial origin of giant ripple marks in Kuray was denied by E.V. Deviatkin,[12] who referred to an oral conclusion made by E.V. Shantser and wrote that the large ripple marks in Kuray Basin were results of heavy erosional processing of a huge fluvioglacial fan. M.V. Petkevich expressed a similar opinion in her candidate thesis. She believed that the ridged relief on the right bank of the Tetio River in Kuray Basin was a washed proluvial fan.[13]

Giant current ripples from Helicopter. From south to north. Altay, Kuray, 2000

Every single diagnostic sign of the giant ripples given in the corresponding section contradict this theory, especially the cross-layered texture of the sediments in the ripple marks which correlates with their morphology and the regular asymmetry of their slopes at all the locations. The petrography composition of the coarse-fragmental material in the ripple marks witnesses also against this hypothesis, it is alien to the bed rock of the basins of the Tetio and the Aktru rivers.

In addition, G.G. Rusanov[14] found malachite, axinite, sillimanite and cinnabar in the schlichs of the ripple marks in Kuray Basin, which are characteristic of the Kuray Ridge but not found in the schlichs of the end moraines of the Tetio River, the latter adjoining the fields of the giant ripples. Cinnabar is a heavy, fragile and quickly worn mineral. That is why, as G.G. Rusanov remarks, it cannot be carried away from its original source farther than over first hundreds of metres. Over longer distances this mineral can be transported only in suspension state. At the same time, galena, which is very characteristic of the moraines of the Tetio and the Aktru Valleys, is not found in the ripple sediments. Hence, pebble deposits adjoining the end moraines of the Tetio cannot be fluvioglacial or proluvial formations of the meltwater from the glaciers of the Aktru and the Tetio.

At that time P.A. Okishev flatly disagreed with his predecessors and contemporaries. He argued that the proofs of the erosional extension of a vast fluvioglacial fan here (in Kuray Basin) are unconvincing. In 1970 P.A. Okishev put forward the idea that the giant current ripple marks in Kuray depression are "inversional formations". "The ridges presently expressed in the relief used to accumulate as channel sediments within above-glacial floods of a vast flat glacial field and projected afterwards onto the substratum" (,[15] p. 49).

A. N. Rudoy shall point out in this quotation that 1) P.A. Okishev simply described, though superficially, the mechanism of the eskers, and 2) he emphasised the fluvial, channel origin of the ridges proceeding from their material composition and morphology.[16] This investigator developed his theory later in his book[17] and his doctoral thesis (1984), but practically at the same time he put forward another hypothesis, a "glacial" one, without explaining anything or mentioning the "inversional relief". P.A. Okishev wrote that the giant current ripples in Kuray Basin are "bedded, small-ridged, poly-ridged" moraines. The "inversional relief" was forgotten by the author for ever and has never been mentioned again. This author's unclear explanations of the essence of his second "moraine" hypothesis (he would have a third one as well) may be regarded in general as an attempt "to introduce something new" into the works by B.A. Borisov and E.A. Minina who, after many years of their geological surveys in the mountains of southern Siberia, discovered and described the relief of "a washing board" (the phase of the rogen moraine according to the classification by Yu. A. Lavrushin.[18] B.A. Borisov and E.A. Minina ascribed the relief of

giant current ripples of all the districts where it had been found, described and more or less studied to that relief of the ribbed moraine,[19] the latter really exists in many ancient glacial mountainous valleys of Siberia, Middle Asia and in other mountains.

The first investigator in Russia who not only correctly defined the genesis of the giant current ripples (we shall remind that this was done first by G.F. Lungershausen and O.A. Rakovets about twenty-five years before that time) but also described their composition and reconstructed (in a complex with other flood forms) palaeoglaciohydrology of the region of the geological surveys was V.V. Butvilovsky. However, his discovery was made far from the region where nowadays "lances are being broken". It was in the valley of the Bashkaus River in the Easter Altai[20]]. As a matter of fact, V.V. Butvilovsky managed to describe the whole palaeohydrologic scenario of the last glacial age based on a small district, which corresponds well to the modern ideas about glacial palaeohydrology of the dryland. He also showed that the Quaternary ice-dammed lake of Tuzhar Village discovered by him outburst into the valley of the Chulyshman River after having reached its critical level. He emphasised that in the valley of the Bashkaus River and the Chulyshman River there was only one but very powerful superflood with its maximum discharge of about 880 000 m3/s (the calculation was done according to the formula by Schezi). Later on, V.V. Butvilovsky developed his ideas and defended them in his doctoral thesis [Butvilovsky, 1993]. When working in the Central and South-Eastern Altay, A. N. Rudoy studied in this years the largest in the Altay ice-dammed lakes of Chuya, Kuray and Uymon Basins[21] (Butvilivsky was in 1970s his student in Tomsk State University). In autumn 1983 Rudoy carried out some field research on the left bank site of the Katun River which is now known as "the field of giant current ripples of Platovo-Podgornoje". The result of the research was the first published work dedicated to the multiple cataclysmic outbursts of those tremendous Pleistocene ice-dammed lakes.[22] That work was the first to give a detailed description of the structure of the relief of the giant current ripples at the foothills. Also the first attempt was made to define the palaeohydraulic characteristics of the diluvial floods according to the morphologic peculiarities of the ripples and their material composition.

Giant current ripples on the left bank of Katun River, Altai Platovo Area.

In the early and middle 1980s special filed studies headed by the Alexei Rudoy were carried out at the discovered sites of the fields of the giant current ripples, four of which have become key ones in the course of time, i.e. they have been specially studied for many years by professionals from different countries and of different specialities. These key sites include: the location of giant current ripples of Platovo-Podgornoje; the location of diluvial dunes of the Little Yaloman – the Inia; the field of the giant current ripples in the central part of Kuray Basin and the diluvial dunes at the Basin (in Russian: urochishtshe) Kara-Kol on its western raised periphery.

Some reconstruction of the regime of the last glacial age, estimates of the glacial runoff at its maxima and post-maxima, on the one hand, and the discovery of the diluvial morpholithocomplex on the other hand, enabled us already at the late 1980s to outline a common palaeoglaciohydrologic situation of the Glacial Pleistocene for those territories of the Earth where the oroclimatic condition were similar to those of the mountains of Siberia. At the same time M.G. Grosswald[23] described and physically interpreted for the first time fields of giant current ripples not in the Altai only but also in the intermountain depressions of Tuva and in the valleys of the Upper Yenisei. Nowadays these fields are also studied by international expeditions, some works paying a special attention to the giant ripple marks on the Sayany-Tuva table-land have been already published.[24]

The Fieldworks of the Students of Tomsk State University on Platovo Area of Giant Ripples. August 1984, Katun River, Altay

In early 1990s first international expeditions which specially studied the diluvial morpholithologic complex in Asia. Their purpose was to compare main palaeohydromorphologic characteristics of mountain scablands of Central Asia which had been already developed in Russia by that time[25] with those of the known plain diluvial associations of the Channeled Scabland territory in North America. The participants of those first expeditions were specialists from Russia (M.R. Kirianova, A.N. Rudoy), the United States (V.R. Baker), Great Britain (P.A. Carling), Germany (K. Fischer and M. Kuhle) and Switzerland (Ch. Siegenthaler).[26]

In the second half of 1990s and at the beginning of the 21st century (until the field season of 2010) P.A. Carling carried out some more special expeditions in the Altai, their results were summed up in a cooperative work.[27]

Later, a group of German sedimentologists under the direction of Ju. Herget worked successfully in the Altai. Several big articles presented the refined data of the palaeohydraulic parameters of the diluvial floods in the river valleys of the Chuya River and Katun River.[28]

In 1998 S.V. Parnachov defended his candidate thesis based on the analysis of some well-known sections of the diluvial terraces at the Katun River and the Chuya River, as well as on the data by P.A. Carling and conclusions of his own. The thesis paid a certain amount of attention to the key locations of the fields of giant current ripples discovered before. The investigator fulfilled, in particular, the petrographic and granulometric analyses of the clastic material of the giant ripples at the key sites. S.V. Parnachov based himself on the calculations of the jokulhlaup discharges by P.A. Carling – 750,000 m^3 per second – and came to the conclusion that there were no fluvial catastrophes but there were several lake outbursts with the discharges not higher than those of contemporary big rivers. Instead of the diluvial sediments this author suggested a new geological formation – the "flood alluvium".[29]

Consequently, S.V. Parnachov distinguished the "flooding period" in the Altay of about 150 000 years long. The genesis of the basinal lakes, however, S.V. Parnachov admitted so far as ice-dammed one. Two years later I.S. Novikov joined the investigations by S.V. Parnachov.[30] These geologists drew a conclusion that "the glaciers could not" dam themselves such big lake depressions, consequently the dams were "ice-tectonic" ones. So, according to the authors quoted, during the "flooding period" that lasted for about 150 000 years there were no less than seven cataclysmic flooding occurrences associated with the outbursts of the palaeolakes. Moreover, a tectonic obstacle also played a role in the damming of the lakes during the very last degradation phases of the Würm glacier.

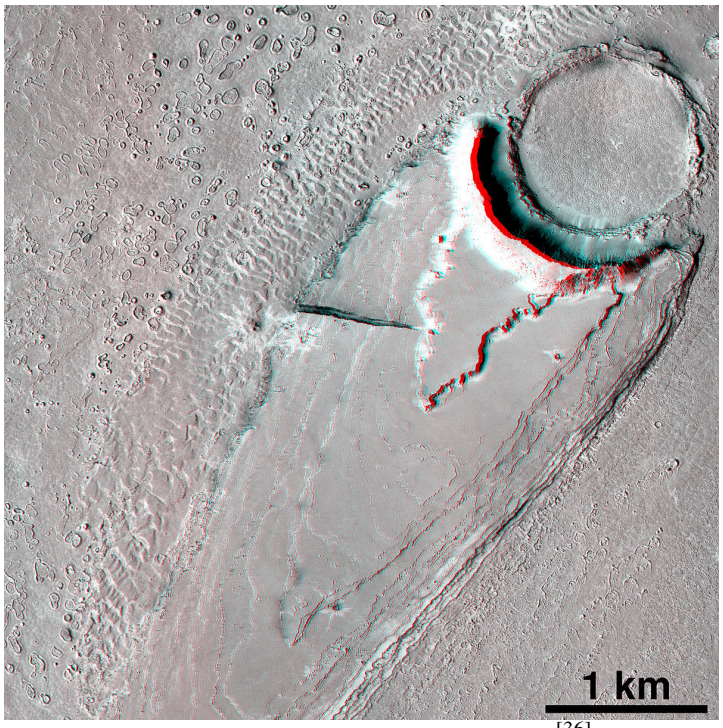
Alternate explanations

"*New antidiluvialists*" have put forth alternate explanations to the giant current ripples theory.[31]

- *The giant current ripples in the valleys of the Altai (except Kuray depression) are ordinary ripples like contemporary river dunes of large rivers (i.e. – "nothing special").* The author of the quotation is A.V. Pozdniakov who observed some forms of such ripples in the valleys in the Far East. He was joined by D.A. Timofeev[32] and some participant of a school-seminar of the geography Committee of the Russian Academy of Sciences,[33] including G. Ya. Baryshnikov who, 10 years earlier, proved the cataclysmic origin of the giant current ripple marks at the foothills of the Altai and at the middle reaches of the Katun.
- *The giant current ripples in Kuray depression are ripples but they developed "under the conditions which were similar to or slightly different from the contemporary ones, and not on the bottoms of the deep pre-glacial lakes which outburst catastrophically".* Quoted from an essay in "The Geomorphology" written by G. Ya. Baryshnikov and others with references to the opinion of the participants of the above-mentioned school-seminar adopted after the discussion.
- *The giant current ripples in Kuray depression are not ripples at all but the consequence of a* meteorite fall.
- *The giant current ripples in Kuray depression are not ripples at all but the consequence of an earthquake.* These hypotheses contain both elastic vibrations and cryptoexplosion structures… The authors are A.V. Pozdniakov and A.V. Khon.[34]
- *The giant current ripples in Kuray depression are cryogenic erosional formations.* The authors are A.V. Pozdniakov and A.V. Khon again, also P.A. Okishev.[35]

Megaflooding on Earth and Mars

While the Russian science is discussing the genesis of the giant current ripples at the just briefly described scientific level, American and British geologists and planetologists have discovered such relieves on Mars according to the data on the giant current ripples in the Altai and even calculated the hydraulic parameters of those diluvial floods.[37]



Giant Current Ripples in Athabasca Valles, Mars.[36]

Main diagnostic features of the giant current ripple marks

Up to the present, hundreds of locations of the fields of giant current ripples have been discovered in North America and Northern Asia. Here is a brief description of main characteristics of this relief and its sediments at the key, today most often visited, sites in the Altai and Tuva with the necessary references to the chief publications for the other territories.

1. Wave height from 2–20 m with the wave length from 5–10 m to 300 m
2. Ripple marks are stretched transversely to the diluvial floods. They are clearly and regularly asymmetric. The proximal slopes are orientated towards the flood, they are more gentle with slightly prominent profiles (The profile of "the whale back"); the distal slopes are steeper with slightly concave profiles nearer to the crest
3. Big poorly-rounded boulders and blocks are often to be found at pre-crest and upper part of the slopes
4. Giant current ripple marks are constituted by deposits of pebbles and small boulders with a low percentage of coarse- and big-grained sand. The fragmentary material is diagonally cross-bedded agreed with the dip of the distal slope. Irrespective of the age of the ridges (normally, it is the time of the last late- and post-glacial age) the sediments are loose and dry, fragments are not hardened with loamy and silt.
5. Fields of giant current ripples are situated close to the run-off ways from basinal ice-dammed lakes and to vortex zones within valley expansions[38]

Unfortunately, no diagnostic features of the lithology of giant current ripples have been cleared up, yet, that could differentiate the latter from other genetic types of loosed sediments in sections. The presence of cross-bedded series in some layers with evidently fluvial genesis which were diagnosed by V.V. Butvilovsky as buried ripples (e.g. an exposure in a pit near the mouth of the Isha River, etc.) does not look as remarkable in the nature as it is described by the author. A. N. Rudoy useds to work for a long time at this and similar exposures (e.g. by the settlement of Karlushka). Nothing, except the fact of the cross dipping of fluvial boulder pebbles, can tell the investigator that he sees some buried giant current ripples. One can nothing but assume this. And an abrupt dipping of bedded alluvial channel fractions is a very often seen phenomenon. The problem of diagnosing diluvial sediments in a buried state, i.e. without any geomorphological control, may apparently be solved not only, if at all, by studying peculiarities of the diluvial texture, but by means of the microscopic lithological studies of the sediments of giant current ripples, i.e. mineralogy of fine fractions, grain shapes, analysis of accessories, etc. Then these correctly summarised data must be compared with various phases of the contemporary mountainous alluvium at the analogous sections.

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External links

- Chuya Flood Video (http://ice.tsu.ru/index.php?option=com_content&task=view&id=342&Itemid=88)
- The channeled scabland (http://purl.galileo.usg.edu/ugafax/J84xNASx1x18xCx36): a guide to the geomorphology of the Columbia Basin, Washington : prepared for the Comparative Planetary Geology Field Conference held in the Columbia Basin, June 5–8, 1978 / sponsored by Planetary Geology Program, Office of Space Science, National Aeronautics and Space Administration ; edited by Victor R. Baker and Dag Nummedal.
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- Missoula Flood Giant Current Ripples (http://wikimapia.org/13067604/Missoula-Flood-Giant-Current-Ripples) at Wikimapia
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- Diluvium Video (http://www.ovguide.com/diluvium-9202a8c04000641f80000000008d7c38#)
- Athabasca-video in large Scale (http://video.mail.ru/mail/larisaterehova1953/8614/8949.html?liked=1)
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Glacitectonism

What is glacitectonism?

Some glacial deposition processes produce unsorted material, whereas fluvioglacial processes produce sorted and stratified material.

Glacitectonic processes disrupt and deform these sediments and the bedrock below, either at the base of the glacier or in front of it. We have found that this process mainly occurs where glaciers are known to be surging and/or the sediments involved are frozen. In proglacial positions (in front of glaciers), coherent blocks of sediment and bedrock can be displaced vertically and horizontally by a glacier, producing both folding and faulting. This is known as proglacial glacitectonics and includes both ductile and brittle failure of materials.

■ Ductile failure involves the flow and creep of a material, producing folds which often develop into overfolds as glacier ice continues to advance.

■ Brittle failure involves the breakage of a material along a fracture, resulting in the thrusting of coherent or semicoherent blocks; this is similar to faulting seen in solid rocks.

Glacitectonic structures

The folding and thrusting that takes place in sediments as a product of glacitectonism at the margins of some glaciers, results in the creation of complex geological structures similar to thrust fold belts in the collision zones of drifting continents. Therefore, it is to structural geology that we must turn in order to describe and explain glacitectonic structures. Once subjected to compression by an advancing glacier, the mostly horizontal strata that occur in proglacial zones will dislocate along low angle failure planes called thrust faults or overthrust faults and will also undergo folding. Individual blocks or 'plates' of sediment may climb over each other in a piggyback style and can be distorted into a range of fold types, depending on how great a pressure is applied. Folds can be of the simple open style or of the more compressed isoclinal style, and thrusts may develop in the fold limbs to produce thrust folds if compression continues. Continued glacier advance may result in the complete overriding of a proglacial thrust moraine, plastering subglacial tills over the glacitec-tonised strata.

Glacitectonic landforms

A wide variety of glacitectonic landforms has been recognised in glacial environments.

Composite ridges

Composite ridges, also referred to as thrust hlock moraines, are the most common and distinctive glacitectonic landform, occurring in a wide range of sizes. They are composed of multiple slices of upthrust and contorted strata, sometimes even bedrock, produced by compression. Because they are the product of icemarginal glacitectonics, composite ridges mark the positions of glacier stillstands or readvances and even surges. A close association between composite ridges and surging glacier snouts in Iceland and Svalbard may be explained by a combination of three factors:

■ the snout advances and applies stress on proglacial sediments rapidly; ■ there is extreme compressive deformation (squeezing) at the snout during a surge; ■ porewater pressures in the sediment are increased during a surge, leading to an increased potential for internal failure.

Hill-hole pairs

Hill-hole pairs are represented by a hill of glacier-thrust material located a short distance down-glacier from a depression of similar size and volume. The hill is essentially a thrust and compressed mass of sediment which has been removed from its original location by glacier overriding, leaving the hole as a source depression. Because they

are overridden and modified by glacier ice and the depressions often become infilled by lake sediments, hill-hole pairs are difficult to identify, but many more maj *be identified in glaciated landscapes like Britain once the internal structures of isolated hills are better known. In addition, hill-hole pairs possess a typical morphology comprising:*

■ an arcuate planform; ■ a series of sub-parallel ridges and depressions on the hill surface; ■ an asymmetric long-profile where the highest point and steepest slope occurs on the down-glacier side; ■ the hole is approximately the same shape and volume as the hill.

Most of these characteristics are similar to those of a composite ridge, indicating similar processes of formation. Indeed, the early stages of hill-hole pair construction are simply the formation of a com¬posite ridge, which is then dislocated and transported down-glacier from its source.

Cupola hills

Cupola hills, from the Danish kuppelbakke, are irregular hills containing evidence of glacitectonic disturbance but lacking the distinct morphology of the composite ridge or hill-hole pair. Cupola hill morphology and structure comprise:

■ dome-like and circular to oval shapes; ■ detached and deformed blocks of sediment or bedrock; ■ an overlying shell (or carapace) of till which covers the sediment or bedrock blocks.

Excellent examples of cupola hills are Ristinge Klint in Denmark and the offshore islands of New England, USA. Because cupola hills probably represent overridden composite ridges, some impression of transverse ridges may be visible through the till cover, although glacier overriding and streamlining eventually transforms the hills into drumlins and flutings, thereby masking the glacitec-tonic origin.

Megablocks

Megablocks and rafts are large blocks of sediment or bedrock which have been dislocated and transported a considerable distance from their source outcrop by glacier ice. They are often very difficult to locate and differentiate from other glacitectonic landforms but can produce large flattopped buttes or plateaux where subhorizontal strata have been displaced vertically as well as laterally. Most megablocks and rafts are only identified after considerably large exposures are made available in glacitectonised materials or numerous borehole records locate anomalies in the subsurface stratigraphy.

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Granite dome

A **granite dome** is a dome of granite, formed by exfoliation.

Half Dome, Yosemite, a classic granite dome (though not, contrary to popular belief, "Glacier-sliced")

Formation

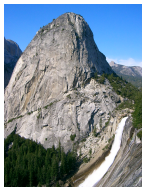
Granite forms plutons of igneous rock several kilometers below the surface as magma slowly cools and crystallizes. The granite is under great overhead pressure.

Then, granite is uplifted to the surface during a mountain-building event. During the mountain building process, the overlying rock is eroded as the granite is uplifted, and the pressure on the granite reduced. The granite expands and forms fractures or sheet joints parallel to the surface. The granite then erodes in concentric layers (similar to how an onion peels) forming rounded masses called exfoliation domes.

While found worldwide, many such domes are found in the Sierra Nevada range in California, which includes the most famous exfoliation dome in the United States, Half Dome. Granitic surfaces in this region that have been exfoliated are identified by their lack of glacial polish.

Stone Mountain, in the American state of Georgia.

Granite domes in Rio de Janeiro



Liberty Cap Yosemite, by Nevada Fall.

A number of the domes are clustered at the upper end of Tenaya Lake, Yosemite.

External links

- Granite domes of the Cairngorms [1]

References

[1] http://www.fettes.com/cairngorms/dome.htm

Gravitational erosion

Gravitational erosion is caused by gravity in contrast to the physical movement of wind and water required for other types of soil erosion. Gravitational erosion involves both large scale mass wasting and smaller scale erosion. Forms of gravitational erosion include avalanche, landslide, debris flow, mudflow, and sinkhole formation. [1] Two types of mass movements are slump and creep.

Slump

- Material slips down along a curved surface
- When the slope becomes too steep, the base material cannot support the rock and sediment above.
- Water can cause slump by slipping weakening the slipping mass.
- Where a stronger layer rests on top of a weaker layer, it collapses.
- A curved scar is left where the slumped materials originally rested.

Creep

- Materials slowly shift downhill
- Creep is caused by gravity alone
- This process is extremely slow and would be difficult to see without a LOT of time and measurements

Gravitational erosion can leave major scars and land.

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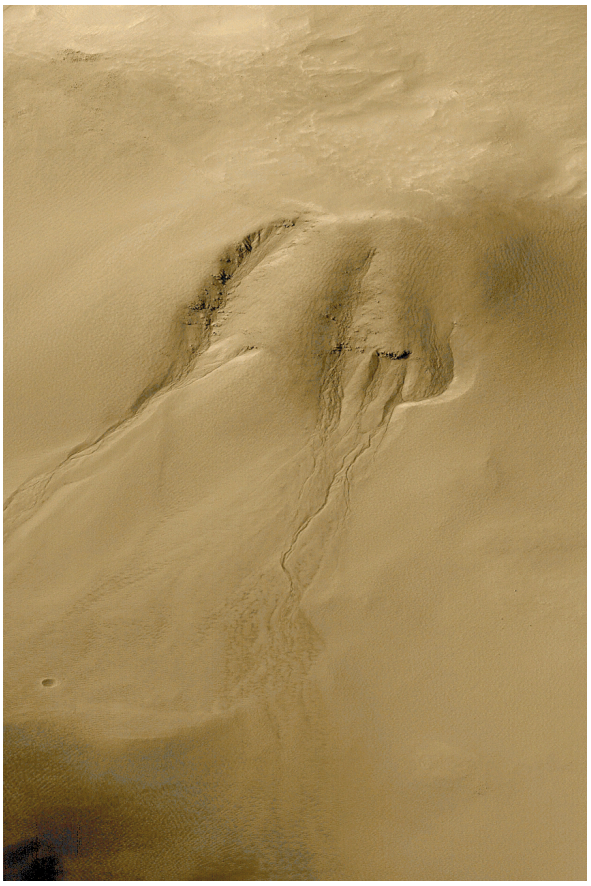
Groundwater sapping

Groundwater sapping is the geomorphic process in which groundwater exits a bank or hillslope laterally as seeps and springs and erodes soil from the slope. This often causes the slope to be undermined and undergo mass wasting, hence the word *sapping*.

This is one of the processes involved in the formation of gullies, such as lavaka. Erosion by sapping tends to produce steep-sided U-shaped valleys of fairly uniform width with box-like, "theater-shaped" headwalls. This contrasts with the more common branching or *dentritic* pattern of V-shaped valleys produced by overland flows that become wider with distance from their source. Groundwater sapping has been suggested as the cause for erosion of the valley and channel networks on Mars, although studies show that groundwater alone can not excavate and transport the material required to create these canyons.[1]



Scientists believe that groundwater sapping created these gullies in Noachis Terra on Mars. *NASA image.*

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External links

- Simulation of Groundwater Sapping (http://erode.evsc.virginia.edu/marssap.htm)
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The two canyons at center-left in this photo from Canyonlands National Park in Utah have the *theater-shaped* heads typical of valley features shaped by groundwater sapping. The Green River is at right.

Guelta

A **guelta** is a peculiar type of wetland, typical of desert regions. They are formed when underground water in lowland depressions spills to the surface and creates permanent pools and reservoirs.

Examples

- Guelta d'Archei

A guelta, close to Oubankort in Adrar des Ifoghas.

Hack's law

Hack's law is an empirical relationship between the length of streams and the area of their basins. If L is the length of the longest stream in a basin, and A is the area of the basin, then Hack's law may be written as

$$L = CA^h$$

for some constant C where the exponent h is slightly less than 0.6 in most basins. Note that h varies slightly from region to region, and also slightly decreases for larger basins (>8,000 mi², or 20,720 km²). A theoretical value $h = 4/7 \approx 0.571$ for the exponent has been derived (Birnir, 2008).

References

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Head Cut (Stream Geomorphology)

Head Cut (Stream Geomorphology) is an erosional feature of some intermittent streams and perennial streams where an abrupt vertical drop in the stream bed occurs. Head cuts resemble a small waterfall or, when not flowing, the head cut will resemble a very short cliff or bluff. A small plunge pool may be present at the base of the head cut due to the high energy of falling water. Groundwater seeps and springs are sometimes found along the face, sides, or base of a head cut.[1]

References

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External links

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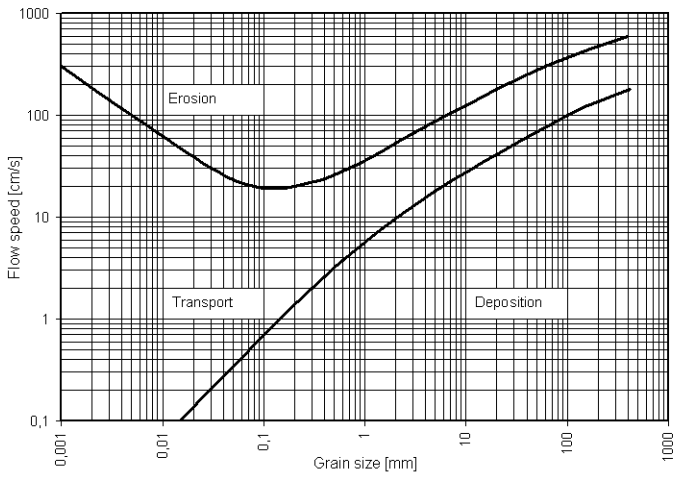
Hjulström curve

The **Hjulström curve**, named after Filip Hjulström (1902–1982), is a graph used by hydrologists to determine whether a river will erode, transport, or deposit sediment. It was originally published in his doctoral thesis "The River Fyris" in 1935. The graph takes sediment size and water velocity into account.



The Hjulström curve

The upper curve shows the critical erosion velocity in cm/s as a function of particle size in mm, while the lower curve shows the deposition velocity as a function of particle size. Note that the axes are logarithmic.

The plot shows several key concepts about the relationships between erosion, transportation, and deposition. For particle sizes where friction is the dominating force preventing erosion, the curves follow each other closely and the required velocity increases with particle size. However, for cohesive sediment, mostly clay but also silt, the *erosion* velocity increases with decreasing grainsize, as the cohesive forces are relatively more important when the particles get smaller. The critical velocity for deposition, on the other hand, depends on the settling velocity, and that decreases with decreasing grainsize. The Hjulström curve shows that sand particles of a size around 1 mm require the lowest stream velocity to erode.

The curve was in 1956 expanded by Hjulström's disciple and successor as professor, Åke Sundborg. He significantly improved the level of detail in the cohesive part of the diagram, and added lines for different modes of transportation. The result is called the **Sundborg diagram**, or the **Hjulström-Sundborg Diagram**, in the academic literature.

External links

- A diagram of the Hjulstrom curve [1]

References

[1] http://www.utexas.edu/depts/grg/hudson/grg338c/schedule/3_erosion_sed/erosion_sed_images/hjulstrom_curve.jpg

Hogback (geology)

A **hogback** is a homoclinal ridge, formed from a monocline, composed of steeply tilted strata of rock protruding from the surrounding area. The name comes from the ridge resembling the high, knobby spine between the shoulders of a hog. In most cases, the two strata that compose a hogback are different types of sedimentary rock with differing weathering rates. The softer rock erodes more quickly than overlying hard rock. Over time, the softer rock retreats to a point where the hard and soft rock strata are adjacent. This creates cliffs that steepen as the softer rock continues to erode. Hogbacks are often found as ridges along the "eroded flanks of large, tightly folded anticlines and synclines."[1] The defining characteristic of a hogback is a steep dip slope that is greater than 30° - 40° with a near symmetric slope on each ridge face. A cuesta is a homoclinal ridge with a more gentle dip slope.[2] [3]

Hogback west of Denver, Colorado. It is formed by the more erosionally resistant Lytle and South Platte Formations protecting the softer, slope-forming Morrison Formation.

Dome-encircled hogbacks

Black Hills hogback

While most hogbacks snake along a surface in a relatively straight line, few, such as those in Sundance, Wyoming, encircle a dome. The Dakota Sandstone Hogback encircles the Black Hills, an elliptical dome spanning from northwestern South Dakota to northeastern Wyoming. The Black Hills are approximately 125 miles long and 65 miles wide. The Dakota Hogback ridge formed when the resistant layers of the Dakota Sandstone and underlying layers were thrust upward near the center of the present-day Black Hills due to a granite intrusion, approximately 60 million years ago. The Black Hills are "the farthest outlying segment of a great mid-continental uplift known as the Laramide orogeny" (Raventon, 33). The Dakota hogback rim separates the surrounding flat plains from the two mile wide Red Valley trench of the Black Hills. The ridge "presents a steep face towards the valley and rises several hundred feet above it" (Cleland, 355).

Green Mountain hogbacks

Green Mountain (Google Maps [4]), also known as the Little Sundance Dome, is found just east of Sundance, Wyoming. It is a circular dome about 1800m across and 1400m wide surrounded by a rim of triangluar hogbacks (similar in appearance to flatirons). Green Mountain itself, much like the Black Hills, is a laccolith formed by the intrusion of magma into the Earth's crust (Cleland, 354-355). The hogbacks surrounding the mountain are steep (with dip slopes of approximately 50°) and point upward towards the center of the mountain.

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[4] http://maps.google.com/maps?hl=en&q=green%20mountain%2Bsundance%2C%20wy&um=1&ie=UTF-8&sa=N&tab=wl

Homocline

In structural geology, a **uniclinal structure**, **homoclinal structure**, **unicline** or **homocline** (from old Greek: *homo* = same, *cline* = inclination)[1] is a sedimentary rock unit, which may also be associated with a stratigraphic landform, where the underlying strata are tilted in the same direction,[2] [3] especially with near uniform dip angle.[4] [5] A homocline may be formed by uplift of coastal plain sediments, or as a limb of a large dome or fold.[6] On a topographic map, homoclines exhibit nearly parallel elevation contour lines that show a steady change in elevation in a given direction.[3]

A **homoclinal ridge**, or **strike ridge**, is a stratigraphic landform typically characterized by a steep escarpment or *scarp slope* (also known as a *strike slope* or *antidip slope*) on the side that cuts across the strata, and a more gentle dip slope on the side of the ridge that follows the dip.[7] [8] A homoclinal ridge forms when tilted strata with dissimilar erosional resistance erode at different rates. The more durable erosion resistant materials are the slope-formers found on the typically shallower back slope, while more easily eroded layers are the cliff-formers.[9] These ridges are well formed when harder sandstones and limestones are interbedded with softer shales, siltstones, and mudstones in tilted exposed strata, resulting in differential erosion.[10] Ridges associated with homoclines having steeply tilted strata, and exhibiting nearly symmetrical cross-section, are also known as hogback ridges; those with gently tilting strata, with highly asymmetric profiles, are known as cuestas.[7] [8] [9] Homoclinal ridges differ from synclinal or anticlinal ridges, in that they have strata dipping in only one direction.[11] Most of the stratigraphic ridges in the Ridge-and-Valley Appalachians of the eastern United States are homoclinal ridges.[12]

Etymology

Homocline was introduced as a new term at the 1915 meeting of the Geological Society of America, but its precise definition and usage have been inconsistent, as was the case with the term *monocline* before then.[13] Both terms have been used to describe "beds dipping in one direction" and a "one-limbed flexure", with different authors making incompatible distinctions.[13] Henry Darwin Rogers introduced the term *monoclinal* in 1842, and it supplanted the previously used term *uniclinal*,[14] but is now considered obsolete.[5]

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[6] Sugden, David E.; Chorley, Richard J.; Schumm, Stanley Alfred (1985). *Geomorphology*. London: Methuen. ISBN 0-416-32590-4. "These structures are produced in two main ways, either by the uplift of a sequence of off-lapping coastal plain sediments or as part of one limb of a large dome or fold."

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Hypsometric curve

A **hypsometric curve** is an empirical cumulative distribution function of elevations in a catchment. Differences in hypsometric curves between landscapes arise because the geomorphic processes that shape the landscape may be different. The hypsometric curve may also be shown as a continuous function and graphically displayed as an x-y plot with elevation on the vertical, y-axis and area above the corresponding elevation on the horizontal or x-axis. The curve can also be shown in non-dimensional or standardized form by scaling elevation and area by the maximum values. The non-dimensional hypsometric curve provides hydrologist and geomorphologist with a way to assess the similarity of watersheds — and is one of several characteristics used for doing so.

References

- Hypsometric Curve [1]

References

[1] http://scienceworld.wolfram.com/astronomy/HypsometricCurve.html

Hypsometry

Hypsometry (from Greek ὕψος, *hupsos*, "height"[1] and μέτρον, *metron*, "measure"[2]) is the measurement of land elevation relative to sea level.[3] Bathymetry is the underwater equivalent. A hypsometer is an instrument used in hypsometry, which estimates the elevation by boiling water — water boils at different temperatures depending on the air pressure, and thus altitude.

On Earth, the elevations can take on either positive and negative (underwater) values, and are bimodal due to the contrast between the continents and oceans. On other planets within this solar system, elevations are typically unimodal, due to the lack of oceans on those bodies.

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[3] "MSN Encarta" (http://www.webcitation.org/5kwr8Xfwz). Archived from the original (http://encarta.msn.com/dictionary_1861619735/hypsometry.html) on 2009-10-31. .

Ice dune

An **ice dune** (also called an **ice ridge** or an **ice foot**) is a formation of ice that accumulates on the shores of many arctic beaches and is also common along the shores of the Great Lakes during the winter.[1]

Ice dunes on Lake Huron

Cause

An ice dune is produced by ice washing ashore, snowfall, and the gradual freezing of wave spray that accumulates on to the shore.[2] They form when the air temperature is below freezing and the water temperature is near freezing.[2] Ice dunes are commonly at least 6 feet (1.8 m) tall, but the dune's size depends on the beach and the weather.[2] The tidal range, the "storminess" of the water and the topography of the beach all can effect the size of the dunes.[3] The dunes will also stop forming if the body of the water they border freezes over, which often happens on Lake Erie.[2] Ice dunes will usually break up in the early stages of spring thaw.

Effects

Ice dunes are important in places that are greatly effected by the erosion of sand by waves, like Presque Isle State Park in Pennsylvania. When the dunes form, they form a barrier between the waves and the shore and prevent the waves from reaching the shore, keeping the sand in place.

Because of the way ice dunes form, they are inherently weak and filled with cracks and air pockets. People who venture out onto the dunes sometimes will fall through. If the dune extends out over the water, they would fall through the dune and into the freezing water underneath and eventually drown.[2]

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[3] French 2007 p. 276.

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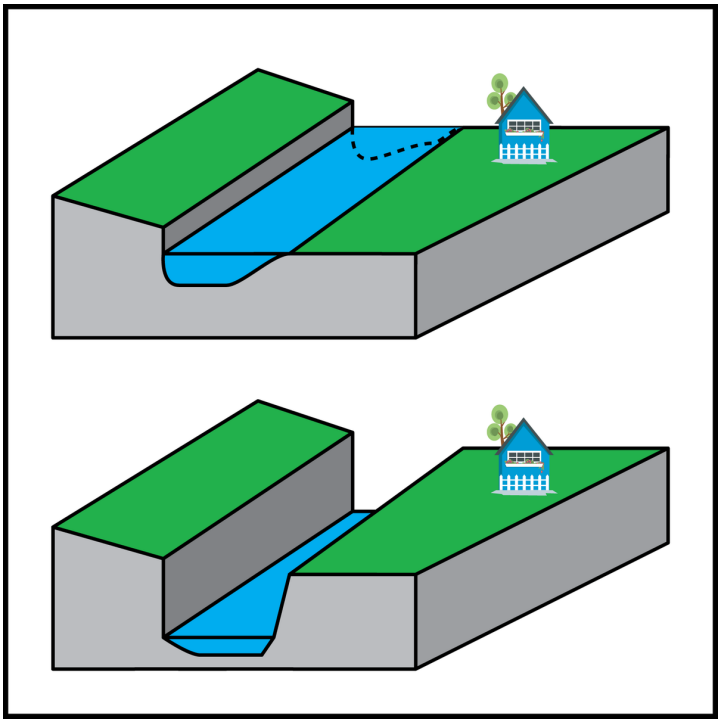
Incised

Incised means cut, particularly with a "V" shape. It is a term found in a number of disciplines.

A small, incised alluvial plain from Red Rock Canyon State Park (California)

Geology



Schematic of a river incising downward through bedrock (gray). Process begins with the top image.

In geomorphology, the term **Incised** refers to when a river has cut downward through its riverbed. The river may have been incising through sediment or bedrock. The river begins at one elevation and incises downward through its bed while leaving its floodplain behind (higher). Although, it is possible for the floodplain to be lowered at the same time. Examples include Mobile Bay along the Gulf of Mexico.

Medicine

In medicine an incised wound is one made with a cutting instrument, often a deep wound. (See incision)

Biology

An incised structure is one with a deep "V" shaped notch, often used to refer to the outline of a leaf, or the membranes on a fish's fin.

Archaeology and the Plastic Arts

Incised in archaeology and the plastic arts refers to cutting into the surface of a medium, for example stone or wood. It often refers to the use of a "V" shaped tool to carve out the design. Writing carved into stone tablets or columns is often referred to as "incised".

Typography

Incised is a san-serif typeface.

Interlocking spur

An **interlocking spur** is a natural geographical feature that occurs in the upper course of a river in which downward erosion is the dominant force determining the river's course. As a river wanders between banks that are far apart, the promontories of the hills tend to jut out into the river valley resulting in a staggered formation, interlocked together somewhat like the teeth of a zip. These promontories are referred to as interlocking spurs.

If the river valley is subsequently subject to glaciation, the glacier shears off the tips of the interlocking spurs, due to its straighter course, creating *truncated spurs*.

While similar in general appearance, the mechanism behind the formation of interlocking spurs is different to that behind meanders, which arise out of a combination of horizontal erosion and deposition.

Interlocking spurs at Ashes Hollow, tributary to the River Severn

Interlocking spurs looking up Oxendale Beck, tributary to the River Brathay in Great Langdale, Cumbria

External links

- Animation of development [1]

References

[1] http://www.cleo.net.uk/resources/displayframe.php?src=308/consultants_resources%2F_files%2Fintespur2.swf

Inverted relief

Inverted relief is a landscape that is part of a planet's surface, i.e. Mars, that contains positive landforms, i.e. hills and ridges, that were once depressions in it surface. On Earth, inversion of relief can occur whenever either the sediments or other strata underlying a depression, typically the floor of a floodplain or fluvial valley, becomes more resistant to erosion than the strata in which the valley has been cut. Then differential erosion preferentially removes the less resistant the strata underlying the walls of the depressions and adjacent uplands leaving the floor of the depression as a topographic high.[1]

Formation

Multiple processes can cause the floor of a depression to become more resistant to erosion than its surrounding slopes and uplands. First, coarse-grained sediments, i.e. gravel, accumulated within depressions, i.e. stream valleys and lake basins. Later, erosion — possibly by wind, which can't move coarse-grained sediments — removed fine-grained sediments comprising the surround surface layers, but left behind the more resistant coarse-grained sediments as a ridge. Second, another process by which inverted relief might be created would be the filling of a fluvial valley with either lava or welded tuff. A layer composed of either of these volcanic rocks would resist erosion while the surrounding surface is eroded away to create a ridge out of what was formally a valley. Finally, inverted topography might be formed by the cementation by minerals dissolved in water of sediments that once either filled or underlay a topographic depression such as a lake or fluvial valley. In terrestrial environments, such cementation often occurs within stream valleys as the result of the formation of duricrusts, i.e. silcrete or ferricrete, by pedogenic processes. As in case of lava, the cemented sediments would resist erosion while the surrounding countryside is eroded away to create a ridge or hill where a depression once existed.[1] [2]

A classic example of terrestrial inverted relief is Table Mountain, Tuolumne County, California. In case of Table Mountain, multiple lavas flows filled an ancient fluvial valley that cut westward through the across the central Sierra Nevada to the Central Valley about 10.5 million years ago. These Miocene lava flows filled this ancient river valley with a thick sequence of high-K, trachyandesite lavas that are significantly more resistant to erosion than the Mesozoic siltstone and other rock in which the valley was cut. As a result, subsequent differential erosion left these volcanic rocks as sinuous ridge, which now stands well above landscape underlain by more deeply eroded Mesozoic rocks.[3]

Inverted relief in the form of sinuous and meandering ridges, which are indicative of ancient, inverted fluvial channels, is argued to be evidence of water flowing on the Martian surface in the past.[2] [4] [5] Examples of such ridges, which might represent ancient fluvial channels, are shown below from various parts of Mars. Because of sinuous ridges, which might be ancient fluvial channels, and minerals that indicated the past presence of water, Miyamoto Crater was proposed in 2010 as a potential location to be searched for evidence of life on Mars.[6]

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[1] Pain, C.F., and C.D. Ollier, 1995, *Inversion of relief - a component of landscape evolution.* Geomorphology. 12(2):151-165.

[2] Pain, C.F., J.D.A. Clarke, and M. Thomas, 2007, *Inversion of relief on Mars.* Icarus. 190(2):478–491.

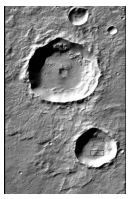
[3] Gornya, C., C. Busbya, C.J. Pluhar, J. Hagana and K. Putirkab, 2009, *An in-depth look at distal Sierra Nevada palaeochannel fill: drill cores through the Table Mountain Latite near Knights Ferry.* International Geology Review. 51(9–11):824–842.

[4] HiRISE, 2010a, *Inverted Channels North of Juventae Chasma (PSP_006770_1760).* (http://hirise.lpl.arizona.edu/PSP_006770_1760) Operations Center, Department of Planetary Sciences, Lunar and Planetary Laboratory, Tucson, Arizona.

[5] Williams, R.M.E., T.C. Chidsey, Jr., and D.E. Eby, D.E., 2007, *Exhumed paleochannels in central Utah - analogs for raised curvilinear features on Mars*, in G.C. Willis M.D. Hylland, D.L. Clark, and T.C. Chidsey, Jr., eds., pp. 220-235, Central Utah - diverse geology of a dynamic landscape. Publication 36, Utah Geological Association, Salt Lake City, Utah.

[6] Newsom, H.E., N.L. Lanza, A.M. Ollila, S.M. Wiseman, T.L. Roush, G.A. Marzo, L.L. Tornabene, C.H. Okubo, M.M. Osterloo, V.E. Hamilton, and L.S. Crumpler, 2010, *Inverted channel deposits on the floor of Miyamoto crater, Mars.* Icarus. 205(1):64-72.

Inverted Terrain in Aeolis quadrangle



CTX image of craters with black box showing location of next image.

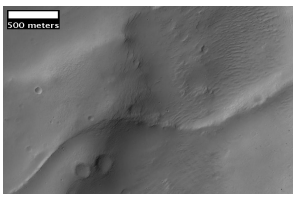
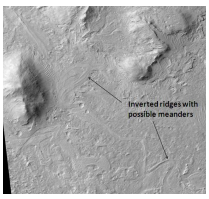
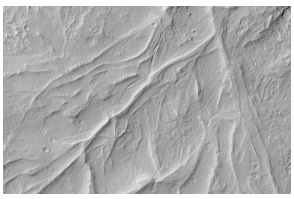


Image from previous photo of a curved ridge that may be an old stream that has become inverted. Image taken with HiRISE under the HiWish program.



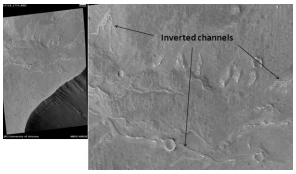
Meandering Ridges that are probably inverted stream channels. Image taken with HiRISE.



Sinuous Ridges within a branching fan in lower member of Medusae Fossae Formation, as seen by HiRISE. Location is Aeolis quadrangle.

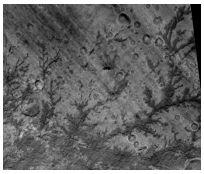
Inverted Terrain in Syrtis Major quadrangle

Inverted Streams near Juventae Chasma, as seen by Mars Global Surveyor. These streams begin at the top of a ridge then run together.

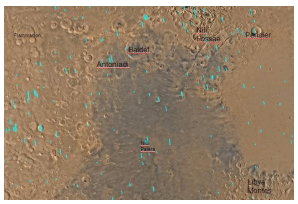


Inverted Channels near Juventae Chasma, as seen by HiRISE. Channels were once regular stream channels. Image in Coprates quadrangle. Scale bar is 500 meters long.

Inverted Channel with many branches in Syrtis Major quadrangle.

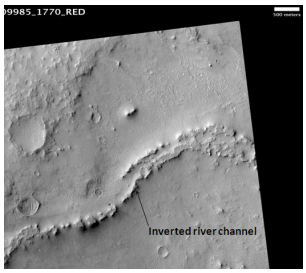


Inverted Stream Channels in Antoniadi Crater, as seen by HiRISE. Image in Syrtis Major quadrangle.

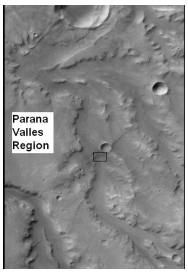


Map of Syrtis Major quadrangle. Antoniadi Crater is near the top of the map.

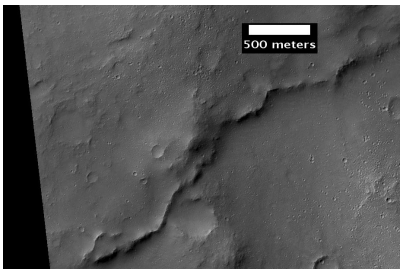
Inverted terrain in Margaritifer Sinus quadrangle



Inverted Channel in Miyamoto Crater, as seen by HiRISE. The scale bar is 500 meters long.



CTX context image for next image that was taken with HiRISE. Note long ridge going across image is probably an old stream. Box indicates area for HiRISE image.

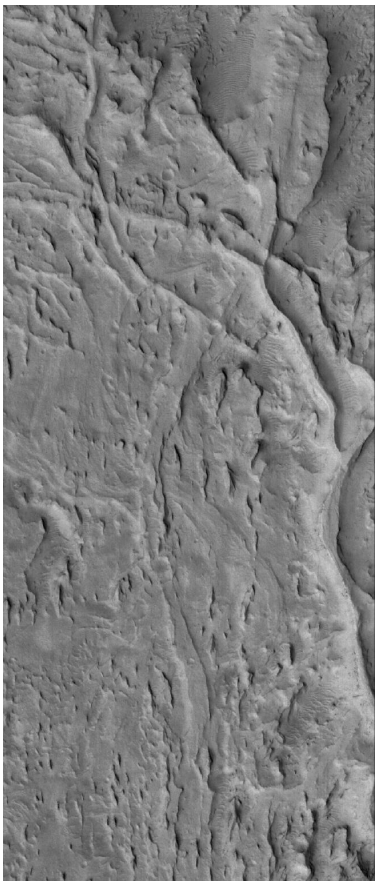


Example of inverted terrain in Parana Valles region, as seen by HiRISE under the HiWish program.

Inverted topography

Inverted topography or **topographic inversion** refers to landscape features that have reversed their elevation relative to other features. It most often occurs when low areas of a landscape become filled with lava or sediment that hardens into material that is more resistant to erosion than the material that surrounds it. *Differential erosion* then removes the less resistant surrounding material, leaving behind the younger resistant material which may then appear as a ridge where previously there was a valley. Terms such as "inverted valley" or "inverted channel" are used to describe such features. Plateaus, mesas and buttes may also be formed as inverted features. Examples of inverted topography have been discovered on Mars.

Topographic inversion should not be confused with folding, a geological process in which rock strata shift position because of tectonic forces or kinetic impact. Inversion is something like molding and casting (*see Sand casting)*, in which the feature remains stationary, but changes its elevation relative to the surrounding surface. In the image at right, channels on Mars became ridges through the processes of sedimentation and differential erosion.



Inverted channels on Mars. These curved and crisscrossing ridges in the Aeolis region were once channels in a sediment fan. The channels were more resistant to wind erosion than the surrounding materials, so now they are left standing as ridges rather than valleys. Image Credit: NASA/JPL/Malin Space Science Systems

External links

- Science Encyclopedia: Mountains - Inverted Topography [1]
- Everything2.com: Topographic Inversion [2]
- MarsToday.com: Inverted Topography of Huo Hsing Vallis [3]
- MarsToday.com: NASA Mars Picture of the Day: Inverted channels [4]
- NASA: Inverted Topography, Patagonia, Argentina [5]
- Utah Geological Survey: Inverted Topography in the St. George Area of Washington County [6]
- California State University Department of Geologial Sciences: View of table mountain on eastern edge of the Sierra Nevada [7]

References

[1] http://science.jrank.org/pages/4486/Mountains-Inverted-topography.html
[2] http://everything2.com/e2node/Topographic%2520inversion
[3] http://www.marstoday.com/news/viewsr.html?pid=5648
[4] http://www.marstoday.com/news/viewsr.html?pid=21125
[5] http://visibleearth.nasa.gov/view_rec.php?id=651
[6] http://geology.utah.gov/surveynotes/geosights/invertedtopo.htm
[7] http://seis.natsci.csulb.edu/deptweb/SkinnyCalSites/bigpictext/TableMtn.html

Island welding

Island welding is a geomorphological term to describe the process of welding sandy barrier islands back on to the mainland. Often the stabilisation of coastal navigation entrances disrupts the sustainability of the island welding process.

Isostasy

Isostasy (Greek *ísos* "equal", *stásis* "standstill") is a term used in geology to refer to the state of gravitational equilibrium between the earth's lithosphere and asthenosphere such that the tectonic plates "float" at an elevation which depends on their thickness and density. This concept is invoked to explain how different topographic heights can exist at the Earth's surface. When a certain area of lithosphere reaches the state of isostasy, it is said to be in *isostatic equilibrium*. Isostasy is **not** a process that upsets equilibrium, but rather one which restores it (a negative feedback). It is generally accepted that the earth is a dynamic system that responds to loads in many different ways. However, isostasy provides an important 'view' of the processes that are happening in areas that are experiencing vertical movement. Certain areas (such as the Himalayas) are **not** in isostatic equilibrium, which has forced researchers to identify other reasons to explain their topographic heights (in the case of the Himalayas, which are still rising), by proposing that their elevation is being "propped-up" by the force of the impacting Indian plate.

In the simplest example, isostasy is the principle of buoyancy where an object immersed in a liquid is buoyed with a force equal to the weight of the displaced liquid. On a geological scale, isostasy can be observed where the Earth's strong lithosphere exerts stress on the weaker asthenosphere which, over geological time flows laterally such that the load of the lithosphere is accommodated by height adjustments.

Isostatic models

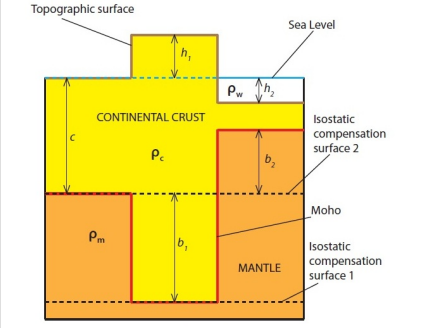
Three principal models of isostasy are used:

- The Airy-Heiskanen Model

  - where different topographic heights are accommodated by changes in crustal thickness.

The basis of the model is the Pascal's law, and particularly its consequence that, within a fluid in static equilibrium, the hydrostatic pressure is the same on every point at the same elevation (surface of hydrostatic compensation). In other words: $h_1 \cdot \rho_1 = h_2 \cdot \rho_2 = h_3 \cdot \rho_3 = ... h_n \cdot \rho_n$

For the simplified picture shown the depth of the mountain belt roots (b_1) are:

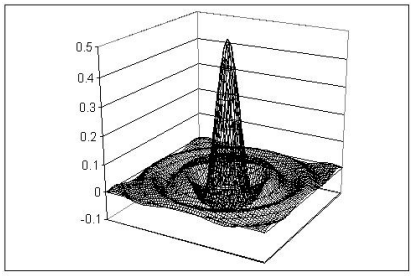


Simplified diagram of Airy Isostasy

$$(h_1 + c + b_1)\rho_c = (c\rho_c) + (b_1\rho_m)$$
$$b_1(\rho_m - \rho_c) = h_1\rho_c$$
$$b_1 = \frac{h_1\rho_c}{\rho_m - \rho_c}$$

where ρ_m is the density of the mantle (ca. 3,300 kg m^{-3}) and ρ_c is the density of the crust (ca. 2,750 kg m^{-3}). Thus, we may generally consider:

$b_1 \cong 5 \cdot h_1$



Simplified diagram of Airy's Isostasy

In the case of negative topography (i.e., a marine basin), the balancing of lithospheric columns gives:

$$c\rho_c = (h_w\rho_w) + (b_2\rho_m) + [(c - h_w - b_2)\rho_c]$$

$$b_2(\rho_m - \rho_c) = h_w(\rho_c - \rho_w)$$

$$b_2 = (\frac{\rho_c - \rho_w}{\rho_m - \rho_c})h_w$$

where ρ_m is the density of the mantle (ca. 3,300 kg m^{-3}), ρ_c is the density of the crust (ca. 2,750 kg m^{-3}) and ρ_w is the density of the water (ca. 1,000 kg m^{-3}). Thus, we may generally consider:

$b_2 \cong 3.2 \cdot h_w$

- The Pratt-Hayford Model

  - where different topographic heights are accommodated by lateral changes in rock density. For the simplified model shown the new density is given by: $\rho_1 = \rho_c \frac{c}{h_1 + c}$, where h_1 is the height of the mountain and c the thickness of the crust.

- The Vening Meinesz, or Flexural Model

  - where the lithosphere acts as an elastic plate and its inherent rigidity distributes local topographic loads over a broad region by bending. This hypothesis was suggested to explain how large topographic loads such as seamounts (eg. Hawaiian Islands) could be compensated by regional rather than local displacement of the lithosphere. This is the more general solution for flexure, as it approaches the locally-compensated models above as the load becomes much larger than a flexural wavelength or the flexural rigidity of the lithosphere approaches 0.

Isostatic effects of deposition and erosion

When large amounts of sediment are deposited on a particular region, the immense weight of the new sediment may cause the crust below to sink. Similarly, when large amounts of material are eroded away from a region, the land may rise to compensate. Therefore, as a mountain range is eroded down, the (reduced) range rebounds upwards (to a certain extent) to be eroded further. Some of the rock strata now visible at the ground surface may have spent much of their history at great depths below the surface buried under other strata, to be eventually exposed as those other strata are eroded away and the lower layers rebound upwards again.

An analogy may be made with an iceberg - it always floats with a certain proportion of its mass below the surface of the water. If more ice is added to the top of the iceberg, the iceberg will sink lower in the water. If a layer of ice is somehow sliced off the top of the iceberg, the remaining iceberg will rise. Similarly, the Earth's lithosphere "floats" in the asthenosphere.

Isostatic effects of plate tectonics

When continents collide, the continental crust may thicken at their edges in the collision. If this happens, much of the thickened crust may move *downwards* rather than up as with the iceberg analogy. The idea of continental collisions building mountains "up" is therefore rather a simplification. Instead, the crust *thickens* and *the upper part of the thickened crust* may become a mountain range.

However, some continental collisions are far more complex than this, and the region may not be in isostatic equilibrium, so this subject has to be treated with caution.

Isostatic effects of ice-sheets

The formation of ice-sheets can cause the Earth's surface to sink. Conversely, isostatic post-glacial rebound is observed in areas once covered by ice-sheets which have now melted, such as around the Baltic Sea and Hudson Bay. As the ice retreats, the load on the lithosphere and asthenosphere is reduced and they *rebound* back towards their equilibrium levels. In this way, it is possible to find former sea-cliffs and associated wave-cut platforms hundreds of metres above present-day sea-level. The rebound movements are so slow that the uplift caused by the ending of the last glacial period is still continuing.

In addition to the vertical movement of the land and sea, isostatic adjustment of the Earth also involves horizontal movements, changes in the gravitational field, Earth's rotation rate, polar wander, and can induce earthquakes. For details see Postglacial rebound.

Eustasy and relative sea level change

Eustasy is another cause of relative sea level change quite different from isostatic causes. The term "eustasy" or "eustatic" refers to changes in the amount of water in the oceans, usually due to global climatic changes. When the Earth's climate cools, a greater proportion of the earths water is stored on land masses in the form of glaciers, snow, etc. This results in a relative fall in global sea levels (**relative** to a stable land mass). The refilling of ocean basins by glacier meltwater at the end of ice ages is an example of eustatic sea level rise.

A second significant cause of eustatic sea level rise is thermal expansion of sea water, when the Earth's mean temperature increases. Current estimates of global eustatic rise from tide gauge records and satellite altimetry is about +3 mm/a (see 2007 IPCC report). Global sea level is also affected by vertical crustal movements, changes in the rotational rate of the Earth, (see Postglacial rebound), large scale changes in continental margin and changes in the spreading rate of the ocean floor.

When the term "relative" is used in context with "sea level change", the implication is that both eustasy and isostasy are at work, or that the author does not know which cause to invoke.

Further reading

- Lisitzin, E. (1974) "Sea level changes". Elsevier Oceanography Series, 8
- AB Watts (2001). *Isostasy and Flexure of the Lithosphere* [1]. Cambridge University Press. ISBN 0521006007. A very complete overview with much of the historical development.

References

[1] http://books.google.com/books?id=CNkiZU7enWUC&printsec=frontcover#v=onepage&q=&f=false

Karst

Karst topography is a geologic formation shaped by the dissolution of a layer or layers of soluble bedrock, usually carbonate rock such as limestone or dolomite,[1] but has also been documented for weathering resistant rocks like quartzite given the right conditions.[2]

Due to subterranean drainage, there may be very limited surface water, even to the absence of all rivers and lakes. Many karst regions display distinctive surface features, with sinkholes or dolines being the most common. However, distinctive karst surface features may be completely absent where the soluble rock is mantled, such as by glacial debris, or confined by a superimposed non-soluble rock strata. Some karst regions include thousands of caves, even though evidence of caves that are big enough for human exploration is not a required characteristic of karst.

The Kravice waterfall on the Trebižat river in Bosnia and Herzegovina

A karst landscape in Minerve, Hérault, France

The karst hills of The Burren on the west coast of Ireland

Background

Karst topography is characterized by subterranean limestone caverns, carved by groundwater. The geographer Jovan Cvijić (1865–1927) was born in western Serbia and studied widely in the Dinaric Kras region. His publication of *Das Karstphänomen* (1893) established that rock dissolution was the key process and that it created most types of dolines, "the diagnostic karst landforms". The Dinaric Kras thus became the type area for dissolutional landforms and aquifers; the regional name *kras*, Germanicised as "karst", is now applied to modern and paleo-dissolutional phenomena worldwide. Cvijić related the complex behaviour of karstic aquifers to development of solutional conduit networks and linked it to a cycle of landform evolution. Cvijić defined two main types of karstic area, **holokarst**, wholly developed, as in the Dinaric region along the eastern Adriatic and deeper inland in the Balkan Peninsula and **merokarst**, imperfectly developed with some karstic forms, as in eastern Serbia. Cvijić is recognized as "the father of karst geomorphology".

The international community has settled on *karst*, the German name for Kras, a region in Slovenia partially extending into Italy, where it is called "Carso" and where the first scientific research of a karst topography was made. The name has an Indo-European origin (from *karra* meaning "stone"),[3] and in antiquity it was called "Carusardius" in Latin. The Slovene form *grast* is attested since 1177, and the Croatian *kras* since 1230.. "Krš" – "Krsh" meaning in Serbo-Croatian "barren land" which is typical feature in the Northern Dinaric limestone mountains could also be an origin to the word Karst.

Chemistry

Karst landforms are generally the result of mildly acidic water acting on weakly soluble bedrock such as limestone or dolostone. The mildly acidic water begins to dissolve the surface along fractures or bedding planes in the limestone bedrock. Over time, these fractures enlarge as the bedrock continues to dissolve. Openings in the rock increase in size, and an underground drainage system begins to develop, allowing more water to pass through the area, and accelerating the formation of underground karst features.[4]

Karst lake (Doberdò del Lago, Italy), fed by an underground water source into a depression and has no surface inlet or outlet

Main dissolution mechanism: carbonic acid

The carbonic acid that causes these features is formed as rain passes through the atmosphere picking up CO_2, which dissolves in the water. Once the rain reaches the ground, it may pass through soil that can provide much more CO_2 to form a weak carbonic acid solution which dissolves calcium carbonate. The sequence of reactions involved in the limestone dissolution are the following:

$$H_2O + CO_2 \rightarrow H_2CO_3$$
$$CaCO_3 \rightarrow Ca^{2+} + CO_3^{2-}$$
$$CO_3^{2-} + H_2CO_3 \rightarrow 2\ HCO_3^-$$
$$CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2\ HCO_3^-$$

This is the main dissolution mechanism of calcium carbonate in limestone.

Secondary dissolution mechanism: sulfide oxidation

However, in particular and very rare conditions such as these encountered in the past in Lechuguilla Cave in New Mexico (and more recently in the Frasassi Caves in Italy), other mechanisms may also play a role. The oxidation of sulfides leading to the formation of sulfuric acid can also be one of the corrosion factors in karst formation. As O_2-rich surface waters seep into deep anoxic karst systems it brings oxygen which reacts with sulfide present in the system (pyrite or H_2S) to form sulfuric acid (H_2SO_4). Sulfuric acid then reacts with calcium carbonate causing an increased erosion within the limestone formation. This can be summarized by the cascade of the following reactions:

$$H_2S + 2\ O_2 \rightarrow H_2SO_4 \text{ (sulfide oxidation)}$$
$$H_2SO_4 + 2\ H_2O \rightarrow SO_4^{2-} + 2\ H_3O^+ \text{ (sulfuric acid dissociation)}$$
$$CaCO_3 + 2\ H_3O^+ \rightarrow Ca^{2+} + H_2CO_3 + 2\ H_2O \text{ (calcium carbonate dissolution)}$$
$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2CO_3 \text{ (global reaction leading to calcium sulfate)}$$
$$CaSO_4 + 2\ H_2O \rightarrow CaSO_4 \cdot 2\ H_2O \text{ (hydration and gypsum formation)}$$

As a result of this reaction the mineral gypsum forms.[5]

Morphology

The karstification of a landscape may result in a variety of large or small scale features both on the surface and beneath. On exposed surfaces, small features may include flutes, runnels, clints and grikes, collectively called karren or lapiez. Medium-sized surface features may include sinkholes or cenotes (closed basins), vertical shafts, foibe (inverted funnel shaped sinkholes), disappearing streams, and reappearing springs. Large-scale features may include limestone pavements, poljes and blind valleys. Mature karst landscapes, where more bedrock has been removed than remains, may result in karst towers, or haystack/eggbox landscapes. Beneath the surface, complex underground drainage systems (such as karst aquifers) and extensive caves and cavern systems may form.

Limestone pavement in Dent de Crolles, France

The Witch's Finger stalagmite in Carlsbad Caverns, USA

Erosion along limestone shores, notably in the tropics, produces karst topography that includes a sharp makatea surface above the normal reach of the sea and undercuts that are mostly the result of biological activity or bioerosion at or a little above mean sea level. Some of the most dramatic of these formations can be seen in Thailand's Phangnga Bay and Halong Bay in Vietnam.

Calcium carbonate dissolved into water may precipitate out where the water discharges some of its dissolved carbon dioxide. Rivers which emerge from springs may produce tufa terraces, consisting of layers of calcite deposited over extended periods of time. In caves, a variety of features collectively called speleothems are formed by deposition of calcium carbonate and other dissolved minerals.

Hydrology

Farming in karst areas must take into account the lack of surface water. The soils may be fertile enough, and rainfall may be adequate, but rainwater quickly moves through the crevices into the ground, sometimes leaving the surface soil parched between rains.

A karst fenster is where an underground stream emerges onto the surface between layers of rock, cascades some feet, and then disappears back down, often into a sinkhole. Rivers in karst areas may disappear underground a number of times and spring up again in different places, usually under a different name (like Ljubljanica, the

A karst spring in the Jura mountains near Ouhans in eastern France at the source of the river Loue

river of seven names). An example of this is the Popo Agie River in Fremont County, Wyoming. At a site simply named "The Sinks" in Sinks Canyon State Park, the river flows into a cave in a formation known as the Madison Limestone, and then rises again a half-mile down the canyon in a placid pool. A Turlach is a unique type of seasonal lake found in Irish karst areas which are formed through the annual welling-up of water from the underground water system.

Water supplies from wells in karst topography may be unsafe, as the water may have run unimpeded from a sinkhole in a cattle pasture, through a cave and to the well, bypassing the normal filtering that occurs in a porous aquifer. Karst formations are cavernous and therefore have high rates of permeability, resulting in reduced opportunity for contaminants to be filtered out.

Groundwater in karst areas is just as easily polluted as surface streams. Sinkholes have often been used as farmstead or community trash dumps. Overloaded or malfunctioning septic tanks in karst landscapes may dump raw sewage directly into underground channels.

The karst topography itself also poses difficulties for human inhabitants. Sinkholes can develop gradually as surface openings enlarge, but quite often progressive erosion is unseen and the roof of an underground cavern suddenly collapses. Such events have swallowed homes, cattle, cars, and farm machinery.

The Driftless Area National Wildlife Refuge in Iowa protects *Discus macclintocki*, a species of ice age snail surviving in air chilled by flowing over buried karst ice formations.

Pseudokarst

Pseudokarsts are similar in form or appearance to karst features, but are created by different mechanisms. Examples include lava caves and granite tors—for example, Labertouche Cave in Victoria, Australia and paleocollapse features.

Notable pseudokarst areas

North America

Belize

- Great Blue Hole near the center of Lighthouse Reef, Belize

United States

- Arroyo Tapiado in Anza-Borrego Desert State Park. Over two-dozen mud caves are found in this desert area east of San Diego, California.

References

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[2] Geomorphological Landscapes of the World.

[3] Gams, I., *Kras v Sloveniji — v prostoru in casu* (Karst in Slovenia in space and time), 2003, ISBN 9616500465.

[4] "What is Karst (and why is it important)?" (http://www.karstwaters.org/kwitour/whatiskarst.htm). *Karst Waters Institute*. .

[5] S. Galdenzi, M. Cocchioni, L. Morichetti, V. Amici, and S. Scuri; Sulfidic ground water chemistry in the Frasassi Cave, Italy. *Journal of Cave and Karst Studies*, V. 70, No. 2, p.94-107.

Further reading

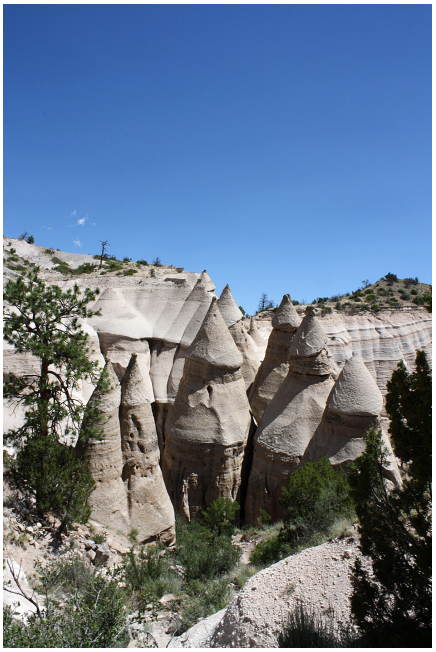
- Jennings, J.N., *Karst Geomorphology*, 2nd ed., Blackwell, 1985, ISBN 0631140328
- Sweeting, M.M., *Karst Landforms*, Macmillan, 1973, ISBN 023103623X

External links

- Speleogenesis Network, a communication platform for physical speleology and karst science research (http://www.network.speleogenesis.info/index.php)
- Speleogenesis and Karst Aquifers (http://www.speleogenesis.info/glossary/index.php) – a large glossary of Karst related terms
- Acta Carsologica (http://carsologica.zrc-sazu.si) – research papers and reviews in all the fields related to karst
- SERA Karst Task Force (http://sktfi.org) – a non-profit resource organization dedicated to karst conservation and the clean up of cave and karst features
- CDK Citizens of the Karst (http://cdk-pr.org) – Citizens of the Karst, a non profit NGO dedicated to the protection of the Puerto Rican Karst (English site available)

Kasha-Katuwe Tent Rocks National Monument

Kasha-Katuwe Tent Rocks National Monument	
IUCN Category III (Natural Monument)	
[[Image:|px|link=|alt=|]]	
Location	Sandoval County, New Mexico, USA
Nearest city	Santa Fe, NM
Coordinates	35°40′25″N 106°25′10″W
Area	4,148 acres (16.78 km²)



Kasha-Katuwe Tent Rocks National Monument, located 40 miles southwest of Santa Fe, New Mexico (near Cochiti), is a Bureau of Land Management (BLM) managed site that was established as a U.S. National Monument by President Bill Clinton in January 2001 shortly before leaving office.

The area owes its remarkable geology to layers of volcanic rock and ash deposited by a volcanic explosion. Over time, weathering and erosion of these layers has created canyons and tent rocks. The tent rocks themselves are cones of soft pumice and tuff beneath harder caprocks.

The monument is open for day use only and may be closed by order of the Cochiti Pueblo Tribal Governor. A 1.2 mile (1.9 km) recreation trail leads up through a slot canyon to a lookout point where the tent rocks may be viewed from above. A 1.3 mile (2 km) loop trail leads past their base. The park is located between 5700 and 6400 feet (1737-1951 m) above sea level. The monument is closed to dogs.

The monument is a unit of the BLM's National Landscape Conservation System.

Gallery

Tent Rocks next to Monument Entrance

Swirl curve pattern in slot canyon

Tent Rocks near Monument Entrance

Tent Rocks viewed from Lookout Point

Slot canyon on trail

Tent Rocks with scale comparison

External links

- U.S. Bureau of Land Management webpage for Kasha-Katuwe Tent Rocks National Monument [1]
- The Conservation System Alliance [2]
- Geologic Tour for Kasha-Katuwe Tent Rocks National Monument, New Mexico Bureau of Geology & Mineral Resources [3]
- More Hiking Information for Kasha-Katuwe Tent Rocks National Monument [4]
- History and Driving Suggestions for Kasha-Katuwe Tent Rocks National Monument [5]
- Kasha-Katuwe Tent Rocks National Monument on TripAdvisor [6]

References

[1] http://www.nm.blm.gov/recreation/albuquerque/kasha_katuwe.htm
[2] http://www.conservationsystem.org/conservationsystem
[3] http://geoinfo.nmt.edu/tour/federal/monuments/tentrocks/home.html
[4] http://www.explorenm.com/hikes/TentRocks/
[5] http://www.americansouthwest.net/new_mexico/kasha-katuwe-tent-rocks/national-monument.html
[6] http://www.tripadvisor.com/
Attraction_Review-g46992-d268906-Reviews-Kasha_Katuwe_Tent_Rocks_National_Monument-Cochiti_Pueblo_New_Mexico.html

Kilometre per square kilometre

Kilometre per square kilometre is an SI derived unit used for measurement of density of a linear feature in an area. It is used to measure, for example, drainage density[1] or road density.[2]

References

[1] http://www.eoearth.org/article/Stream_morphometry
[2] http://www.balochistan.gov.pk/index.php?option=com_content&task=view&id=113&Itemid=164

Knickpoint

A **knickpoint** is a term in geomorphology to describe a location in a river or channel where there is a sharp change in channel slope, such as a waterfall or lake, resulting from differential rates of erosion above and below the knickpoint. Differential rates of erosion can result from a change in the lithology of the river channel. Sharp changes in channel slope caused by faulting or in-channel construction are not considered knickpoints.

The Horseshoe Falls, one of the three Niagara Falls. The falls are a knickpoint, formed by slower erosion above the falls than below.

Knickpoints can also be caused by a change in base level. When a river is rejuvenated (that is, has a negative change in base level, the sea level falls), the long profile is lengthened as land rises from the sea. This increases the gradient of the long profile and causes the river to gain more erosive energy. The first knickpoint marks the position of the former base level but the knick point moves towards the source of the river as under rock erodes away to create a graded profile.

The river, having gained more potential energy due to gravity, will then proceed to work the knickpoints out of its system by either erosion (in the case of waterfalls) or deposition (in the case of lakes) in order for the river to reattain its smooth concave graded profile.

As is observed for many major waterfalls, knickpoints migrate upstream due to bedrock erosion.[1]

References

[1] Paul Bierman, Milan Pavich, E-an Zen, and Marc Caffee, *Determining Rates and Patterns of Bedrock Incision by Large Rivers* (http://www.uvm.edu/cosmolab/projects/potomac/potomac.html)

Kolk

A **kolk** (also known as *colc*) is an underwater vortex that is created when rapidly rushing water passes an underwater obstacle in boundary areas of high shear. High velocity gradients produce a violently rotating column of water, similar to a tornado. Kolks are capable of plucking multi-ton blocks of rock and transporting them in suspension for some thousands of meters. [1] [2]

One of many kolk-formed depressions or "potholes" in the channeled scablands in eastern Washington at 46°54′21.40″N 119°16′47″W.

Kolks leave clear evidence in the form of plucked-bedrock pits, called rock-cut basins or kolk lakes and downstream deposits of gravel-supported blocks that show percussion but no rounding.[1]

Examples

Kolks were first identified by the Dutch, who observed kolks hoist several ton blocks of riprap from dikes and transport them away suspended above the bottom.[1]

Kolk from the 1717 Christmas flood in Horumersiel with information board

Kolks are credited with creating the pothole-type geographical features in the highly jointed basalts in the channeled scablands of the Columbia Basin region in eastern Washington. Depressions were scoured out within the scablands that resemble virtually circular steep-sided potholes.[2] Examples from the Missoula Floods in this area include[1] :

- The region below Dry Falls includes a number of lakes scoured out by kolks.
- Sprague Lake is a kolk-formed basin created by a flow estimated to be 8 miles wide and 200 feet deep.
- The Alberton Narrows on the Clark Fork River shows evidence that kolks plucked boulders from the canyon and deposited them in a rock and gravel bar immediately downstream of the canyon.
- The south wall of Hellgate Canyon in Montana shows the rough plucked surface characteristic of kolk-eroded rock.
- Both the walls of the Wallula Gap and the Columbia River Gorge also show the rough plucked surfaces characteristic of kolk-eroded rock.
- Oswego Lake, in the middle of Lake Oswego, Oregon (a Portland suburb), was an abandoned channel of the Tualatin River that was scoured by a kolk
- The Larrelt Kolk near Emden appeared during the 1717 Christmas flood which broke through a long section of the dyke. The newly formed waterbody measured roughly 500 × 100 m and was 25 m deep. In spite of the repair to the dyke, there was another breach in 1721, which produced more kolks between 15 and 18 m deep. In 1825 during the February flood near Emden a kolk of 31 m depth was created. The soil was saturated from here for a further 5 km inland.

References

[1] Alt, David. *Glacial Lake Missoula & its Humongous Floods*. Mountain Press Publishing Company. ISBN 0-87842-415-6.

[2] Bjornstad, Bruce (2006). *On the Trail of the Ice Age Floods: A Geological Guide to the Mid-Columbia Basin*. San Point, Idaho: Keokee Books. ISBN 978-1-879628-27-4.

Landscape evolution model

A **landscape evolution model** is a physically based numerical model that simulates changing terrain over the course of time. This can be due to glacial erosion and deposition; erosion, sediment transport, and deposition in fluvial systems such as rivers; regolith production; the movement of material on hillslopes; more intermittent events such as rockfalls, debris flows, landslides, and other surface processes. This can also be due to surface uplift and/or subsidence. A typical landscape evolution model takes many of these factors into account.

Landscape evolution models are used primarily in the field of geomorphology. As they improve, they are beginning to be consulted by land managers to aid in decision making.

The earliest of these models were developed in the 1970s. In these models, water was run across a mesh, and cell elevations were changed in response to calculated erosion.[1]

References

[1] Coulthard, T. J. (2001). "Landscape evolution models: a software review". *Hydrological Processes* **15**: 165. doi:10.1002/hyp.426.

Large scale coastal behaviour

Large scale coastal behaviour is an attempt to model the morphodynamics of coastal change at time and space scales appropriate to management and prediction. Temporally this is at the decade to century scale, spatially at the scale of tens of kilometers. It was developed by de Vriend.

Modelling large scale coastal behaviour involves some level of parameterisation rather than simply upscaling from process or downscaling from the geological scale. It attempts to recognise patterns occurring at these scales. Cowell and Thom (2005) recognise the need to admit uncertainty in large scale coastal behaviour given incomplete process knowledge.

Ledoyom

Ledoyom (Russian: ледоём) is a term proposed by the Russian geologist V.P. Nekhoroshev for intermontane depressions which might get completely filled by glaciers from the surrounding mountains at the maxima of glaciation[1] .

In the 1930s the Russian geologist V.P. Nekhoroshev marked out intermontane depressions in the Altai which might get completely filled by glaciers from the surrounding mountains at the maxima of glaciation. He called such depressions "ledoyoms". The Russian term "*Ledoyom* (ледоём)" means an "ice body" by analogy with a "water body"[2] . Ledoyoms produced large valley glaciers within outlet runoff valleys from the depressions at culmination stages of their development. Diagnostic marks of the so-called classical ledoyoms are moraines, eskers and kames on the bottoms of the corresponding depressions.

In the 80-s and 90-s the Russian geologist Alexei Rudoy (Russian: Алексей Рудой) of glacier-dammed lakes which used to fill most of the inter-montane basins of the mountain belt of Siberia, the depressions of Teletskoye and Baikal lakes including, took place. It also became clear that many depressions, even very large ones, had been already occupied by dammed water basins by the time when the glaciers of the mountain frame moved forward into them. Thus, mountain glaciers turned into original "shelf" glaciers and armored completely the surface of the glacier-dammed lake joining together floating on the surface. That is the way the so-called "captured lakes" came to exist.

At maximum lowering of the snow-line (in the Altai and the Sayan its depression gave about 1200 m in late pleistocene) some of the lakes (Chuya, Kuray, Uymon and others) began functioning in an under-ice regime because they never got free from ice for thousands of years. Such lakes turned into ice bodies of the "aufeis" type. They consisted of a thick lens of lake water, which was covered by lake ice, aufeis and glacier ice, and by snow-firn sequence, too. "Aufeis" ledoyoms became independent centers of glaciation with subradial ice outlets. Possible analogies of such an evolution mechanism and pre-glacial lakes are thick water lenses under a 3-4 kilometer-thick unit of the glacier cover at the sites of Dome B and Dome Charlie and the Vostok Station in Eastern Antarctica.

Thus, depending on the intermontane depression topography, the values, of the snow-line depression and of the glaciation energy, the interrelation of the glaciers and the ice-dammed lakes in the mountains of south of Western Siberia could develop according to the following scenarios: (1) A ledoyom only (no ice-dammed lake). In such cases some glacial and water-glacial relief forms and sediments would remain in the basins; (2) A water body and a ledoyom together (the stage of "catch lakes"). Certain forms of "dead ice" may remain in the basins, as well as intraglacial water-ice forms - eskers and kames which were projected onto the bottom lake deposits when the "shelf" ice descended; (3) "Aufeis" ledoyoms; (4) An ice-dammed lake only. Under different extensions of the glacier at different time periods, one and the same basin underwent different sequences of the lake-glacier events[3] .

References

[1] В. П. Нехорошев. Современное и древнее оледенение Алтая // Труды III съезда геологов. — Ташкент, 1930. — Вып. 2. — С. 143—156.

[2] *Rudoy A.N.* Mountain Ice-Dammed Lakes of Southern Siberia and their Influence on the Development and Regime of the Runoff Systems of North Asia in the Late Pleistocene. Chapter 16. — In: Palaeohydrology and Environmental Change / Eds: G. Benito, V.R. Baker, K.J. Gregory. — Chichester: John Wiley & Sons Ltd., 1998. — P. 215—234.

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- Ледоёмы Горного Алтая. (http://geo.metodist.ru/altai/theory/ledoyom.htm)
- Ledoyom. Museum of Learning Explore a Virtual Museum of Knowledge (http://www.museumstuff.com/learn/topics/Ledoyom)

- Alexei Rudoy. Ледоёмы (ice body): обзор (http://knol.google.com/k/alexei-rudoy/Đ»ĐµĐ´Đ¾Ñ□Đ¼Ñ□-ice-body-Đ¾Đ±Đ·Đ¾Ñ□/2mjmwx6ls3hzt/2#)
- Alexei Rudoy. Giant current ripples: A Review (Гигантская рябь течения: обзор новейших данных). 29. 12. 2010. (http://knol.google.com/k/alexei-rudoy/Đ³Đ¸Đ°Đ½Ñ□Ñ□ĐºĐ°Ñ□-Ñ□Ñ□Đ±Ñ□-Ñ□ĐµÑ□ĐµĐ½Đ¸Ñ□-Đ¾Đ±Đ·Đ¾Ñ□-Đ½Đ¾Đ²ĐµĐ¹Ñ□Đ¸Ñ /2mjmwx6ls3hzt/1?collectionId=2mjmwx6ls3hzt.12&position=1#)
- Alexei Rudoy. Прошлогодний снег. - Climate, ice, water, landscapes (http://ice.tsu.ru/index.php?option=com_content&view=category&layout=blog&id=8&Itemid=99)

Lena Pillars

Lena Pillars is the name given to a natural rock formation along the banks of the Lena River in far eastern Siberia. This unique ecological and tourism location was submitted as a World Heritage site in 2006.[1] Lena Pillars National Park lies less than a day's boat ride upriver (south) from the city of Yakutsk, the autonomous capital of the Sakha Republic.[2]

The pillars viewed from a river cruise boat.

Tourism

A view of the lone maiden in the far right.

One may plan a river cruise by contacting a travel service in the city of Yakutsk. Those interested in Limnology or Ecotourism, and others who visit Lake Baikal, can coordinate a river sojourn with the aid of a guide from the Lake Baikal region; however, consider that Yakutsk, the world's coldest city and where the river cruises originate, is approximately 900 miles northeast of Lake Baikal.

Few modern amenities exist in this part of the world (Siberia), unless one travels by cruise ship on the Lena River.

Hiking trails in the region are steep and at times precarious.

References

[1] http://whc.unesco.org/en/tentativelists/5067/

[2] http://www.yakutiatravel.com/eng/travdir/lenatrips.htm

Lick (stream)

A **lick** is a small watercourse or an ephemeral stream. It ranks hydrologically between a rill, shown left, and a stream, shown right.

Picture of a rill in Holford Combe.

Yellow River in rural Indiana, USA. Rivers and streams of this size are often referred to as "creeks."

Lineament

See also Line (geometry)

A **lineament** is a linear feature in a landscape which is an expression of an underlying geological structure such as a fault. Typically a lineament will comprise a fault-aligned valley, a series of fault or fold-aligned hills, a straight coastline or indeed a combination of these features. Fracture zones, shear zones and igneous intrusions such as dykes can also give rise to lineaments.

Lineaments are often apparent in geological or topographic maps and can appear obvious on aerial or satellite photographs. There are for example, several instances within Great Britain. In Scotland the Great Glen Fault and Highland Boundary Fault give rise to lineaments as does the Malvern Line in western England and the Neath Disturbance in South Wales.

The term 'megalineament' has been used to describe such features on a continental scale. The trace of the San Andreas Fault might be considered an example.[1] The Trans Brazilian Lineament and the Trans-Saharan Belt, taken together, form perhaps the longest coherent shear zone on the Earth, extending for about 4,000 km.[2]

Lineaments have also been identified on other planets and their moons. Their origins may be radically different from those of terrestrial lineaments due to the differing tectonic processes involved.

References

[1] Whitten & Brooks, The Penguin Dictionary of Geology 1972

[2] Attoh, K.; Brown, L. D. (2008). "The Neoproterozoic Trans-Saharan/Trans-Brasiliano shear zones: Suggested Tibetan Analogs" (http://adsabs.harvard.edu/abs/2008AGUSM.S51A..04A). American Geophysical Union. . Retrieved 2011-01-30.

List of important publications in geology

This list is incomplete.

This is a list of **important publications** in geology, organized by field.

Some reasons why a particular publication might be regarded as important:

- **Topic creator –** A publication that created a new topic
- **Breakthrough –** A publication that changed scientific knowledge significantly
- **Introduction –** A publication that is a good introduction or survey of a topic
- **Influence –** A publication which has significantly influenced the world
- **Latest and greatest –** The current most advanced result in a topic

Foundations

Theory of the Earth

Author: James Hutton

Transactions of the Royal Society of Edinburgh, vol. 1, Part 2, 1788, pp. 209-304. (2nd Ed., 1795)

Description: Hutton's *Theory of the Earth; or an Investigation of the Laws observable in the Composition, Dissolution, and Restoration of Land upon the Globe* was the first publication to clearly articulate the principle of deep time, and to recognize that rocks record the evidence of the past action of processes which still operate today. These ideas were to grow into the idea of Uniformitarianism. Hutton is widely regarded as the "Father of Modern Geology".

Importance: Topic creator, Breakthrough, Influence

Principles of Geology

Author: Charles Lyell

Publication data: 1830–1833.

Online version: Online version at esp.org [1]

Description: The work's subtitle was "An Attempt to Explain the Former Changes of the Earth's Surface by Reference to Causes now in Operation", and this explains Lyell's impact on science: he was, along with the earlier John Playfair, the major advocate of the then-controversial idea of uniformitarianism, that the Earth was shaped entirely by slow-moving forces acting over a very long period of time. This was in contrast to catastrophism, a geologic idea that went hand-in-hand with the age of the Earth suggested by biblical chronology. In various revised editions (twelve in all, through 1872), *Principles of Geology* was the most influential geological work in the middle of the 19th century, and did much to put geology on a modern footing.

Importance: Topic creator, Breakthrough, Influence

Economic geology

Mineral Resources On-Line Spatial Data

Subtitle: A source for regional and global geology, geochemistry, geophysics, and mineral resource maps and data, by US Geological Survey

URL: http://mrdata.usgs.gov/

(accessed June 25, 2006; page last revised 31 May 2006)

Description: This is the portal for a basic tool for finding information on the location and characteristics of almost all known mineral deposits in the United States, with some information on major mineral deposits worldwide.

Importance: A key online mineral-resource database for economic geology

Ore Deposits of the United States, 1933-1967: the Graton-Sales volume

Editor John D. Ridge

AIME, New York, 1968. Two volumes.

Description: Descriptions of major ore deposits. Updates the earlier Lindgren volume.

Importance: A basic reference work for all economic geologists

Engineering geology

Engineering Geology: Rock in Engineering Construction

Author: Richard E. Goodman

John Wiley and Sons, New York, 1993 ISBN 0471544248

Geochemistry

Victor Moritz Goldschmidt: Father of Modern Geochemistry

Author: Brian Mason

(ISBN 0-941809-03-X)

Description:

Importance:

Geodetics

Map Projections - A Working Manual.

Author: Snyder, J. P.

U.S. Geological Survey Professional Paper 1395 (Book), 1987.

Description:

Importance:

Geomorphology

Report on the Geology of the Henry Mountains

Author: Grove Karl Gilbert

U.S.G.S. Professional Paper, 1877

Description:

Importance:

In this work, G. K. Gilbert lays the groundwork for many ideas in modern geomorphology, such as the diffusive profiles of hillslopes and the formation of pediments. In addition to its geomorphic significance, it is a description of the last major mountain range to be mapped by Europeans in the contiguous United States[2] (the Henry Mountains being located in a remote part of Utah) and a description of its formation as a laccolith.

Soils and Geomorphology

Author: Peter Birkeland

Description:

This book cover soil development, its relationship to climate and Earth history, connections between soil formation and geomorphic evolution of a region, and ways to use soils to establish chronologies. In addition to these topics, it offers a review of soil description and classification.

Importance:

A classic work in the analysis of soils and their relationships to geomorphic processes and chronologies, this book is used and referenced extensively by many quaternary geologists and geomorphologists.

Geophysics

Geodynamics

Author: Donald L. Turcotte and Gerald Schubert

Cambridge University Press, 2nd edition, 2001, ISBN 0521666244

Description: Provides a mathematical account of the geophysical processes occurring within the outer ~100 km of the Earth. A highly respected classic on the subject by two members of the National Academy of Sciences.

Importance: Influence

Geomagnetism (2 volumes)

Author: Sydney Chapman and Julius Bartels

Oxford, 1951

Description: A classic reference on the Earth's magnetic field and related phenomena

Importance: Influence

Geophysical Geodesy: The Slow Deformation of the Earth

Author: Kurt Lambeck

Oxford University Press, 1988, ISBN 0198544375

Description: Provides an understanding of and solutions to many problems in geodesy, gravity, and surface deformation

Importance:

The Solid Earth: An Introduction to Global Geophysics

Author: C.M.R. Fowler

Cambridge University Press, 2nd edition, 2004, ISBN 0521893070

Description: Provides a broad and largely non-mathematical introduction to global geophysics.

Importance:

Geotechnical engineering

Theoretical Soil Mechanics

Author: Karl von Terzaghi

John Wiley and Sons, New York, 1943

Description:

Importance:

Hydrogeology

The Public Fountains of the City of Dijon.

Author: Henry Darcy, English translation by Patricia Bobeck

Kendall/Hunt Publishing Co., 1856 (reprint ISBN 0-7575-0540-6).

Description:

Importance:

Groundwater

Author: R. Allan Freeze and John A. Cherry

Prentice Hall, 1979, (ISBN 0-13-365312-9).

Description:

Importance:

Mineralogy

Textbook on Mineralogy (De Natura Fossilium)

Author: Georg Frederick Agricola, translated from Latin by Mark Chance Bandy and Jean Bandy

PUBLISHED BY THE GEOLOGICAL SOCIETY OF AMERICA

Description: Systematic treatise of then known minerals and gemstones as well as other rocks.

Importance: The first systematic mineralogical treatise since Pliny's *Natural History*, first published in 1564

URL http://www.farlang.com/gemstones/agricola_textbook_of_mineralogy/page_001

An Introduction to the Rock-Forming Minerals

Author: W. A. Deer, R. A. Howie and J. Zussman

Addison Wesley Longman Ltd., 1992, ISBN: 0-582-30094-0 (1st Ed., 1966)

Description: The much beloved, student-friendly version of the epic 5 volume treatise "Rock-Forming Minerals" by the same authors, published 1962-63. Presents a more or less comprehensive summary of the physical, chemical, mineralogical, petrological and optical properties of essentially all minerals with nontrivial abundances to be found in terrestrial rocks. Also presents information regarding common origins and associations of each mineral, as well as a practical commentary on how to distinguish each mineral from others which may appear similar.

Importance: Influence, advanced reference.

Petroleum geology

Atlas of seismic stratigraphy

Authors: P. R. Vail

(ISBN 0-941809-03-X)

Description:

Importance: Original work on seismic sequence stratigraphy

An overview of the fundamentals of sequence stratigraphy and key definitions

Authors: Wagoner, J. C. van, Posamentier, H. W., Mitchum, R. M., Vail, P. R., Sarg, J. F., Loutit, T. S., and Hardenbol, J.

(ISBN 0-941809-03-X)

Description:

Importance: Sequence stratigraphy is one of the most important concepts that helps geologists understand clastic depositional sequences and their reservoir potential.

Plate tectonics

The Origin of Continents and Oceans

Author: Alfred Wegener

Published: 1915

Description: *Die Entstehung der Kontinente und Ozeane* was the first book to marshall considerable geological evidence that the continents are mobile relative to each other on the surface of the Earth. His theory was based upon numerous matches between the topography, paleontology and past climate of continents now separated by oceans. At the time of publication his ideas were not taken seriously by most of the geological community as he could not provide a mechanism for continental motion, but his ideas form the foundations of the modern theory of plate tectonics.

Importance: Topic creator, Breakthrough, Influence

Sedimentology

Sedimentary Environments and Facies

Editor: H.G. Reading

(ISBN 0-444-00276-6)

Description: A detailed look at sedimentary environments and the deposits they produce.

Importance: advanced reference

Principles of Sedimentology and Stratigraphy

Author: Sam Boggs, Jr.

(ISBN 0-13-154728-3)

Description:

Importance: introduction

Stratigraphy

De solido intra solidum naturaliter contento dissertationis prodromus

Author: Steno, Nicolaus (Stensen, Niels),

Firenze, 79p, 1669.

Description:

Importance:

Einleitung in die Geologie als historische Wissenschaft. Beobachtung über die Bildung der Gesteine und ihrer organischen Einschlüsse

Author: Walther, Johannes,

G. Fischer, Jena, 1055p, 1893.

Description:

Importance:

International Stratigraphic Chart

Author: Ogg, Gabi (drafter) for International Commission on Stratigraphy

2008-01, 1 page.

Structural geology

Folding and fracturing of rocks

Author: J. G. Ramsay

McGraw-Hill, 1967

Description:

Importance: Began a whole school of structural geology that used the techniques of continuum mechanics to understand rock structures.

Petrology

The Evolution of the Igneous Rocks

Author: Norman L. Bowen

1928

Description:

Importance: breakthrough, influence

Metamorphic Phase Equilibria and Pressure-Temperature-Time Paths

Author: Frank S. Spear

1993

Description:

Presents the thermodynamic basis for modern, quantitative petrology and systematically reviews metamorphism for most rock types.

Seismology

Quantitative Seismology, 2nd Edition

Author: Keiiti Aki, Paul G. Richards University Science Books, 2002

Description: Chapters outline basic theorems in dynamic elasticity, representation of seismic sources, elastic waves from a point dislocation, plane waves in homogeneous media and their reflection and transmission at a plane boundary, reflection and refraction of spherical waves; Lamb's problem, surface waves in a vertically heterogeneous medium, free oscillations of the Earth, body waves in media with depth-dependent properties, the seismic source: kinematics, the seismic source: dynamics, and principles of seismometry

Importance: This is the basic textbook used by theoretical seismologists

Tectonics

Tectonics

Author: E. M. Moores and R. J. Twiss

Publisher: W. H. Freeman

Date:1995

Description:

Importance:

Volcanology

Encyclopedia of Volcanoes

Author: Haraldur Sigurdsson, Bruce Houghton, Stephen R. McNutt, Hazel Rymer, John Stix - Editors

Academic Press, London, 2000

Description:

Importance:

Volcanoes

Author: Gordon A. Macdonald

Prentice-Hall, New Jersey, 1972

(ISBN 0-13-942219-6)

Description:

Importance:

The 1980 Eruptions of Mount St. Helens, Washington

Author: Peter W. Lipman and Donal R. Mullineaux (editors)

USGS Professional Paper 1250, Washington D.C., 1981

Description:

Importance:

Volcanism in Hawaii

Author: Robert W. Decker, Thomas L. Wright and Peter H. Stauffer (editors)

USGS Professional Paper 1350, Washington D.C., 1987 (2 volumes)

Description:

Importance:

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[2] Heath, Steven H. (1997). "A Historical Sketch of the Scientific Exploration of the Region Containing the Grand Staircase-Escalante National Monument" (http://www.blm.gov/pgdata/etc/medialib/blm/ut/grand_staircase-escalante/science___research/1997_symposium.Par.22079.File.dat/general01.htm). Bureau of Land Management Science Symposium. . Retrieved 2009-07-05.

Lithalsa

Lithalsa is a frost-induced raised land form in permafrost areas with mineral-rich soils, where a perennial ice lens has developed within the soil. The term sometimes also refers to palsas and pingos.

Log jam

A **log jam** is an accumulation of Large Woody Debris (logs more than four inches in diameter and over six feet long) that can span an entire stream or river channel.

Effects on stream/river geomorphology

Log jams alter flow hydraulics, which control characteristics of scour and deposition. Thus, log jams become an important factor in the geomorphology of wooded streams and rivers.

Water is often impounded on the upstream side of a log jam, creating a pool. Water draining from this pool often creates a downstream "plunge pool". Decrease in water velocity in the pool often results in deposition of sand or gravel in the pool bottom. This may progress into "bar" formation.

Log jams also cause shifts in stream flow. They often redirect flow into former channels or spur creation of new channels.

Log Jam in Goodell Creek, WA, USA

Effects on ecology

Log jams provide important fish habitat. The pools created and sediment deposited by formation of log jams create prime spawning grounds for many species of salmon. These pools also provide refuge for fish during low water levels when other parts of a stream may be nearly dry. Log jams can provide refuge, as velocity shelters, during high-flow periods.

Pool and bar formation by log jams also provides prime habitat for riparian forests.

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[2] http://www.ct.gov/dep/lib/dep/fishing/restoration/largewoodydebrisfactsheet.pdf
[3] http://www.mattole.org/pdf/9%20Log%20Jams.pdf

Longshore drift

Longshore drift consists of the transport of sediments (generally sand but may also consist of coarser sediments such as gravels) along a coast at an angle to the shoreline, which is dependent on prevailing wind direction, swash and backwash [1] This process occurs in the littoral zone, and in or within close proximity to the surf zone. The process is also known as **longshore transport**, **littoral drift** and **LSD**.[2]

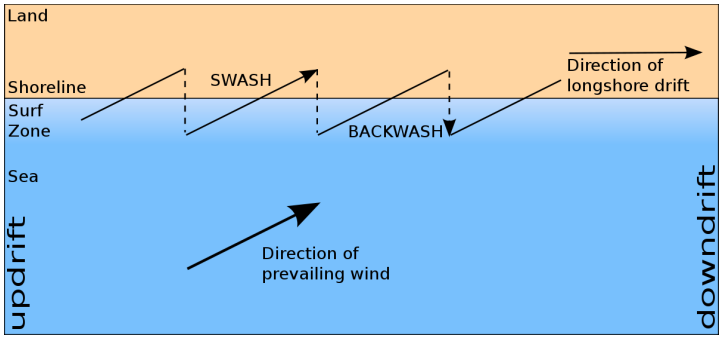

Figure 1. Diagram demonstrating longshore drift

Longshore drift is influenced by numerous aspects of the coastal system, with processes that occur within the surf zone largely influencing the deposition and erosion of sediments. Longshore currents can generate oblique breaking waves which result in longshore transport.[3]

Longshore drift can generally be defined in terms of the systems within the surf zone as seen in figure 1. This figure shows that sediment transport along the shore and surf zone is influenced by the swash (occurs in the direction of prevailing wind), which moves the pebble up the beach at the angle of wind direction and also backwash, which moves the pebble back down the beach due to the influence of gravity.

Longshore drift affects numerous sediment sizes as it works in slightly different ways depending on the sediment (e.g. the difference in long shore drift of sediments from a sandy beach to that of sediments from a shingle beach). Sand is largely affected by the oscillatory force of breaking waves, the motion of sediment due to the impact of breaking waves and bed shear from long shore current.[4] Whereas because shingle beaches are much steeper than sandy ones, plunging breakers are more likely to form, causing the majority of long shore transport to occur in the swash zone, due to a lack of surf zone.[5]

Overview

Longshore drift formulas

There are numerous calculations that take into consideration the factors that produce longshore drift. These formulations are:

1. Bijker formula (1967,1971)
2. The Engelund and Hansen formula (1967)
3. The Ackers and White formula (1973)
4. The Bailard and Inman formula(1981)
5. The Van Rijn formula (1984)
6. The Watanabe formula (1992)[6]

These formulas all provide a different view into the processes that generate longshore drift. The most common factors taken into consideration in these formulas are:

- Suspended and bed load transport
- Waves e.g. breaking and non-breaking
- The shear exerted by waves or the flow associated with waves.[7]

Features of shoreline change

Longshore drift plays a large role in the evolution of a shoreline, as if there is a slight change of sediment supply, wind direction, or any other coastal influence longshore drift can change dramatically, impacting on the formation and evolution of a beach system or profile. These changes do not occur due to one factor within the coastal system, in fact there are numerous alterations that can occur within the coastal system that may affect the distribution and impact of longshore drift. Some of these are:

1. Geological changes, e.g. erosion, backshore changes and emergence of headlands.
2. Change in hydrodynamic forces, e.g. change in wave diffraction in headland and offshore bank environments.
3. Change to hydrodynamic influences, e.g. the influence of new tidal inlets and deltas on drift.
4. Alterations of the sediment budget, e.g. switch of shorelines from drift to swash alignment, exhaustion of sediment sources.
5. The intervention of humans, e.g. cliff protection, groynes, detached breakwaters.[8]

The sediment budget

The sediment budget takes into consideration sediment sources and sinks within a system.[9] This sediment can come from any source with examples of sources and sinks consisting of:

- Rivers
- Lagoons
- Eroding land sources
- Artificial sources e.g. nourishment
- Artificial sinks e.g. mining/extraction
- Offshore transport
- Deposition of sediment on shore

This sediment then enters the coastal system and is transported by longshore drift. A good example of the sediment budget and longshore drift working together in the coastal system is inlet ebb-tidal shoals, which store sand that has been transported by long shore transport.[10] As well as storing sand these systems may also transfer or by pass sand into other beach systems, therefore inlet ebb-tidal shoal systems provide a good sources and sinks for the sediment budget.[11]

Natural features

This section consists of features of long shore drift that occur on a coast where long shore drift occurs uninterrupted by man-made structures.

Spits

Figure 2. Provincetown Spit, at the northern end of Cape Cod, was formed by longshore drift after the end of the last Ice age.

Spits are formed when longshore drift travels past a point (e.g. river mouth or re-entrant) where the dominant drift direction and shoreline do not veer in the same direction.[12] As well as dominant drift direction, spits are affected by the strength of wave driven current, wave angle and the height of incoming waves.[13]

Spits are landforms that have two important features, with the first feature being the region at the up-drift end or proximal end (Hart et al., 2008). The proximal end is constantly attached to land (unless breached) and may form a slight “barrier” between the sea and an estuary or lagoon.[14] The second important spit feature is the down-drift end or distal end, which is detached from land and in some cases, may take a complex hook-shape or curve, due to the influence of varying wave directions.[15]

As an example, the New Brighton spit in Canterbury, New Zealand, was created by longshore drift of sediment from the Waimakariri River to the north.[16] This spit system is currently in equilibrium but undergoes phases of deposition and erosion.

Barriers

Barrier systems are attached to the land at both the proximal and distal end and are generally widest at the down-drift end.[17] These barrier systems may enclose an estuary or lagoon system, like that of Lake Ellesmere enclosed by the Kaitorete Spit.

The Kaitorete Spit in Canterbury, New Zealand, is a barrier/spit system (which generally falls under the definition barrier, as both ends of the landform are attached to land, but has been named a spit) that has existed below Banks Peninsula for the last 8000 years.[18] This system has undergone numerous changes and fluctuations due to avulsion of the Waimakariri River (which now flows to the north or Banks Peninsula), erosion and phases of open marine conditions.[19] The system underwent further changes c.500 year BP, when longshore drift from the eastern end of the “spit” system created the barrier, which has been retained due to ongoing longshore transport.[20]

Tidal inlets

The majority of tidal inlets on longshore drift shores accumulate sediment in flood and ebb shoals.[21] Ebb-deltas may become stunted on highly exposed shores and in smaller spaces, whereas flood deltas are likely to increase in size when space is available in a bay or lagoon system.[22] Tidal inlets can act as sinks and sources for large amounts of material, which therefore impacts on adjacent parts of the coastline.[23]

The structuring of tidal inlets is also important for longshore drift as if an inlet is unstructured sediment may by pass the inlet and form bars at the down-drift part of the coast.[24] Although this may also depend on the inlet size, delta morphology, sediment rate and by passing mechanism.[25] Channel location variance and amount may also influence the impact of long shore drift on a tidal inlet as well.

For example, the Arcachon lagoon is a tidal inlet system in South west France, which provides large sources and sinks for longshore drift sediments. The impact of longshore drift sediments on this inlet system is highly influenced by the variation in the number of lagoon entrances and the location of these entrances.[26] Any change in these

factors can cause severe down-drift erosion or down-drift accretion of large swash bars.[27]

Human influences

This section consists of long shore drift features that occur unnaturally and in some cases (e.g. groynes, detached breakwaters) have be constructed to enhance the effects of longshore drift on the coastline, but in other cases have a negative impact on long shore drift (ports and harbours).

Groynes

Groynes are shore protection structures, placed at equal intervals along the coastline in order to stop coastal erosion and generally cross the intertidal zone.[28] Due to this, groyne structures are usually used on coasts/shores with low net and high annual longshore drift in order to retain the sediments lost in storm surges and further down the coast.[29]

Figure 3. Timber groyne from Swanage bay, UK

There are numerous variations to groyne designs with the three most common designs consisting of:

1. zig-zag groynes, which dissipate the destructive flows that form in wave induced currents or in breaking waves.
2. T-head groynes, which reduce wave height through wave diffraction.
3. 'Y' head, a fish tail groyne system.[30]

Artificial headlands

Artificial headlands are also shore protection structures, which are created in order to provide a certain amount of protection to beaches or bays.[31] Although the creation of headlands involves accretion of sediments on the up-drift side of the headland and moderate erosion of the down-drift end of the headland, this is undertaken in order to design a stabilised system that allows material to accumulate in beaches further along the shore.[32]

Artificial headlands can occur due to natural accumulation or also through artificial nourishment.

Figure 4.Picture showing the use of artificial headlands and detached breakwaters in a coastal system

Detached breakwaters

Detached breakwaters are shore protection structures, created to build up sandy material in order to accommodate drawdown in storm conditions.[33] In order to accommodate drawdown in storm conditions detached breakwaters have no connection to the shoreline, which lets currents and sediment pass between the breakwater and the shore.[34] This then forms a region of reduced wave energy, which encourages the deposition of sand on the lee side of the structure.[35]

Detached breakwaters are generally used in the same way as groynes, to build up the volume of material between the coast and the breakwater structure in order to accommodate storm surges.[36]

Ports and Harbours

The creation of ports and harbours throughout the world can seriously impact on the natural course of longshore drift. Not only do ports and harbours pose a threat to longshore drift in the short term, they also pose a threat to shoreline evolution.[37] The major influence the creation of a port or harbour can have on longshore drift is the alteration of sedimentation patterns, which in turn may lead to accretion and/or erosion of a beach or coastal system.[38]

As an example, the creation of a port in Timaru, New Zealand in the late 1800s led to a significant change in the longshore drift along the South Canterbury coastline.[39] Instead of longshore drift transporting sediment north up the coast towards the Waimataitai lagoon, the creation of the port blocked the drift of these (coarse) sediments and instead caused them to accret to the south of the port at South beach in Timaru.[40] The accretion of this sediment to the south, therefore meant a lack of sediment being deposited on the coast near the Waimataitai lagoon (to the north of the port), which led to the loss of the barrier enclosing the lagoon in the 1930s and then shortly after, the loss of the lagoon itself.[41] As with the Waimataitai lagoon the Washdyke Lagoon, which currently lies to the north of the Timaru port is undergoing erosion and may eventually breach causing loss of another lagoon environment.

Notes

[1] Brunn, 2005
[2] Brunn, 2005
[3] Reeve et al., 2004
[4] Reeve et al., 2004
[5] Reeve et al., 2004
[6] http://www.tpub.com/content/ArmyCIR/bayram_etal02/bayram_etal020004.htm
[7] http://www.tpub.com/content/ArmyCIR/bayram_etal02/bayram_etal020004.htm
[8] Reeve et al., 2004
[9] Brunn, 2005
[10] Brunn, 2005, Michel and Howa, 1997
[11] Brunn, 2005, Michel and Howa, 1997
[12] Hart et al., 2008
[13] IPetersen et al., 2008
[14] Hart et al., 2008, Petersen et al., 2008
[15] Hart et al., 2008, Petersen et al., 2008
[16] Hart et al., 2008
[17] Kirk and Lauder, 2000
[18] Soons et al., 1997
[19] Soons et al., 1997
[20] Soons et al., 1997
[21] Brunn, 2005
[22] Brunn, 2005
[23] Michel and Howa, 1997
[24] Michel and Howa, 1997
[25] Brunn, 2005
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[29] Reeve et al., 2004
[30] Reeve et al., 2004
[31] Reeve et al., 2004
[32] Reeve et al., 2004
[33] Reeve et al., 2004
[34] Reeve et al., 2004
[35] Reeve et al., 2004
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[37] Reeve et al., 2004
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- Soons, J.M; Schulmeister, J; Holt, S (1997). "The Holocene evolution of a well nourished gravelly barrier and lagoon complex, Kaitorete "Spit", Canterbury, New Zealand". *Marine Geology*. **26**. pp. 69–90.

External links

- Photos, animation and explanation for schools (http://www.geography-site.co.uk/pages/physical/coastal/longshore.html), geography-site.co.uk
- Intranet.lissjunior.hants.sch.uk (http://intranet.lissjunior.hants.sch.uk/water/picsweb_ks2geography/flash/g2reswa0015.swf) has a brief animation on longshore drift.
- USGS — Coastal Erosion on Cape Cod (http://woodshole.er.usgs.gov/staffpages/boldale/capecod/quest.html), woodshole.er.usgs.gov
- Shore drift (http://www.ecy.wa.gov/programs/sea/pugetsound/bluffs/drift.html), ecy.wa.gov
- Longshore drift in South Carolina (http://www.cofc.edu/CGOInquiry/longshoredrift.htm), cofc.edu

Losing stream

A **losing stream**, or **effluent stream**, is a stream or river that loses water as it flows downstream. The water infiltrates into the ground recharging the local groundwater, because the water table is below the bottom of the stream channel. This is the opposite of a more usual *gaining stream* (or *influent stream*) which increases in water volume farther down stream as it gains water from the local aquifer.

Losing streams are common in arid areas[1]. Losing streams are also common in regions of karst topography where the streamwater may be completely captured by an underground cavern system, becoming a subterranean river.

Examples of losing streams

Examples of losing streams include:

- There are two rivers in Idaho, the Big Lost River and the Little Lost River, which both flow into the same depression and become subterranean, feeding the Snake River Plain Aquifer. Via the aquifer and numerous springs, they are tributaries of the Snake River.
- The Lost River in Indiana rises in Vernon Township, Washington County, Indiana, and discharges into the East Fork of the White River. The Lost River is about 85 miles (137 km) long and its name is derived from the fact that at least 23 miles (37 km) of the primary course of the river flows completely underground. The river disappears into a series of sink holes of the type that are abundant in the karstland of southern Indiana.[2]

Map of the lost streams of Idaho

- The Lost River of New Hampshire is a 6.5-mile (10.5 km) long stream located in the White Mountains of New Hampshire in the United States. It is a tributary of the Pemigewasset River, part of the Merrimack River watershed. The Lost River begins in Kinsman Notch, one of the major passes through the White Mountains. As it flows through the notch, it passes through Lost River Gorge, an area where enormous boulders falling off the flanking walls of the notch at the close of the last Ice Age have covered the river, creating a network of boulder caves.[3]
- The Lost River of West Virginia is located in the Appalachian Mountains of Hardy County in the Eastern Panhandle region of the state. It flows into an underground channel northeast of Baker along West Virginia Route 259 at "the Sinks" and reappears near Wardensville as the Cacapon River.

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[1] http://jersey.uoregon.edu/~mstrick/AskGeoMan/geoQuerry62.html
[2] Amazing Tales from Indiana By Fred D. Cavinder, 1990, Pg 4 (http://books.google.com/books?id=xU5NF4EAbQMC&pg=PA6&dq=harrison+spring+indiana&as_brr=3&sig=vtmZ2aQQILJjADDIVYbfEFFG4KI#PPA5,M1)
[3] New Hampshire GRANIT state geographic information system (http://www.granit.sr.unh.edu)

- Tom Aley, Karst Groundwater, Missouri Conservationist Online, Mar. 2000 - Vol. 61 No. 3 (http://mdc.mo.gov/conmag/2000/03/20.htm)

Managed retreat

In the context of coastal erosion, **managed retreat** (also managed realignment) allows an area that was not previously exposed to flooding by the sea to become flooded by removing coastal protection. This process is usually in low lying estuarine areas and almost always involves flooding of land that has at some point in the past been claimed from the sea.

Managed retreat is often a response to sea level rise exacerbated by local subsidence of the land surface due to isostatic rebound in the north.

Tollesbury Managed Realignment site in Essex, the first large scale attempt at salt marsh restoration in the UK

Coastal defence

In the UK the main reason for implementation of Managed Realignment is generally to improve coastal stability, essentially replacing artificial 'hard' coastal defences with natural 'soft' coastal landforms (Pethick 2002). This process can be used to protect areas of land further inland rather than that near the coast by relying on natural defences to absorb or dampen the force of waves.

Habitat loss

In addition to being used as a means of coastal defence, Managed Realignment has also been used in a number of cases to mitigate for loss of intertidal habitat.

Although land claim has been an important factor for salt marsh loss in the UK in the past (Allen 1992) the majority of current salt marsh loss in the UK is believed to be due to erosion (Morris et al. 2004). This erosion may involve coastal squeeze, where protective sea walls prevent the landward migration of salt marsh in response to sea level rise when sediment supply is limited (Hulme 2005; Morris et al. 2004). Salt marshes are protected under the EU Habitats Directive as well as providing habitat for a number of species protected by the Birds Directive(see Natura 2000). Following this guidance, the UK's biodiversity action plan aims to prevent net losses to the area of salt marsh present in 1992. It is therefore a legal requirement that all losses in marsh area must be compensated by replacement habitat with equivalent biological characteristics (Crooks et al. 2001). This equates to the need to restore approximately 1.4 km² of salt marsh habitat per year in the UK.

Advantages

There are no direct costs apart from that of removing any defences already in place and maintenance costs are very low.

Sediment flow is also restored to its natural state, beaches can be naturally replenished due to erosion of the coast, providing protection and the balance of the coastline returns.

Disadvantages

A certain amount of land will inevitably be lost in this process while beaches are being built up resulting in settlements, farmland and other property being destroyed. Because of this, managed retreat is often not a socially acceptable plan and may invoke the need for compensation to land-owners. Intertidal sites are often a rich archaeological resource and the loss of heritage is a factor to weighed in managed retreat projects.

There are no agreed protocols on the monitoring of MR sites (Atkinson et al. 2001) and, consequently, very few of the sites are being monitored consistently and effectively (Wolters et al. 2005c). Due to the low levels of monitoring there is little evidence on which to base future managed realignment projects. This has led to the results of Managed Realignment schemes being extremely unpredictable.

Examples

In the UK, the first managed retreat site was an area of 8,000 square metres at Northey Island in Essex flooded in 1991, followed by larger sites at Tollesbury and Orplands (1995), Freiston Shore (2001) and Abbott's Hall Farm, at Great Wigborough in the Blackwater Estuary, it is one of the largest managed retreat schemes in Europe. It covers nearly 280 hectares of land on the north side of the estuary (2002) and a number of others.

Freiston Shore Managed Realignment site, Lincolnshire

Current progress

At present approximately 6 km² of salt marsh have been restored by MR in the UK (Mossman et al. In prep). One of the major reasons cited for the slow pace of current salt marsh restoration in the UK (Morris et al. 2004) is the uncertainty associated with the practice (Foresight).

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Morris, R. K. A., I. S. Reach, M. J. Duffy, T. S. Collins, and R. N. Leafe. 2004. On the loss of salt marshes in south-east England and the relationship with Nereis diversicolor. Journal of Applied Ecology 41:787-791.

Mossman, H., A. Grant, and A. J. Davy. In prep. Halophyte community development on a salt marsh following managed coastal realignment.

Pethick, J. 2002. Estuarine and Tidal Wetland Restoration in the United Kingdom: Policy Versus Practice. Restoration Ecology 10:431-437.

External links

The following references review the UK and US experience respectively:

Atkinson, P.W., Crooks, S., Grant, A. and Rehfisch, M. M., 2001. The success of creation and restoration schemes in producing intertidal habitat suitable for waterbirds. English Nature Research Report 425.

Available online in three sections: http://www.english-nature.org.uk/pubs/publication/PDF/ENRR425_1.pdf

- http://www.english-nature.org.uk/pubs/publication/PDF/ENRR425_2.pdf
- http://www.english-nature.org.uk/pubs/publication/PDF/ENRR425_3.pdf
- Board on Environmental Studies and Toxicology, 2001. Compensating for Wetland Losses Under the Clean Water Act [1]
- Pictures of the Tollesbury and Orplands managed retreat sites [2]
- Information on Abbott's Hall from Essex Wildlife Trust [3]
- The UK Environment Agency's Managed Realignment Electronic Platform [4]
- The Online Managed Realignment Guide (OMReG): A website designed to act as a 'collecting point' for information about coastal Managed Realignment and Regulated Tidal Exchange projects in the UK and Northern Europe [5]
- Animation explaining basic principle of Managed Realignment [6]

References

[1] http://darwin.nap.edu/books/0309074320/html
[2] http://www.uea.ac.uk/~e130/Tollesbury.htm
[3] http://www.essexwt.org.uk/visitor_centres__nature_reserves/abbotts_hall_farm/
[4] http://www.intertidalmanagement.co.uk
[5] http://www.abpmer.net/omreg/
[6] http://www.archipelago.co.uk/our-work/what-is-managed-realignment-animation

Manning formula

The **Manning formula**, known also as the **Gauckler–Manning formula**, or **Gauckler–Manning–Strickler formula** in Europe, is an empirical formula for open channel flow, or free-surface flow driven by gravity. It was first presented by the French engineer Philippe Gauckler in 1867,[1] and later re-developed by the Irish engineer Robert Manning in 1890.

The Gauckler–Manning formula states:

$$V = \frac{k}{n} R_h^{2/3} \cdot S^{1/2}$$

where:

- V is the cross-sectional average velocity (ft/s, m/s)
- k is a conversion constant equal to 1.486 for U.S. customary units or 1.0 for SI units
- n is the **Gauckler–Manning coefficient** (independent of units)
- R_h is the hydraulic radius (ft, m)
- S is the slope of the water surface or the linear hydraulic head loss (ft/ft, m/m) ($S = h_f/L$)

The discharge formula, $Q = A\,V$, can be used to *manipulate* Gauckler–Manning's equation by substitution for V. Solving for Q then allows an estimate of the volumetric flow rate (discharge) without knowing the limiting or actual flow velocity.

The Gauckler–Manning formula is used to estimate flow in open channel situations where it is not practical to construct a weir or flume to measure flow with greater accuracy. The friction coefficients across weirs and orifices are less subjective than n along a natural (earthen, stone or vegetated) channel reach. Cross sectional area, as well as n', will likely vary along a natural channel. Accordingly, more error is expected in predicting flow by assuming a Manning's n, than by measuring flow across a constructed weirs, flumes or orifices.

The formula can be obtained by use of dimensional analysis. Recently this formula was derived theoretically using the phenomenological theory of turbulence.[2]

Hydraulic radius

The **hydraulic radius** is a measure of a channel flow efficiency. Flow speed along the channel depends on its cross-sectional shape (among other factors), and the hydraulic radius is a characterisation of the channel that intends to capture such efficiency. Based on the 'constant shear stress at the boundary' assumption[3] , hydraulic radius is defined as the ratio of the channel's cross-sectional area of the flow to its wetted perimeter (the portion of the cross-section's perimeter that is "wet"):

$$R_h = \frac{A}{P}$$

where:

R_h is the hydraulic radius (m),

A is the cross sectional area of flow (m^2),

P is wetted perimeter (m).

The greater the hydraulic radius, the greater the efficiency of the channel and the less likely the river is to flood. For channels of a given width, the hydraulic radius is greater for the deeper channels.

The hydraulic radius is *not* half the hydraulic diameter as the name may suggest. It is a function of the shape of the pipe, channel, or river in which the water is flowing. In wide rectangular channels, the hydraulic radius is approximated by the flow depth. The measure of a channel's efficiency (its ability to move water and sediment) is used by water engineers to assess the channel's capacity.

Gauckler–Manning coefficient

The Gauckler–Manning coefficient, often denoted as *n*, is an empirically derived coefficient, which is dependent on many factors, including surface roughness and sinuosity[4] . When field inspection is not possible, the best method to determine *n* is to use photographs of river channels where *n* has been determined using Gauckler–Manning's formula.

Note : The coefficient "n" is not independent of unit as stated above but expressed in s/m^1/3 (second per meter power 1/3) and the constant 1.486 for US customary units is the ratio between metric system and US system as "n" is all over the world expressed in metric system.

In natural streams, *n* values vary greatly along its reach, and will even vary in a given reach of channel with different stages of flow. Most research shows that *n* will decrease with stage, at least up to bank-full. Overbank *n* values for a given reach will vary greatly depending on the time of year and the velocity of flow. Summer vegetation will typically have a significantly higher *n* value due to leaves and seasonal vegetation. Research has shown, however, that *n* values are lower for individual shrubs with leaves than for the shrubs without leaves.[5] This is due to the ability of the plant's leaves to streamline and flex as the flow passes them thus lowering the resistance to flow. High velocity flows will cause some vegetation (such as grasses and forbs) to lay flat, where a lower velocity of flow through the same vegetation will not.[6]

In open channels, the Darcy–Weisbach equation is valid using the hydraulic diameter as equivalent pipe diameter. It is the only sound method to estimate the energy loss in man-made open channels. For various reasons (mainly historical reasons), empirical resistance coefficients (e.g. Chézy, Gauckler–Manning–Strickler) were and are still used. The Chézy coefficient was introduced in 1768 while the Gauckler–Manning coefficient was first developed in 1865, well before the classical pipe flow resistance experiments in the 1920–1930s. Historically both the Chézy and the Gauckler–Manning coefficients were expected to be constant and functions of the roughness only. But it is now well recognised that these coefficients are only constant for a range of flow rates. Most friction coefficients (except perhaps the Darcy–Weisbach friction factor) are estimated *100% empirically* and they apply only to fully-rough turbulent water flows under steady flow conditions.

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External links

- Hydraulic Radius Design Equations Formulas Calculator (http://www.ajdesigner.com/phphydraulicradius/hydraulic_radius_equation.php)
- History of the Manning Formula (http://manning.sdsu.edu/)
- Manning formula calculator for several channel shapes (http://www.wq.uiuc.edu/dg/Equations/Mannings.exe)
- Manning *n* values associated with photos (http://wwwrcamnl.wr.usgs.gov/sws/fieldmethods/Indirects/nvalues/index.htm)
- Table of values of Manning's n (http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm)

Manpupuner rock formations

The **Manpupuner rock formations** (Man-Pupu-Nyer; Мань-Пупу-нёр) or the **Seven Strong Men Rock Formations** or **Poles of the Komi Republic** are a set of 7 gigantic abnormally shaped stone pillars located north of the Ural mountains in the Troitsko-Pechorsky District of the Komi Republic. These monoliths are around 30 to 42 meters high and jut out of a hilly plateau formed through the weathering effects of ice and winds [1] .

According to a local legend, the stone pillars were once an entourage of Samoyeds giants walking through the mountains to Siberia in order to destroy the Vogulsky people. However, upon seeing the holy Vogulsky mountains, the shaman of the giants dropped his drum and the entire team froze into the stone pillars [2] .

Deemed one of the Seven Wonders of Russia, the Manpupuner rock formations are a very popular attraction in Russia, though not well-known on an international level and relatively unspoiled by tourism[1] . Their height and abnormal shapes supposedly make the top of these rock giants inaccessible even to experienced rock-climbers.

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[2] *7 чудес России: Столбы выветривания* (http://www.utro-russia.ru/news.html?id=35043), utro-russia.ru, April 2008,

External links

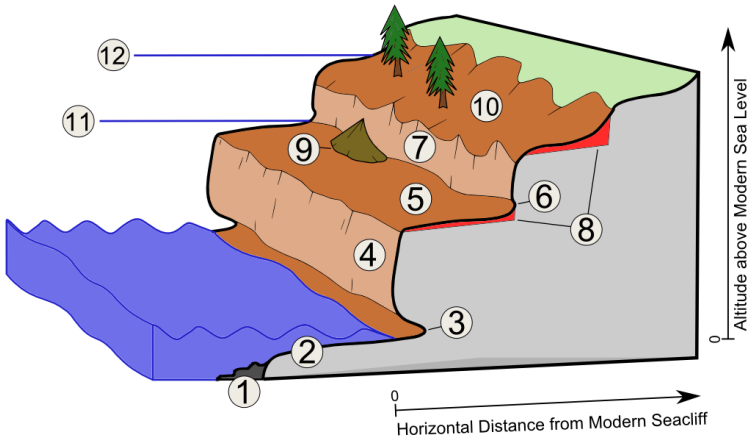
- Official images of the Manpupuner rocks (http://rkomi.ru/en/services/albom/19/)
- В гости к семерым великанам (http://www.izvestia.ru/obshestvo/article3132688/) (Izvestia, 9 avril 2009)
- Столбы выветривания на плато Мань-Пупу-нёр (http://www.ruschudo.ru/miracles/277/) (7 чудес России)
- Manpupuner. Seven Wonders of Russia. Seven Wonders of Komi. (http://www.tomovl.ru/painting/Manpypyner.html)

Marine terrace

A **marine terrace**, **coastal terrace**[1] , **raised beach** or **perched coastline** is a relatively flat, horizontal or gently inclined surface of marine origin[2] , mostly an old abrasion platform which has been lifted out of the sphere of wave activity (sometimes called "tread"). Thus it lies above or under the current sea level, depending on its time of formation[3] [4] . It is bounded by a steeper ascending slope on the landward side and a steeper descending slope on the seaward side[2] (sometimes called "riser"). Due to its reasonably flat shape it is often used for anthropogenic structures like settlements and infrastructure[3] .

Morphology

The platform of a marine terrace usually has a gradient between 1°- 5° depending on the former tidal range with commonly a linear to concave profile. The width is very variable, reaching up to 1000 m, and seems to differ between northern and southern hemisphere[7] . The cliff faces, delimiting the platform, can vary in steepness depending on the relative roles of marine and subaerial processes[8] . At the intersection of the former shore (wave-cut/abrasion-) platform and the rising cliff face it commonly retains a shoreline angle or inner edge (notch) which indicates the location of the shoreline at the time of maximum sea ingression and therefore a paleo sea level[9] . Sub-horizontal platforms usually terminate in a low tide cliff and it is believed that the occurrence of these platforms depends on tidal activity[8] . Marine terraces can extend for several tens of kilometers parallel to the coast[3] .



Typical sequence of erosional marine terraces. 1) low tide cliff/ramp with deposition, 2) modern shore (wave-cut/abrasion-) platform, 3) notch/inner edge, modern shoreline angle, 4) modern sea cliff, 5) old shore (wave-cut/abrasion-) platform, 6) paleo-shoreline angle, 7) paleo-sea cliff, 8) terrace cover deposits/marine deposits, colluvium, 9) alluvial fan, 10) decayed and covered sea cliff and shore platform, 11) paleo-sea level I, 12) paleo-sea level II. - after various authors[5] [1] [6] [3]

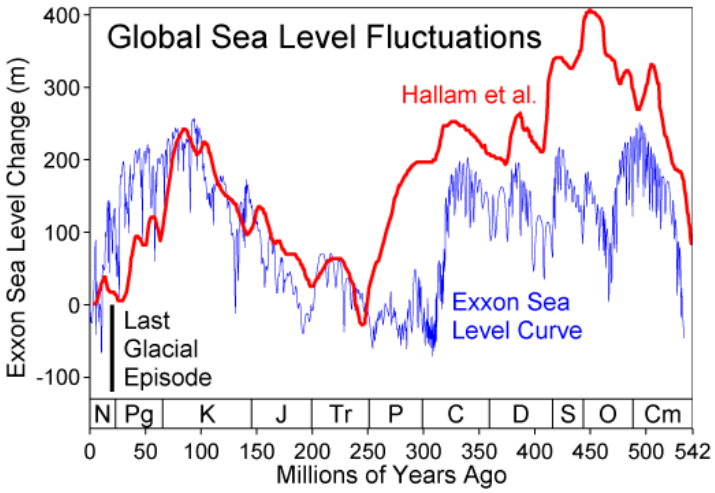
Older terraces are covered by marine and/or alluvial or colluvial materials while the uppermost terrace levels usually are less well-preserved[10] . While marine terraces in areas of relatively rapid uplift rates (> 1 mm/year) can often be correlated to individual interglacial periods or stages, those in areas of slower uplift rates may have a polycyclic origin with stages of returning sea levels after times of exposure to weathering[2] .

Marine terraces can be covered by a wide variety of soils with complex histories and different ages. In protected areas allochtonous sandy parent materials from tsunami deposits may be found. Common soil types found on marine terraces include Planosols and Solonetz[11] .

Formation

Causes

The formation of marine terraces is controlled by changes in environmental conditions and by tectonic activity during recent geological times. Changes in climatic conditions have led to eustatic sea-level oscillations and isostatic movements of the earth's crust, especially with the changes between glacial and interglacial periods.



Comparison of two sea level reconstructions during the last 500 Ma. The scale of change during the last glacial/interglacial transition is indicated with a black bar.

Processes of eustasy lead to glacioeustatic sea level fluctuations due to changes of the water volume in the oceans and hence to regressions and transgressions of the shoreline. E.g. at times of maximum glacier extend during the last glacial period the sea level was about 100 m lower compared to today. Eustatic sea level changes can also be caused by changes of the void volume of the oceans, either through sedimento-eustasy or tectono-eustasy[12] .

Processes of isostasy involve the uplift of continental crusts including their shorelines. Today the process of glacial isostatic adjustment mainly applies to during Pleistocene glaciated areas[12] . In Scandinavia, for instance, the present rate of uplift reaches up to 10 mm/year[13] .

In general, eustatic marine terraces were formed during separate sea level highstands of interglacial stages[12] [14] and can be correlated to Marine Oxygene Isotopic Stages (MIS)[15] [16] . Glacioisostatic marine terraces were mainly created during stillstands of the isostatic uplift[12] . When eustasy was the main factor for the formation of marine terraces, derived sea level fluctuations can indicate former climate changes. This conclusion has to be treated with care, as isostatic adjustments and tectonic activities can be extensively overcompensated by an eustatic sea level rise. Thus, in areas of both eustatic and isostatic or tectonic influences, the course of the relative sea level curve can be complicated[17] . Hence most of today's marine terrace sequences were formed by a combination of tectonic coastal uplift and Quaternary sea level fluctuations.

Jerky tectonic uplifts can also lead to marked terrace steps while smooth relative sea level changes may not result in obvious terraces and their formations are often not referred to as marine terraces[9] .

Processes

Marine terraces often result from marine erosion along rocky coast lines[2] in temperate regions due to wave attack and sediment carried in the waves. Erosion also takes place in connection with weathering and cavitation. The speed of erosion is highly dependent on the shoreline material (hardness of rock[8]), the bathymetry and the bedrock properties and can be between only a few millimeters per year for granitic rocks and more than 10m per year for volcanic ejecta[18] [8] . The retreat of the sea cliff generates a shore (wave-cut/abrasion-) platform through the process of abrasion. A relative change of the sea level leads to regressions or transgressions and eventually forms another terrace (marine-cut terrace) at a different altitude while notches in the cliff face indicate short stillstands[18] . It is believed that the terrace gradient increases with tidal range and decreases with rock resistance. In addition the relationship between terrace width and the strength of the rock is inverse and higher rates of uplift and subsidence as well as a higher slope of the hinterland increases the number of terraces formed during a certain time[19] .

Furthermore shore platforms are formed by denudation and marine-built terraces arise from accumulations of materials removed by shore erosion[2] . Thus a marine terrace can be formed by both erosion and accumulation. However, there is an ongoing debate about the roles of wave erosion and weathering in the formation of shore platforms[8] .

Reef flats or uplifted coral reefs are another kind of marine terrace found in intertropical regions. They are a result of biological activity, shoreline advance and accumulation of reef materials[2] .

While a terrace sequence can date back hundreds of thousands of years, its degradation is a rather fast process. On the one hand a deeper transgression of cliffs into the shoreline may completely destroy previous terraces; on the other hand older terraces might be decayed[18] or covered by deposits, colluvia or alluvial fans[3] . Erosion and backwearing of slopes caused by incisive streams play another important role in this degradation process[18] .

Mapping and surveying

For exact interpretations of the morphology extensive datings, surveying and mapping of marine terraces is applied. This includes stereoscopic aerial photographic interpretation (ca. 1 : 10,000 - 25,000[9]), on-site inspections with topographic maps (ca. 1 : 10,000) and analysis of eroded and accumulated material. Moreover the exact altitude can be determined with an aneroid barometer or preferably with a levelling instrument mounted on a tripod. It should be measured with the accuracy of 1 cm and at about every 50 - 100 m, depending on the topography. In remote areas technics of photogrammetry and tacheometry can be applied[17] .

Aerial photograph of lowest marine terrace at Tongue Point, New Zealand

Correlation and dating

Different methods for dating and correlation of marine terraces can be used and combined.

Correlational dating

The morphostratigraphic approach focuses especially in regions of marine regression on the altitude as the most important criterion to distinguish coast lines of different ages. Moreover individual marine terraces can be correlated based on their size and continuity. Also paleo-soils as well as glacial, fluvial, eolian and periglacial landforms and sediments may be used to find correlations between terraces[17] . On New Zealand's North Island, for instance, tephra and loess were used to date and correlate marine terraces[20] . At the terminus advance of former glaciers marine terraces can be correlated by their size, as their width decreases with age due to the slowly thawing glaciers along the coast line[17] .

The lithostratigraphic approach uses typical sequences of sediment and rock strata to prove sea level fluctuations on the basis of an alternation of terrestrial and marine sediments or littoral and shallow marine sediments. Those strata show typical layers of transgressive and regressive patterns[17] . However, an unconformity in the sediment sequence might make this analysis difficult[21] .

The biostratigraphic approach uses remains of organisms which can indicate the age of a marine terrace. For that often mollusc shells, foraminifera or pollen are used. Especially Mollusca can show specific properties depending on their depth of sedimentation. Thus they can be used to estimate former water depths[17] .

Marine terraces are often correlated to Marine Oxygene Isotopic Stages (MIS) (e.g. Johnson, M. E.; Libbey, L. K. 1997[15]) and can also be roughly dated using their stratigraphic position[17] .

Direct dating

There are various methods for the direct dating of marine terraces and their related materials including ^{14}C radiocarbon dating, which is the most common one[22] . E.g. this method has been used on the North Island of New Zealand to date several marine terraces[23] . It utilizes terrestrial biogenic materials in coastal sediments such as mollusc shells analyzing the ^{14}C isotope[17] . In some cases dating based on the $^{230}Th/^{234}U$ ratio was applied though in case of detrital contamination or low Uranium concentrations a high resolution dating was found to be difficult[24] . In a study in southern Italy paleomagnetism was used to carry out paleomagnetic datings[25] and luminescence dating (OSL) was used in different studies on the San Andreas Fault[26] and on the Quaternary Eupcheon Fault in South Korea[27] .

In order to calculate the eustatic sea level for each dated terrace it is assumed that the eustatic sea-level position corresponding to at least one marine terrace is known and that the uplift rate has remained essentially constant in each section[2] .

Relevance for other research areas

Marine terraces play an important role in the research on tectonics and earthquakes. They may show patterns and rates of tectonic uplift[26] and thus may be used to estimate the tectonic activity in a certain region[27] . In some cases the exposed secondary landforms can be correlated with known seismic events such as the 1855 Wairarapa earthquake on the Wairarapa Fault near Wellington/New Zealand which produced a 2.7 m uplift[28] . This figure can be estimated from the vertical offset between raised shorelines in the area[29] .

Furthermore with the knowledge of eustatic sea level fluctuations the speed of isostatic uplift can be estimated[30] and eventually the change of relative sea levels for certain regions can be reconstructed. Thus marine terraces also provide information for the research on climate change and trends in future sea level changes[31] [8] .

When analyzing the morphology of marine terraces it must be considered, that both eustasy and isostasy can have an influence on the formation process. This way can be assessed, whether there were changes in sea level or whether tectonic activities took place.

Prominent examples

Marine terraces can be found on many geodynamically influenced coastlines around the world.

Important sites include various coasts of New Zealand, e.g. Turakirae Head south of Wellington being one of the world's best and most thoroughly studied examples[28] [29] [32] . Also along the Cook Strait in New Zealand there is a well-defined sequence of uplifted marine terraces from the late Quaternary at Tongue Point. It features a well preserved lower terrace from the last interglacial, a widely eroded higher terrace from the penultimate interglacial and another still higher terrace, which is nearly completely decayed[28] . Furthermore on New Zealand's North Island at the eastern Bay of Plenty a sequence of seven marine terraces has been studied[23] [10] .

Quaternary marine terraces at Tongue Point, New Zealand

Air photograph of the marine terraced coastline north of Santa Cruz, California, note Highway 1 running along the coast along the lower terraces

Along many coasts of mainland and islands around the Pacific, marine terraces are typical coastal features. An especially prominent marine terraced coastline can be found north of Santa Cruz, near Davenport, California, where terraces probably have been raised by repeated slip earthquakes on the San Andreas Fault[26] [33] . But also along the coasts of South America marine terraces are present, where the highest ones are situated where plate margins lie above subducted oceanic ridges and the highest and most rapid rates of uplift occur[5] . At Cape Laundi, Sumba Island, Indonesia an ancient patch reef can be found at 475 m above sea level as part of a sequence of coral reef terraces with 11 terraces being wider than 100m[34] . The coral marine terraces at Huon Peninsula, New Guinea, which extend over 80 km and rise over 600 m above present sea level[35] are currently on UNESCO's tentative list for world heritage sites under the name *Houn Terraces - Stairway to the Past*[36] .

Other considerable examples include marine terraces rising up to 360 m on some Philippine Islands[37] and along the Mediterranean Coast of North Africa, especially in Tunisia, rising up to 400 m[38] .

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Mass wasting

Mass wasting, also known as **slope movement** or **mass movement**, is the geomorphic process by which soil, regolith, and rock move downslope under the force of gravity. Types of mass wasting include creep, slides, flows, topples, and falls, each with its own characteristic features, and taking place over timescales from seconds to years. Mass wasting occurs on both terrestrial and submarine slopes, and has been observed on Earth, Mars, Venus, and Jupiter's moon Io.

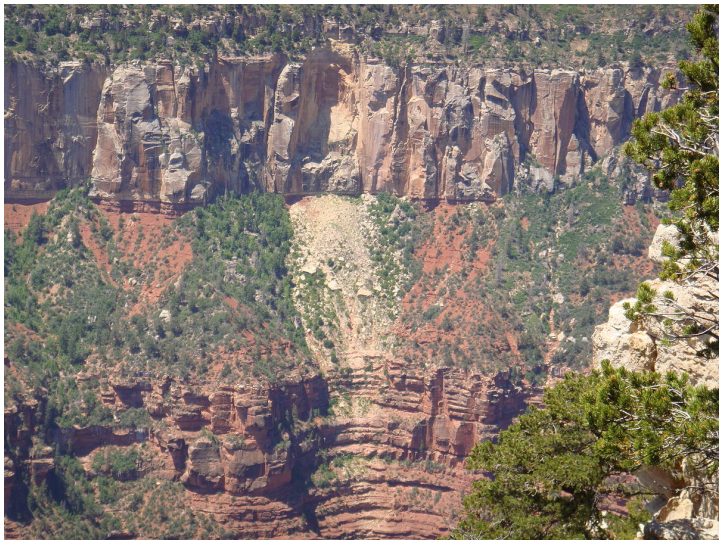
When the gravitational force acting on a slope exceeds its resisting force, slope failure (mass wasting) occurs. The slope material's strength and cohesion and the amount of internal friction between material help maintain the slope's stability and are known collectively as the slope's shear strength. The steepest angle that a cohesionless slope can maintain without losing its stability is known as its angle of repose. When a slope possesses this angle, its shear strength perfectly counterbalances the force of gravity acting upon it.

Mass wasting may occur at a very slow rate, particularly in areas that are very dry or those areas that receive sufficient rainfall such that vegetation has stabilized the surface. It may also occur at very high speed, such as in rock slides or landslides, with disastrous consequences, both immediate and delayed, e.g., resulting from the formation of landslide dams.

Factors that change the potential of mass wasting include: change in slope angle; weakening of material by weathering; increased water content; changes in vegetation cover; and overloading.

Example of mass wasting at Palo Duro Canyon (2002)

Talus cones produced by mass wasting, north shore of Isfjord, Svalbard, Norway.



A rockfall in Grand Canyon National Park

The importance of water in mass wasting

Water can increase or decrease the stability of a slope depending on the amount present. Small amounts of water can strengthen soils because the surface tension of water gives the soil a lot of cohesion. This allows the soil to resist erosion better than if it were dry. If too much water is present the water may act as a lubricant, accelerating the erosion process and resulting in different types of mass wasting (i.e. mudflows, landslides, etc.). A good example of this is to think of a sand castle. Water must be mixed with sand in order for the castle to keep its shape. If too much water is added the sand washes away, if not enough water is added the sand falls and can not keep its shape.

Types of mass movement

Types of mass movement are distinguished based on how the soil, regolith or rock moves downslope as a whole.

Creeps

Downhill creep is a long term process. The combination of small movements of soil or rock in different directions over time are directed by gravity gradually downslope. The steeper the slope, the faster the creep. The creep makes trees and shrubs curve to maintain their perpendicularity, and they can trigger landslides if they lose their root footing. The surface soil can migrate under the influence of cycles of freezing and thawing, or hot and cold temperatures, inching its way towards the bottom of the slope forming terracettes. This happens at a rate that is not noticeable to the naked eye.

Landslides

Where the mass movement has a well-defined zone or plane of sliding, it is called a landslide. This includes rock slides, slumps and sturzstroms.

It is also one of the common classification of mass wasting.

Flows

Movement of soil and regolith that more resembles fluid behavior is called a flow. These include avalanches, mudflows, debris flows, earth flow, lahars and sturzstroms. Water, air and ice are often involved in enabling fluidlike motion of the material.

Topples

Topples are instances when blocks of rock pivot and fall away from a slope.

Slump

A slipping of coherent rock material along the curved surface of a decline. Slumps involve a mass of soil or other material sliding along a curved surface (shaped like a spoon). It forms a small, crescent-shaped cliff, or abrupt scarp at the top end of the slope. There can be more than one scarp down the slope.

Falls

A fall, including rockfall, is where regolith cascades down a slope, but is not of sufficient volume or viscosity to behave as a flow. Falls are promoted in rocks which are characterised by presence of vertical cracks. Falls are a result of undercutting of water as well as undercutting of waves. They usually occur at very steep slopes such as a cliff face. The rock material may be loosened by earthquakes, rain, plant-root wedging, expanding ice, among other things. The accumulation of rock material that has fallen resides at the base of the structure and is known as talus.

Triggers of mass wasting

Soil and regolith remain on a hillslope only while the gravitational forces are unable to overcome the frictional forces keeping the material in place (see Slope stability). Factors that reduce the frictional resistance relative to the downslope forces, and thus initiate slope movement, can include:

- seismic shaking
- increased overburden from structures
- increased soil moisture
- reduction of roots holding the soil to bedrock
- undercutting of the slope by excavation or erosion
- weathering by frost heave
- bioturbation

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External links

- Mass Wasting [1]

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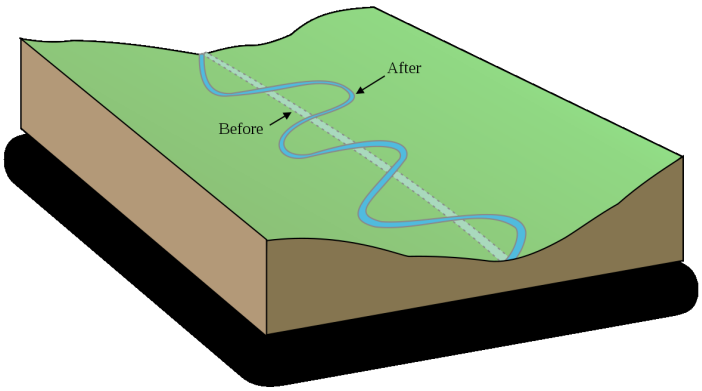
Meander

A **meander** in general is a bend in a sinuous watercourse. A meander is formed when the moving water in a stream erodes the outer banks and widens its valley. A stream of any volume may assume a *meandering* course, alternatively eroding sediments from the outside of a bend and depositing them on the inside. The result is a *snaking* pattern as the stream meanders back and forth across its down-valley axis. When a meander gets cut off from the main stream, an oxbow lake is formed. Over time meanders migrate downstream, sometimes in such a short time as to create civil engineering problems for local municipalities attempting to maintain stable roads and bridges.



A hypothetical stream bed following a tilted valley. The maximum gradient is along the down-valley axis represented by a hypothetical straight channel. Meanders develop, which lengthen the course of the stream, decreasing the gradient.

Meanders of the *Rio Cauto* at Guamo Embarcadero, Cuba.

There is not yet full consistency or standardization of scientific terminology used to describe watercourses. A variety of symbols and schemes exist. Parameters based on mathematical formulae or numerical data vary as well, depending on the database used by the theorist. Unless otherwise defined in a specific scheme "meandering" and "sinuosity" here are synonymous and mean any repetitious pattern of bends, or waveforms. In some schemes, "meandering" applies only to rivers with exaggerated circular loops or secondary meanders; that is, meanders on meanders.

Sinuosity is one of the channel types that a stream may assume over all or part of its course. All streams are sinuous at some time in their geologic history over some part of their length.

White River (Washington)

Origin of term

The term derives from a river, located in present-day Turkey, and known to the ancient Greeks as (*Μαίανδρος*) Maiandros or Maeander, characterised by a very convoluted path along the lower reach. As such, even in Classical Greece the name of the river had become a common noun meaning anything convoluted and winding, such as decorative

patterns or speech and ideas, as well as the geomorphological feature. Strabo said: "... its course is so exceedingly winding that everything winding is called meandering."[1]

The Meander River is located, south of Izmir, east of the ancient Greek town of Miletus, now, Milet, Turkey. It flows through a graben in the Menderes Massif, but has a flood plain much wider than the meander zone in its lower reach. In the Turkish name, the Büyük Menderes River, Menderes is from "Meander". Meanders are also formed as a result of deposition and erosion.

Meander geometry

Meanders of the Potomac River at Little Orleans, Maryland

The technical description of a meandering watercourse is termed meander geometry or meander planform geometry.[2] It is characterized as an irregular waveform. Ideal waveforms, such as a sine wave, are one line thick, but in the case of a stream the width must be taken into consideration. The bankfull width is the distance across the bed at an average cross-section at the full-stream level, typically estimated by the line of lowest vegetation.

As a waveform the meandering stream follows the down-valley axis, a straight line fitted to the curve such that the sum of all the amplitudes measured from it is zero. This axis represents the overall direction of the stream.

At any cross-section the River/stream is following the sinuous axis, the centerline of the bed. Two consecutive crossing points of sinuous and down-valley axes define a meander loop. The meander is two consecutive loops pointing in opposite transverse directions. The distance of one meander along the down-valley axis is the meander length or wavelength. The maximum distance from the down-valley axis to the sinuous axis of a loop is the meander width or amplitude. The course at that point is the apex.

In contrast to sine waves, the loops of a meandering stream are more nearly circular. The curvature varies from a maximum at the apex to zero at a crossing point (straight line), also called an inflection, because the curvature changes direction in that vicinity. The radius of the loop is considered to be the straight line perpendicular to the down-valley axis intersecting the sinuous axis at the apex. As the loop is not ideal, additional information is needed to characterize it. The orientation angle is the angle between sinuous axis and down-valley axis at any point on the sinuous axis.

Concave bank and convex bank, Great Ouse Relief Channel, England.

A loop at the apex has an outer or convex bank and an inner or concave bank. The meander belt is defined by an average meander width measured from outer bank to outer bank instead of from centerline to centerline. If there is a flood plain it extends beyond the meander belt. The meander is then said to be free - it can be found anywhere in the flood plain. If there is no flood plain the meanders are fixed.

Various mathematical formulae relate the variables of the meander geometry. As it turns out some numerical parameters can be established, which appear in the formulae. The waveform depends ultimately on the characteristics of the flow but the parameters are independent of it and apparently are caused by geologic factors. In general the meander length is 10-14 times, with an average 11 times, the fullbank channel width and 3 to 5 times, with an average of 4.7 times, the radius of curvature at the apex. This radius is 2-3 times the channel width.

A meander has a depth pattern as well. The cross-overs are marked by riffles, or shallow beds, while at the apices are pools. In a pool direction of flow is downward, scouring the bed material. The major volume, however, flows more slowly on the inside of the bend where, due to decreased velocity, it deposits sediment.

The line of maximum depth, or channel, is the thalweg or thalweg line. It is typically designated the borderline when rivers are used as political borders. The thalweg hugs the outer banks and returns to center over the riffles. The meander arc length is the distance along the thalweg over one meander. The river length is the length along the centerline.

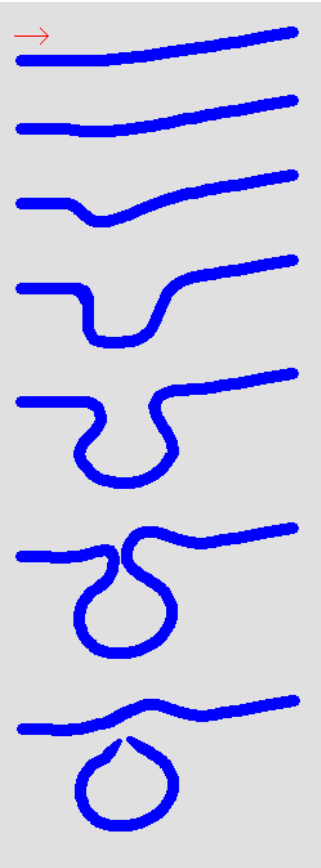
Meander of the River Cuckmere in Southern England

Formation

Meander formation is a result of natural factors and processes. The waveform configuration of a stream is constantly changing. Once a channel begins to follow a sinusoidal path the amplitude and concavity of the loops increase dramatically due to the effect of helical flow sweeping dense eroded material towards the inside of the bend, and leaving the outside of the bend unprotected and therefore vulnerable to accelerated erosion, forming a positive feedback loop. In the words of Elizabeth A. Wood:[3]

> ... this process of making meanders seems to be a self-intensifying process ... in which greater curvature results in more erosion of the bank, which results in greater curvature ...

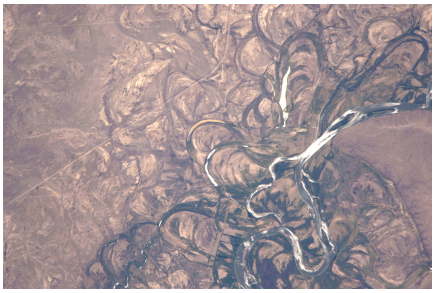
Flow of a fluid around a bend is vortex flow in order to conserve angular momentum. The speed of flow on the inside of the bend is fastest, and on the outside of the bend is slowest.[4] The water surface is also super-elevated towards the outside of the bend, so on the floor of the channel the water pressure is greater on the outside of the bend than on the inside of the bend. This pressure gradient drives a cross-current towards the inside of the bend.[5]



Life history of a meander

In order for a flow to have a curved path there must be a centripetal force inward that is present (this is similar to spinning a bucket on a string, but here we do not have solid body rotation ie. a spinning record). The force presents itself as a pressure gradient outwards (larger pressure on the outside of the bend then inside) or from a change in elevation at the free surface (larger elevation on the outside of the bend). At the free surface of the river the pressure must be constant, equal to atmospheric pressure, so the elevation must change to maintain the curved flow. In the middle (in the vertical) of the river a pressure gradient is present to maintain the curved flow. At the floor of the river, the no slip condition requires no velocity. This sets up a

situation that has lower velocity at the floor which is not enough to overcome the pressure gradient and a secondary cross flow develops (into the bend at the floor). The secondary flow into the bend at the floor due to the pressure gradient must eventually go up due to conservation of mass and the flow is outward above the floor. This entire situation is very similar to the Tea leaf paradox. This secondary flow caries sediment from the outside of the bend to the inside making the river more meandering.[6] [7]



Spectacular meander scars, oxbow lakes and abandoned meanders in the broad flood plain of the Rio Negro, Argentina. 2010 astronaut photo from ISS.

It is a misconception that the flow at the outside is faster then the inside (which would be true for solid body rotation which we don't have here), it is actually the opposite. We consider the flow to be irrotational for the most part here, which requires the flow outside to be slower than the flow inside (otherwise the flow would not be irrotational [8]).

The cross-current along the floor of the channel is part of the secondary flow and sweeps dense eroded material towards the inside of the bend. The cross-current then rises to the surface near the inside of the bend and, moving near the surface, flows towards the outside of the bend, forming a helical flow. The greater the curvature of the bend, and the faster the flow, the stronger is the cross-current and the stronger the sweeping of dense eroded material along the floor of the channel towards the inside bank.[9] [10]

The question of formation is why streams of any size become sinuous in the first place. There are a number theories, not necessarily mutually exclusive.

Stochastic theory

The stochastic theory can take many forms but one of the most general statements is that of Scheidegger:[11]

> The meander train is assumed to be the result of the stochastic fluctuations of the direction of flow due to the random presence of direction-changing obstacles in the river path.

Given a flat smooth, tilted artificial surface, rainfall runs off it in sheets, but even in that case adhesion of water to the surface and cohesion of drops produce rivulets at random. Natural surfaces are rough and erodible to different degrees. The result of all the physical factors acting at random is channels that are not straight, which then progressively become sinuous. Even channels that appear to be straight have a sinuous thalweg that leads eventually to a sinuous channel.

Equilibrium theory

In the equilibrium theory, meanders decrease the stream gradient until an equilibrium between the erodibility of the terrain and the transport capacity of the stream is reached.[12] A mass of water descending must give up potential energy, which, given the same velocity at the end of the drop as at the beginning, is removed by interaction with the material of the stream bed. The shortest distance; that is, a straight channel, results in the highest energy per unit of length, disrupting the banks more, creating more sediment and aggrading the stream. The presence of meanders allows the stream to adjust the length to an equilibrium energy per unit length in which the stream carries away all the sediment that it produces.

Geomorphic/Morphotectonic theory

Geomorphic refers to the surface structure of the terrain. Morphotectonic means having to do with the deeper, or tectonic (plate) structure of the rock. The features included under these categories are not random and guide streams into non-random paths. They are predictable obstacles that instigate meander formation by deflecting the stream. For example, the stream might be guided into a fault line (morphotectonic)..

Associated landforms

Erosion Mechanics

The depositional slip off slope is on the left whilst there is a small river cliff to the right. River Ashes Hollow, UK.

Most meanders occur in the region of a river channel with shallow gradients, a well-developed floodplain, and cohesive floodplain material. Deposition of sediment occurs on the inner edge, because the secondary flow of the river[13] sweeps and rolls sand, rocks and other submerged objects across the bed of the river towards the inside radius of the river bend, creating a slip-off slope called a point bar. Erosion is greater on the outside of the bend where the soil is not protected by deposits of sand and rocks. The current on the outside bend is more effective in eroding the unprotected soil, and the inside bend receives steadily increasing deposits of sand and rocks, and the meander tends to grow in the direction of the outside bend, forming a small cliff called a cut bank. This can be seen in areas where willows grow on the banks of rivers; on the inside of meanders, willows are often far from the bank, whilst on the outside of the bend, the roots of the willows are often exposed and undercut, eventually leading the trees to fall into the river. This demonstrates the river's movement. Slumping usually occurs on the concave sides of the banks resulting in mass movements such as slides.

Deposits

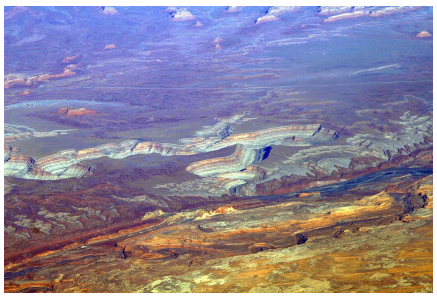
Incised meanders

Glen Canyon, USA

If the slope of an established meandering stream is suddenly increased it will resume downward erosion – this happens when the base level of the stream is reduced, for example due to tectonic uplift of the region, a global fall in sea-level, collapse of a moraine-dammed lake downstream, or by capture of the stream by a steeper one. As the stream erodes downwards, its established meandering pattern will remain as a deep valley known as an *incised meander* or *entrenched meander*. Rivers in the Colorado Plateau and streams in the Ozark Plateau are noted for these incised meanders.

Oxbow lakes

Oxbow lakes are created when growing meanders intersect each other and cut off a meander loop, leaving it without an active cutting stream. Over a period of time, these oxbow lakes tend to dry out or fill in with sediments.



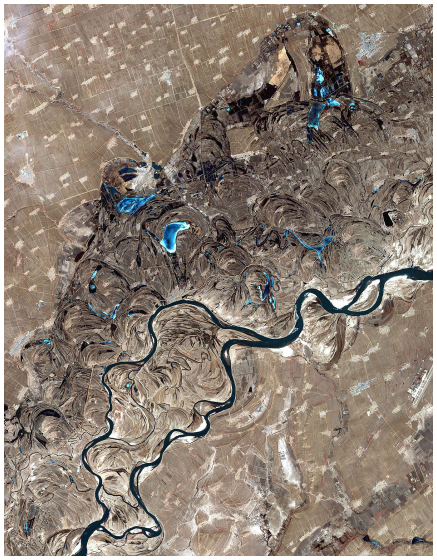
Goosenecks of the San Juan River, SE Utah. Note cut-off meander at right center.

Abandoned meander

Sometimes an incised meander is cut off, similar to an oxbow lake. The resulting landform is known as an **abandoned meander**. In the southwest United States it is also known as a **rincon**. One dramatic example, on Lake Powell, is called "The Rincon."

Scroll-bars

Scroll-bars are a result of continuous lateral migration of a meander loop that creates an asymmetrical ridge and swale topography[14] on the inside of the bends. The topography is generally parallel to the meander and is related to migrating bar forms and back bar chutes[15] which carve sediment out from the outside of the curve and deposit sediment in the slower flowing water on the inside of the loop, in a process called lateral accretion. Scroll-bar sediments are characterized by cross-bedding and a pattern of fining upward.[16] These characteristics are a result of the dynamic river system, where larger grains are transported during high energy flood events and then gradually die down, depositing smaller material with time (Batty 2006). Deposits for meandering rivers are generally homogeneous and laterally extensive unlike the more heterogeneous braided river deposits.[17] There are two distinct patterns of scroll-bar depositions; the eddy accretion scroll bar pattern and the point-bar scroll pattern. When looking down the river valley they can be distinguished because the point-bar scroll patterns are convex and the eddy accretion scroll bar patterns are concave.[18] Scroll bars often look lighter at the tops of the ridges and darker in the swales. This is because the tops can be shaped by wind, either adding fine grains or by keeping the area unvegetated, while the darkness in the swales can be attributed to silts and clays washing in during high water periods. This added sediment in addition to water that catches in the swales is in turn is a favorable environment for vegetation that will also accumulate in the swales.



Meanders, scroll-bars and oxbow lakes in the Songhua River

Derived quantities

The meander ratio[19] or sinuosity index[20] is a means of quantifying how much a river or stream meanders (how much its course deviates from the shortest possible path). It is calculated as the length of the stream divided by the length of the valley. A perfectly straight river would have a meander ratio of 1 (it would be the same length as its valley), while the higher this ratio is above 1, the more the river meanders.

Sinuosity indices are calculated from the map or from an aerial photograph measured over a distance called the reach, which should be at least 20 times the average fullbank channel width. The length of the stream is measured by channel, or thalweg, length over the reach, while the bottom value of the ratio is the downvalley length or air distance of the stream between two points on it defining the reach.

The sinuosity index plays a part in mathematical descriptions of streams. The index may need to be elaborated because the valley may meander as well; i.e., the downvalley length is not identical to the reach. In that case the valley index is the meander ratio of the valley while the channel index is the meander ratio of the channel. The channel sinuosity index is the channel length divided by the valley length and the standard sinuosity index is the channel index divided by the valley index. Distinctions may become even more subtle.[21]

Sinuosity Index has a non-mathematical utility as well. Streams can be placed in categories arranged by it; for example, when the index is between 1 to 1.5 the river is sinuous, but if between 1.5 and 4, then meandering. The index is a measure also of stream velocity and sediment load, those quantities being maximized at an index of 1 (straight).

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Meander cutoff

A **meander cutoff** occurs when a meander bend in a river is breached by a chute channel that connects the two closest parts of the bend. This causes the flow to abandon the meander and to continue straight downslope. Cutoffs are a natural part of the evolution of a meandering river, and have also been used to artificially shorten the length of meandering rivers for navigation.

Mineral spring

For various place names, see Mineral Springs (disambiguation)

Mineral springs are naturally occurring springs that produce water containing minerals, or other dissolved substances, that alter its taste or give it a purported therapeutic value. Salts, sulfur compounds, and gases are among the substances that can be dissolved in the spring water during its passage underground.

The Mineral Spring, etching by Wenceslas Hollar (1607-1677). The unidentified central European spring features a sunken stone basin and ornamental retaining wall.

Mineral water obtained from mineral springs has long been an important commercial proposition.

Mineral spas are resorts that have developed around mineral springs, where (often wealthy) patrons would repair to “take the waters” — meaning that they would drink (see hydrotherapy and water cure) or bathe in (see balneotherapy) the mineral water.

Historical mineral springs were often outfitted with elaborate stone-works — including artificial pools, retaining walls, colonnades and roofs — sometimes in the form of fanciful "Greek temples", gazebos or pagodas. Others were entirely enclosed within spring houses.

Types

A chalybeate (iron-laden) mineral spring at Breznik, Bulgaria.

For many centuries, in Europe, North America and elsewhere, commercial proponents of mineral springs classified them according to the chemical composition of the water produced and according to the medicinal benefits supposedly accruing from each:

- Lithia springs contained lithium salts, Lithia Springs, Georgia
- Chalybeate springs contained salts of iron.
- Alum springs contained alum.
- Sulfur springs contained hydrogen sulfide gas.
- Salt (saline) springs contained salts of calcium, magnesium or sodium.
- Alkaline springs contained an alkali.
- Calcic springs contained lime (calcium hydroxide).
- Thermal (hot) springs could contain a high concentration of various minerals.
- Soda springs contained carbon dioxide gas (soda water).
- Sweet springs were springs with no detectable sulfur or salt content (arguably not 'mineral' springs at all).
- Radioactive springs contain traces of radioactive substances such as radium or uranium.

Deposits

Stepped travertine terrace formations were created over thousands of years as flowing water from Badab-e Surt mineral springs cooled and deposited carbonate minerals

Types of sedimentary rock -- usually limestone (calcium carbonate) -- are sometimes formed by the evaporation, or rapid precipitation, of mineral spring water, especially at the mouths of hot mineral springs. (These mineral deposits can also be found in dried lakebeds.) Spectacular formations, including terraces, stalactites, stalagmites and “frozen waterfalls” can result (see, for example, Mammoth Hot Springs). One light-colored porous calcite of this type is known as travertine and has been used extensively in Italy and elsewhere as building material. Travertine can have a white, tan, or cream-colored appearance and often has a fibrous or concentric “grain”. Another type of spring water deposit, containing siliceous as well as calcareous minerals, is known as tufa. Tufa is similar to travertine but is even softer and more porous.

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Mittelgebirge

A **Mittelgebirge** (singular, the term is German) is a relatively low mountain range, a typical geographical feature of Central Europe, especially Central and Southern Germany; it refers to something between hill country (German: *Hügelland*) and a proper mountain range (German: *Gebirge* or *Hochgebirge*). The term is not precise, but typically refers to topography where the peaks rise at least 200 metres (660 ft) to 500 metres (1600 ft) *above the surrounding terrain* (as opposed to above sea level). In contrast, *Hochgebirge* (e.g. the High Alps) is used to refer to mountain ranges rising above approximately 1500 metres (4900 ft).

Well-known examples are e.g. in Germany the Black Forest, the Swabian Alb and its eastern continuation, the Franconian Jura, in Hungary the Mátra, in France the Vosges and the Massif Central, in Belgium and Luxembourg the Ardennes, in Britain the pikes of the Lake District, the Pennines, the Scottish Highlands and the Snowdon Massif, in Ireland the Macgillycuddy's Reeks, in the United States some ranges of the Appalachians, such as the Green Mountains (Vermont).

In the plural, *die Mittelgebirge* usually refers to the Central Uplands of Germany which is a belt of low mountain ranges or hills between the Northern Lowland and the Alpine Foreland.[1]

References

[1] Dickinson, Robert E (1964). *Germany: A regional and economic geography* (2nd ed.). London: Methuen, p. 18 ff. ASIN: B000IOFSEQ.

Modern recession of beaches

Important segments of low coasts are receding, losing sand and reducing the beaches' dimensions. This loss could occur very rapidly. From more to less natural causes (degree of anthropization downwards):

Locations

France

Atlantic coast

Some of the blockhauss of the Atlantic Wall, built by the German soldiers during the Second World War at the top of the dunes are now underwater 2/3 of the times. It shows 200 meters of recession of the beach in 65 years.

Blockhauss of Capbreton, south-west of France

Sète

The coast recession near Sète is related with coastal drift sand supply interruption due to growth of the Rhone delta, which (like most deltas) is becoming independent of the rest of the coast. The present lido shoreline is 210 meters away from the Roman lido.

California beaches

California's beaches and other shoreline features change according to the availability of beach sand, the wave and current energy impinging on the coast, and other physical processes that affect the movement of sand. A constant supply of sand is necessary for beaches to form and be maintained along this shoreline. Many human activities, including dam construction and river channelization, have reduced the supply of sand that reaches the ocean. This, in turn, has prevented beaches from being replenished and has thus created greater vulnerability for shorelines that have always been subject to varying levels of erosion. There are few practical solutions to improving sand supply from inland sources, so management of shoreline erosion will likely continue to focus at the land/sea interface along the California coastline.

Construction of breakwaters, jetties, or groyne fields to protect harbor entrances, maintain beaches, or protect coastal structures have both helped and harmed the movement of sand along the shoreline. Protective armoring formations trap sand and allow beaches to expand up-coast from the device, but can interrupt the flow of sand to beaches located down-coast.

Southern California beach 10/97 (before winter El Nino storms)

Same location 4/98 (after winter El Nino storms)

Poland

During the last glaciation, the Baltic Polish area was covered in ice and associated morainal sediments. Deglaciation left a substantial amount of unconsolidated sediment. Currently, these unconsolidated sediments are strongly eroded and reworked by the sea.

Aveiro

The North Portuguese coast and its beaches were fed by large Iberian rivers. The massive building of dams in the Douro River basin has cut the sediment supply to the Aveiro coast, resulting in its recession. Hard protective works have been done all along.

The Netherlands

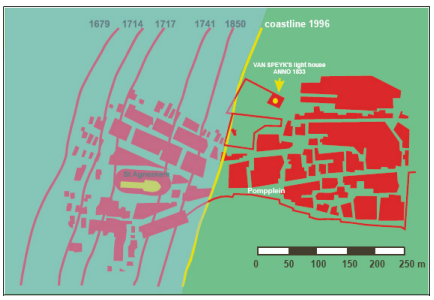
Holland coast

The Dutch coast consists of sandy, multi-barred beaches and can be characterised as a wave-dominated coast. Approximately 290 km of the coast consists of dunes and 60 km is protected by structures such as dikes and dams. With the melting of the ice at the end of the last ice age the coastline shifted eastward until about 5000 years ago the present position of the Dutch coastline was reached.

As the sea level rise stagnated, the sand supply decreased and the formation of the beach ridges stopped, after which when the sea broke through the lines of dunes during storms, men started to defend the land by building primitive dikes and walls. The dunes, together with the beach and the shoreline, offer a natural, sandy defence to the sea. About 30% of the Netherlands lies below sea level.

Over the last 30 years, approximately 1 million m³ sand per year has been lost from the Dutch coast to deep water. In most northern coastal sections, erosion occurs in deep water and also in the nearshore zone. In most southern sections, sedimentation occurs in the nearshore zone and erosion in deep water.

Structural erosion is due to sea level rise relative to the land and, in some spots, it is caused by harbour dams. The Dutch coast looked at as a single unit shows erosive behaviour. Approximately 12 million m3 of sand is transferred annually from the North Sea to the Wadden Sea as a result of relative rising sea level and coastal erosion.



Holland coast recession

Mogote

Mogotes are geomorphologic structures encountered in the Caribbean, especially in Cuba. They appear as hills of limestone which generally occur in regions of tropical or subtropical rainfall.[1]

Mogotes are characterized by their rounded, tower-like structure. The heights of these towers are generally less than 25 m (82 ft); diameters range from 10 to 200 m (33 to 660 ft). The structure forms are elongated with a pronounced, long vertical axis orientation. They have a classification of tropical cone and tower karsts.[2] Mogotes are remnants of eroded limestone sedimentary layers. These layers are originally formed in shallow waters, then folded and faulted during orogenic cycles. Tectonic upraising exposes the limestone layers to the surface where they can be eroded by rainfall, wind, and wave energy.

Dome-like rounded mogotes in Viñales Valley, Cuba.

Two mogotes showing they typical rounded shape growing up in the valley.

View of Viñales Valley in Pinar del Rio Province, Cuba.

Eastern view of the mogotes in Viñales.

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[1] Fairbridge, Rhodes W. (1968). "Mogote". *The Encyclopedia of Geomorphology*. United States of America: Reinhold Book Corporation. p. 708. ISBN 978-0879331795.

[2] Easterbrook, Don J. (1999). *Surface Processes and Landforms* (2nd ed.). Upper Saddle River, New Jersey: Prentice Hall. p. 210. ISBN 0-13-860958-6.

- Day, M. J. (March 1978). "Morphology and distribution of residual limestone hills (mogotes) in the karst of northern Puerto Rico" (http://bulletin.geoscienceworld.org/cgi/content/abstract/89/3/426). *Geological Society of America Bulletin* **89** (3): 426–32.

Monolith

A **monolith** is a geological feature such as a mountain, consisting of a single massive stone or rock, or a single piece of rock placed as, or within, a monument. Erosion usually exposes the geological formations, which are most often made of very hard and solid metamorphic or igneous rock.

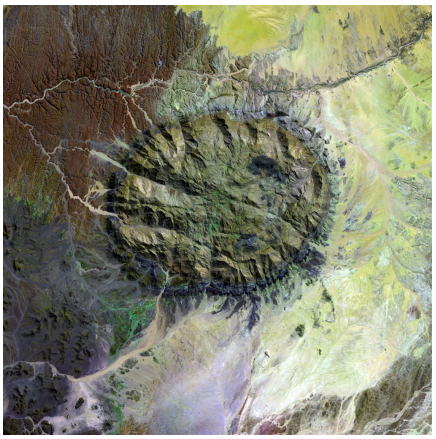
The word derives from the Latin word *monolithus* from the Greek word μονόλιθος (*monolithos*), derived from μόνος ("one" or "single") and λίθος ("stone").

Geological monoliths

Large, well-known monoliths include:

Africa

- Ben Amera, Mauritania
- Brandberg Mountain, Namibia
- Aso Rock, Nigeria
- Zuma Rock, Nigeria
- Oruku, near Ososo



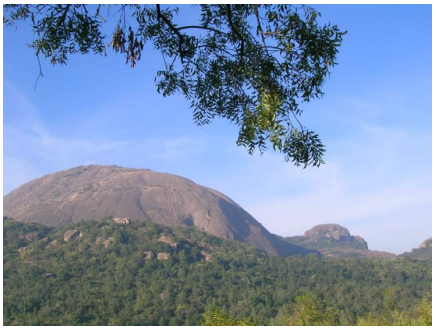
Landsat 7 image Brandberg Massif, Namibia

Antarctica

- Scullin monolith

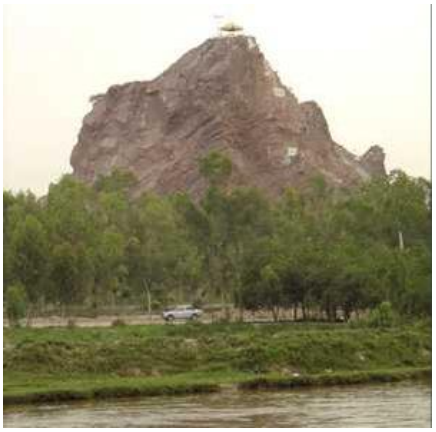
Asia

- Savandurga, India
- Bellary, India
- Madhugiri Betta, India



Savandurga, India from the northern side

- Sangla Hill, Pakistan
- Eagle Mount, Iran



Sangla Hill, Pakistan

Australia

- Uluru (Ayers Rock), Northern Territory, Australia
- Pine Mountain, Victoria, Australia
- Bald Rock, near Tenterfield, New South Wales
- Mount Coolum, Queensland
- Mount Wudinna, near Wudinna, South Australia
- Kokerbin Rock, Western Australia
- Mount Chudalup, D'Entrecasteaux National Park, near Northcliffe, Western Australia

Eagle Mount, Taft, Iran

Europe

- Kalamos, Anafi, Greece
- Frau Holle Stone, near Fulda, Germany
- Humber Stone, Humberstone, near Leicester, England
- King Arthur's Stone, Cornwall, England
- Logan Rock, Trereen, Cornwall, England
- Odin Stone (Stenhouse, Orkney; destroyed in 1814)
- Peñon de Ifach Calpe, Spain
- Rock of Gibraltar, Gibraltar

Rock of Gibraltar

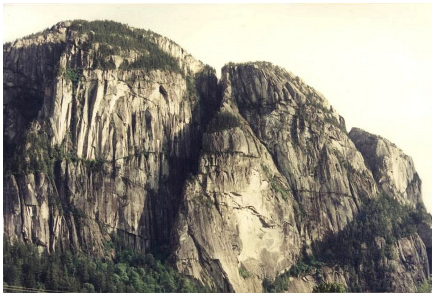
North America

United States

Beacon Rock, Washington viewed from the west

- Beacon Rock, Columbia River Gorge, Washington
- Bottleneck Peak and Moon, Sids Mountain, Utah
- Chimney Rock, Bayard, Nebraska
- Courthouse and Jail Rocks, Bridgeport, Nebraska
- Devils Tower National Monument, Wyoming
- El Capitan, Yosemite National Park, California
- Enchanted Rock, Llano County, Texas
- Half Dome, Yosemite National Park, California
- Haystack Rock, Clatsop County, Oregon
- Looking Glass Rock, Transylvania County, North Carolina
- Scotts Bluff National Monument, Gering, Nebraska
- Stone Mountain, Stone Mountain, Georgia
- Castle Rock, Pineville, West Virginia

Canada



Stawamus Chief as seen from Valleycliffe neighborhood in Squamish

- Stawamus Chief, Squamish, British Columbia
- Satsalla Peak, British Columbia

Mexico

- La Peña de Bernal, Mexico. Claims to be the world's third largest monolith.[1] [2] [3] [4]

South America

- Pedra da Gávea, Brazil the world's largest monolith on the coastline
- Pão de Açúcar, Brazil
- Torres del Paine, Chile
- El Penol, Colombia

Monumental monoliths

A structure which has been excavated as a unit from a surrounding matrix or outcropping of rock.[5]

Gomateswara 983 CE, a Jain god, world's largest standing monolith image

- Stone of the Pregnant Woman, Baalbek
- Aztec calendar stone "Stone of the Sun"
- Great Sphinx of Giza "The Egyptian Sphinx"
- Stonehenge contains several
- Ellora Caves - UNESCO World Heritage Site
- Gomateswara or Lord Bahubali at Sravanabelagola, Karnataka
- Runestones
- Stone circle
- Standing stones
- Stelae

- Obelisks - see this article for a list
- Ogham Stone, Dingle Peninsula, Ireland
- Adam and Eve Stones, Avebury, Wiltshire, England
- Manzanar National Historic Landmark, USA
- Vijayanagara Empire#Architecture medieval South Indian carved examples
- The Church of Saint George is a famous monolithic church in Lalibela, Ethiopia

Ellora Caves, temple in India

Notes

[1] López Domínguez, Leonor (May 2001). "Villa de Bernal and its Magic Mountain" (http://www.mexicodesconocido.com.mx/contenidos/home.html?p=nota&idNota=8897). México Desconocido #291. .

[2] "Peña de Bernal - Bernal - Queretaro" (http://www.de-paseo.com/Bernal/Bernal.htm) (in spanish). . Retrieved 25 November 2008.

[3] Cava Northrop, Laura; Dwight L. Curtis, Inc. Let'S Go, Natalie Sherman, Raul Carrillo (2007). *Let's Go Mexico: On a Budget*. Macmillan. p. 370. ISBN 9780312374525.

[4] Escobar Ledesma, Agustín (1999). *Recetario del semidesierto de Querétaro: Acoyos, rejalgares y tantarrias*. Conaculta. p. 75. ISBN 9789701839102.

[5] "Glossary" (http://www.art-and-archaeology.com/india/glossary1.html#monolith). .

External links

- Regarding Uluru/Ayers Rock and earlier representations of it as the largest monolith
- GA.gov.au (http://www.ga.gov.au/education/facts/landforms/uluru.htm)
- ABC.net.au (http://www.abc.net.au/science/k2/moments/s1469595.htm)
- Wayoutback.com.au (http://www.wayoutback.com.au/uluru-geology.php)

Mouth bar

A **mouth bar** is a bar in a river that is typically created in the middle of a channel in a river delta.[1] It is created by a positive feedback between mid-channel deposition and flow divergence. As the flow diverges near the ocean, sediment settles out in the channel and creates an incipient mouth bar. As flow is routed around the incipient bar, additional sediment is deposited on the incipient bar. This continued process results in the formation of a full-fledged mouth bar, which causes the channel to bifurcate. This continued process leads to the characteristic fractal tree pattern found in some prograding river-dominated deltas.

References

[1] Edmonds, D. A.; Slingerland, R. L. (2007). "Mechanics of river mouth bar formation: Implications for the morphodynamics of delta distributary networks". *Journal of Geophysical Research* **112**: F02034. Bibcode 2007JGRF..11202034E. doi:10.1029/2006JF000574.

Mushroom stones

Mushroom stones, or wave stones, are limestone boulders undercut by water. These take the form of solitary sentinels of limestone which still bear the unmistakable marks of long-continued erosion by lapping waves at the edge of lakes which have since vanished or retreated. These stone sentinels are sometimes shaped like mushrooms; others have an overhang facing in just one direction, but all are notched and undercut in such a fashion as to suggest prolonged exposure to standing water at some time in the past. The mushroom-shaped stones are produced where the notching forms a fairly even circle around the stone. The wavestones in Ireland are always of limestone: generally isolated boulders which are often glacial erratics, or (much more rarely) exposed outcrop. In Ireland, wave stones were first recorded in 1865 by F.J. Foot along the shores of Lough Ree, during the course of field work for the first systematic geological survey of Ireland. He made a drawing of these water-worn limestone blocks ‘eroded up to a certain height by the solvent action of former lake water, showing the level at which Lough Ree once stood – 10 to 15 feet higher than the present summer height: the lake shore, moreover, is now some 300 yards distant.’

The Stone Mushrooms near Beli Plast Village in Bulgaria

Not all mushroom stones are situated close to modern lakes. Many mark the shores of lakes which have vanished altogether, becoming filled in with reedswamp, fen and bog vegetation in the course of time. A remarkable example is located near Crancreagh Bridge in County Offaly, which marks the position of what must have been the

A mushroom stone at Inchiquin Lough, County Clare in Ireland.

north-western edge of ancient Lough Boora, on whose shores the first people of the Irish midlands camped in Mesolithic times 8,500 or so years ago. This ancient lake disappeared long ago, swamped by the growing expanse of bog, which buried not only the lake itself, but preserved the campsites of the early midlanders.

To date, wavestones have been recorded in Counties Offaly, Tipperary, Galway, Clare, Cork, Roscommon and Westmeath.

Limestone accounts for nearly half of the framework of which the land of Ireland is made. Where it breaks through the envelope of soil and other materials which usually cover the rock beneath, it forms some of the most dramatic landscapes in the country. There are very few parts of Ireland where limestone so dominates the landscape as in the baronies of Burren in Clare and Kiltartan in Galway. Here the grey limestone attains a thickness of 780 metres, exposed over an area of more than 250 square kilometres.

The story of the limestone begins about 350 million years ago, at the very end of the Devonian period of earth history, when Ireland was still part of the Old Red Sandstone continent. At around this time the sea - which up to this had lain to the south - began to advance northwards over Ireland, ushering in the Lower Carboniferous period of earth history. A thick sequence of lime-rich (carbonate) sediments was deposited in the warm, shallow sea as the millennia passed. This thick blanket of sediment was later compacted and hardened to become limestone rock.

Where a limestone boulder stands at the edge of a lake so that it is partly covered by water, the underwater part weathers more rapidly then the part above water because it is subject to more constant corrosion by water, accentuated by the abrasive lapping action of waves. If this continues for a long time the upper part will be undercut, and the stone will assume a very distinctive form which is frequently mushroom-like. Much more rarely the same process can be seen in limestone bedrock. Many mushroom stones have a second minor ‘lip’ below the main one, suggesting that the drop in water level which isolated the stones from the lake’s edge took place in two stages.

External links

- http://www.ucd.ie/gpep/gpepinfo/mushroomstones/index.html [1]

References

[1] http://www.ucd.ie/gpep/gpepinfo/mushroomstones/index.html

National Center for Earth-surface Dynamics

National Center for Earth-surface Dynamics (NCED)	
Established	2002
Type	National Science Foundation Science and Technology Center
Director	Efi Foufoula-Georgiou
Location	Minneapolis and Saint Paul, Minnesota
Website	[1]

The **National Center for Earth-surface Dynamics**, or NCED, is an NSF Science and Technology Center- a collaborative partnership among educational, research, and public/private entities that aims to create new knowledge of significant benefit to society. Its mission is to understand the dynamics of the coupled processes that shape the Earth's surface—physical, biological, geochemical, and anthropogenic—and how they will respond to climate, land use, and management change. NCED is headquartered at the University of Minnesota's Saint Anthony Falls Laboratory.[2]

Research

NCED is building interdisciplinary Earth-surface science by integrating elements of geomorphology,ecology, hydrology, sedimentary geology, engineering, economics, and geochemistry. It is creating a predictive Earth-surface science by integrating the advances and approaches of theory, laboratory experiments, numerical modeling,and fieldwork

NCED research is unified by a focus on channel networks and their surroundings. The center's three research initiatives ("Integrated Programs") approach channel networks from a source-to-sink perspective, looking at watersheds (Watersheds), individual stream reaches (Streams), and depositional systems (Deltas).

> In the *Watersheds* Integrated Program, NCED researchers work to develop quantitative expressions for the fundamental geomorphic and biological processes involved in landscape evolution, and combine that knowledge with digital topographic data to predict the locations of landslide hazards, large algal blooms, or other properties of interest. NCED *Watersheds* research seeks to build watershed-scale numerical models of real landscapes to explore problems of long time-scale controls on landscape evolution and short time-scale responses of aquatic ecosystems to land-use change.
>
> NCED *Streams* research works to move the practice of stream restoration beyond analogy and experiential anecdote toward multidisciplinary quantitative prediction. The *Streams* research program involves biologists, civil engineers, ecologists, geochemists, geologists, hydrologists, and economists in a concerted effort to develop practical, predictive models of river systems that can guide stream and watershed restoration practice.
>
> NCED *Deltas* research seeks to understand the processes of delta dynamics to inform the present-day restoration of the Mississippi River Delta. Research in this program uses the subsurface stratigraphy of modern deltas to infer rates, spatial patterns, and mechanisms of natural (pre-human) delta building processes. Simultaneously, researchers at the center perform experiments and field studies to develop predictive models of the processes by which deltas build land and maintain themselves and their associated ecosystems against subsidence and sea-level rise.

Institutions

Institutions that are home to NCED principal investigators who participate directly with NCED include:

- Fond du Lac Tribal and Community College,
- The Johns Hopkins University,
- Science Museum of Minnesota,
- Southern Illinois University Carbondale,
- University of California-Berkeley,
- University of Colorado at Boulder,
- University of Illinois at Urbana-Champaign,
- Louisiana State University,
- University of Texas at Austin,
- St. Anthony Falls Laboratory, and
- University of Minnesota.

References

[1] http://www.nced.umn.edu
[2] "Welcome to NCED!" (http://www.nced.umn.edu/). . Retrieved 2009-08-15.

Ocean Beach Public Policy

Ocean Beach is a beach that runs along the west coast of San Francisco, California, United States, at the Pacific Ocean. It is adjacent to Golden Gate Park, the Richmond District and the Sunset District. The Great Highway runs alongside the beach, and Cliff House and the site of the former Sutro Baths sit at the northern end. The beach is a part of the Golden Gate National Recreation Area, which is administered by the National Park Service.

Over the years, the City of San Francisco and the various public agencies that have jurisdictional control over Ocean Beach have been trying to figure out how to manage this area. Previous efforts and resolutions by the Ocean Beach Task Force (2000) and Ocean Beach Vision Council (2008) did not include a pathway to implementation, and thus a new effort is underway. The new approach that is being taken with the current Ocean Beach Master Plan is to have a non-profit lead the project and incorporate all relevant agencies into the dialogue so they can then incorporate recommendations into their respective agencies.

History/Background

The Ocean Beach Task Force (OBTF) was created in January 2000 by San Francisco's Mayor Willie Brown. The purpose of this task force was to address and preserve the environmental well-being of Ocean Beach as well as identify challenges and solutions for erosion, natural resources, recreation, and aesthetic issues.[1]

The Ocean Beach Vision Council (OBVC) was created in March 2008 by San Francisco's Mayor Gavin Newsom. The purpose of the OBVC was to propose "environmentally sustainable alternatives to improve beach access, enhance underutilized resources, and reconnect Ocean Beach to the city and its international visitors."[2]

The Ocean Beach Master Plan

The current effort to develop a comprehensive plan for this section of San Francisco, California is the **Ocean Beach Master Plan** (OBMP).[3] The OBMP is an interagency effort led by the non-profit, San Francisco Planning and Urban Research Association (SPUR), to develop a long-term vision for Ocean Beach that will address a multitude of issues. Funding for this project is provided by $410,000 in government grants from the California State Coastal Conservancy, the San Francisco Public Utilities Commission, and the National Park Service. The goal of the OBMP is "to knit the unique assets and experiences of Ocean Beach into a seamless and welcoming public landscape, planning for environmental conservation, sustainable infrastructure and long-term stewardship."[4] The OBMP also sets out to define a new approach to coastal resource management that strikes a balance between infrastructure needs, cultural, recreational, and natural-resource values, and one of the most pressing issues for modern day natural resource management: a changing climate.

The OBMP has identified seven major areas of focus to help organize and refine the complexities of such a comprehensive project. These areas include:

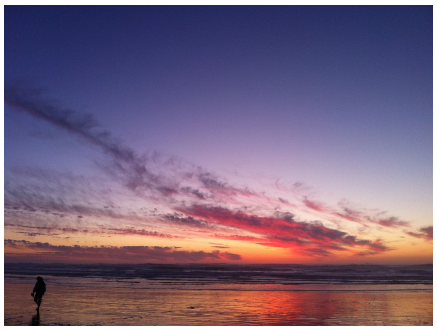
Project Schedule
Startup *(Jun-Aug 2010)*
Problem Definition *(Sep-Dec 2010)*
Alternatives / Scenario Development *(Jan-May 2011)*
Draft Master Plan *(Jun-Sep 2011)*
Final Master Plan *(Oct-Dec 2011)*

1. Image and Character
2. Access and Connectivity
3. Ecology
4. Program and Uses
5. Coastal Dynamics & Climate Change
6. Management & Stewardship
7. Infrastructure

While all are essential to meeting the projects far-reaching goals, SPUR has identified **ecology**, **coastal dynamics and climate change**, and **infrastructure** as the three main areas of focus that will help shape the policies and recommendations for the remaining categories.[4] The final product from this planning process will essentially be a series of project and policy recommendations for the respective agencies that have control over these various focus areas. The Ocean Beach Master Plan will not have the force of regulation on its own. However, once these agencies implement these recommendations and conduct environmental reviews under the California Environmental Quality Act or the National Environmental Policy Act, then the project can take effect.

1) Image & Character

Goal: *preserve and celebrate the beach's raw and open beauty while welcoming a broader public*[4]



Sunset at Ocean Beach, San Francisco, CA

On January 15, 2011, the first Ocean Beach Master Plan public workshop was held at the San Francisco Zoo in an effort to inform the public about the project and to collect feedback from the community and other interested parties. One of themes that permeated the public comments was the desire to keep Ocean Beach 'natural' and maintain its wild quality.[5] Although Ocean Beach is technically within the city limits, many visitors use this urban beach as an escape from the city. The OBMP project team has recognized this observation and aims to address the built and natural environment of Ocean Beach with landscape design that can represent this place's unique image and character.

2) Access and Connectivity

Goal: *provide seamless and fluid connections to adjacent open spaces, the city, and the region*[4]

Ocean beach is not only a popular destination in itself for beach-goers, nature lovers, and sports enthusiasts alike, but acts as an important corridor linking may of the city's open spaces and transit ways for both residents and visitors. The Great Highway, built in the 1920s, and once the widest stretch of pavement for its length in the world, connects Sutro Baths and Lands End at the northern end of Ocean Beach to Golden Gate Park, the San Francisco Zoo and Fort Funston to the south. Narrowed in the 1990s by nearly half, the Great Highway still acts as a major artery connecting California's historic Highway 1 to the Golden Gate Bridge. San Francisco Municipal Railway's (MUNI) transit system provides plentiful public transportation options, including the N-Judah, L-Taraval, and 38-Geary lines, which all end within easy walking distance to the beach. However, pedestrian access ways from public transit to Ocean Beach have been criticized as inadequate and oftentimes confusing. While on a normal usage day plentiful parking can be found along the beach, on hot sunny days when crowds swell parking can often be difficult, highlighting the need for improved public transport options.

A multimodal vision for the future? The City of San Francisco has recently hosted their Sunday Streets program at Ocean Beach several times, closing the Great Highway to cars and offering a full day for bicyclists, pedestrians, and skateboarders to enjoy the open space along the beach car free. The San Francisco Bicycle Coalition has also recently launched a campaign to build a bikeway from SF Bay to Ocean Beach.

3) Ecology

Goal: *restore and establish conditions that support thriving biological communities*[4]

Colony of Bank Swallows

The beach and the dune system at Ocean Beach provide habitat for numerous species; including two birds which are listed as threatened.

The dune system spans about a mile between Great Highway and the beach; starting around the edge of Golden Gate Park and ending around Noriega Street. This ecosystem consists of predominantly non-native vegetation such as ice plant (*Carpobrotus edulis*) and European dune grass (*Ammophila arenaria*). Many participants at the first public workshop suggested restoring the dunes with native

species. Although the OBMP project team will examine this proposal as a possible alternative, they predict that it will most likely be very costly.[4]

Western Snowy Plover

The bank swallow is a state-listed threatened species that inhabits hollows in the bluffs at the south end of Ocean Beach (just south of the Sloat parking lot). The bank swallow colony that lives here inhabits more than one hundred burrows and is the northern most major colony on the California coast.[6] Due to the threat of erosion, this sensitive habitat is at risk of destruction from the ocean or from the proposed coastal armoring aimed at protecting the integrity of the bluffs. In an effort to protect the bank swallows, the San Francisco Department of Public Works (SFDPW) ceases work in this area during their breeding season (April to August).

While the bank swallows occupy the southern end of Ocean Beach, the Western Snowy Plover (*Charadrius alexandrinus nivosus*) inhabit the central part of the beach where the sand is dry. Because Snowy Plovers (plovers) prefer the flat, sandy areas of the beach they are frequently disturbed by human recreational activities. In addition to altering their habitat, these disturbances can contribute to high rates of nest failure and chick mortality. Furthermore, frequent disturbances can disrupt caloric accumulation and result in diminished migration and breeding success.[7] The Western Snowy Plover is a federally listed threatened species so the National Park Service (NPS) has taken measures to protect this species by limiting access to certain parts of the beach where plovers nest.

4) Program & Uses

Goal: *accommodate diverse activities and users, managed for positive coexistence*[4]

Due to Ocean Beach's recreational opportunities, this area is utilized by a wide range of users; from surfers to bird watchers, cyclists to dog walkers. For the most part these various activities are able to share this space without conflict; however, some have inherent competing interests. For example, bird watchers and people concerned with the threatened bird species that inhabit Ocean Beach are at odds with the beach goers who bring dogs to the beach and disturb their habitat. The National Park Service issued a Draft Dog Management Plan in January 2011 to address this concern and the effects that dogs are having in the Golden Gate National Recreation Area, including Ocean Beach. Currently, the NPS does not allow dogs in the Snowy Plover Protection Area (SPPA) located at the northern end of Ocean Beach. The Draft Dog Management Plan's preferred alternative would further limit dog access as follows:[8]

- allows on leash dog walking on the trail along the Great Highway
- regulated off-leash area on the beach north of Stairwell #21
- no dogs on the beach south of Sloat Blvd.
- no dogs in the Snowy Plover Protection Area (SPPA)

Draft Environmental Impact Statement for Dog Management at Ocean Beach - Public Notice, May 2011

5) Coastal Dynamics & Climate Change

> Goal: *identify a proactive approach to coastal management, in the service of desired outcomes*[4]

For the last two hundred and fifty years, humankind's industrial and agricultural activities have been releasing carbon dioxide (CO_2) and other greenhouse gases (GHGs) into the atmosphere at ever increasing rates. Pre-industrial atmospheric CO_2 concentrations of ~280 ppmv (parts per million by volume) have risen steadily to the current rate of ~388 ppmv in 2009, a level that the Earth has not experienced in at least the last 800,000 years.[9] Industrial burning of fossil fuels, as well as cement production, automotive emissions, and deforestation practices are the main contributors to elevated CO_2 emissions, each of these a result of the increasingly global industrialization of our world.[10] As carbon dioxide and other greenhouse gas levels rise, a multitude of changes to important climate properties are expected to occur: significantly increased surface temperatures - both oceanic and atmospheric, variability in storm frequency and strength, sea-ice loss, changes in rainfall patterns and sea level rise, as well as important changes in the carbonate chemistry of the oceans.[10] Climate change may first be apparent along vulnerable, exposed coastlines like that of San Francisco's Ocean Beach, therefore, a comprehensive management plan that attempts to take these many factors into account is essential. The Intergovernmental Panel on Climate Change (IPCC)'s Fourth Assessment Report released in 2007 projected with "very high confidence" that coastal systems will face the following threats due to climate change:

- Coasts will be exposed to increasing risks such as coastal erosion due to climate change and sea-level rise.
- "Increases in sea-surface temperature of about 1-3 °C are projected to result in more frequent coral bleaching events and widespread mortality unless there is thermal adaptation or acclimatization by corals."
- "Many millions more people are projected to be flooded every year due to sea-level rise by the 2080s."[11]

Erosion

Severe erosion at Ocean Beach near the south end of Sloat Blvd. - April 2011

Seasonal and yearly beach and shoreline fluctuation is a naturally occurring process. These natural fluctuations in beach width and shape only become an erosion problem when permanent structures, such as roads, parking lots, and walkways are placed at fixed points near the beach, within this zone of fluctuation. As the shoreline recedes, roads, neighborhoods and other infrastructure will need to be protected or abandoned. The Oceanside Water Pollution Control Plant (OWPCP) and its surrounding roadways situated at the south end of Sloat Blvd. were planned and built in the 1980's to early 1990's, when the Beach at this end was naturally wide. After several years of severe storm events including major storms in both 1997 and again during the el niño winter of 2009-2010, the south end of Ocean Beach near the OWPCP began experiencing severe erosion. In 2010, bluff tops receded as much as 40 feet, undermining parking lots as well as the shoulder of the Great Highway, which ended up being closed southbound for much of the year. Underlying sewer pipes connected to the OWPCP also became threatened by erosion.[12] In 2010 the city's emergency response was the construction of 425 feet of rock revetments (embankments of stone riprap) along this portion of OB. Though temporarily effective, this type of emergency erosion control often draws criticism from environmentalists for causing unnecessary beach and habitat loss.[12]

Sea-Level Rise and Increased Storm Severity

Another likely effect of climate change that may have a significant impact on Ocean Beach is sea-level rise:

- The 2007 Intergovernmental Panel on Climate Change report suggests that global average sea level may rise between 0.6 and 2 feet (7.2 inches - 24 inches) by the end of this century.[11]
- The State of California has predicted that sea-level will rise by 16 inches by 2050 and 55 inches by 2100.[13]
- A study released by the International Arctic Monitoring and Assessment Program (AMAP) in May 2011 predicts that sea level will rise as much as 63 inches by 2100.[14]

Accelerated sea-level rise will likely lead to increased coastal erosion along Ocean Beach. Bluffs and beaches may be exposed to more powerful and more frequent wave action due to both elevated seas and an increase in storm frequency and severity, anther effect of climate change that has been predicted by the IPCC.[11] [15] Protecting the beach, dunes, and any man-made structures from the effects of erosion will require some form of erosion control measure. Currently three options for the management of erosion at Ocean Beach have been utilized or are being considered:[4]

Coastal Armoring

Coastal armoring is a protective measure that seeks to prevent erosion by placing hard structures such as seawalls or revetments (sometimes referred to as riprap) along a receding shoreline. Currently there are approximately linear 10,000 feet of hard structures at Ocean Beach, including three existing seawalls and more recently placed revetments.[4]

Beach Nourishment

Beach nourishment, or the process of replacing lost sediment within the littoral cell, is another option to counteract erosion at Ocean Beach. Beach nourishment is a potentially promising option as the Army Corp of Engineers (ACOE) currently dredge 300,000 cubic yards of sand within the San Francisco Bay annually. In 2006, the ACOE led a demonstration project to determine if beach nourishment is a promising solution to the erosion problem at Ocean Beach.[16] There is currently an effort underway to retrofit the Army Corps' dredge, the Essayons, so that it can pump sand directly onto the beach at Ocean Beach, which would help reestablish a wide beach north of Sloat Blvd. (Need CITE)

Managed Retreat

Managed retreat is the gradual removal of manmade structures that may be exposed to flooding due to an advancing coastline. This strategy is relatively simple and effective when it comes to structures such as roads or parking lots, but for several structures in the vicinity of Ocean Beach, including the publicly-funded Oceanside Wastewater Treatment Plant, managed retreat may be a much more difficult option to pursue. (Need CITE)

6) Management & Stewardship

Goal: *provide an approach to long-term stewardship across agencies, properties and jurisdictions*[4]

Key Stakeholders

The management of Ocean Beach and the surrounding area has been complicated by jurisdictional issues and the oftentimes competing interests of the many stakeholders that play some role in OB governance. This list includes many local, state, and federal regulatory agencies, local businesses, and nearby residents. The creation of the current OBMP attempts to address this regulatory hodgepodge by bringing together the goals and objectives of these various agencies and constituents into one cohesive managerial plan.

Jurisdictional Issues

One of the biggest challenges to creating a comprehensive management plan for Ocean Beach are complicated jurisdictional issues. The following federal, state and local regulatory agencies play some role in owning/managing the beach:

The National Park Service (NPS) is the owner and manager of Ocean Beach, which is completely encompassed within the Golden Gate National Recreation Area (GGNRA). Areas around Ocean Beach are managed by various city agencies, including: the Department of Public Works, which manages the roadways and other surrounding infrastructure, San Francisco Recreation and Park Department (SFRPD), which manages Golden Gate Park and the multi-use pathway bordering Ocean Beach, and the San Francisco Public Utilities Commission (SFPUC), which manages the Oceanside Water Pollution Control Plant and underground sewer lines. The shoreline falls under federal jurisdiction, and so is subject to other regulatory agencies, including the California Coastal Commission and the Army Corp of Engineers.[12]

Community/neighborhood groups

In addition to the regulatory agencies mentioned above, there are numerous community groups, environmental organizations, neighborhood businesses, and local residents that also act as stakeholders, ultimately having some say in any decisions that are made regarding Ocean Beach. Reconciling these various groups' goals, objectives, and oftentimes differing priorities is a complicated yet essential task that has been emphasized throughout the Ocean Beach Master Plan planning process.[4] SPUR has compiled a Public Feedback Summary [17] from their January 15, 2011 Ocean Beach public input meeting; and the following are some of the various community, environmental, and neighborhood groups that have participated in the current OBMP planning process:

- Black Rock Arts Foundation
- Coalition to Save Ocean Beach/Friends of Sutro Heights
- Coastal Sediment Management Workgroup (CSMW)
- Golden Gate National Parks Conservancy
- Golden Gate Audubon Society
- Great Streets Project
- Neighborhood Parks Council
- Planning Association of the Richmond/Friends of Sutro Height
- Save the Waves Coalition
- San Francisco Bicycle Coalition
- San Francisco Zoological Society
- Surfrider Foundation

- SPUR

7) Infrastructure

Goal: *evaluate infrastructure plans and needs in light of uncertain coastal conditions, and pursue a smart, sustainable approach*[4]

Northern end of the Great Highway (Looking south from Sutro Heights Park). *August 2005*

During the winter storm events in 2009/2010, the bluff area south of Sloat Blvd. experienced severe erosion which subsequently exposed and damaged infrastructure. The bluffs under the Great Highway were scoured away, resulting in parts of the road and parking lots crumbling into the ocean and a portion of the Lake Merced Wastewater Tunnel becoming exposed.[18]

The Great Highway is a four-lane (two lanes in each direction) expressway that runs approximately 3.5 miles along Ocean Beach. The route's northern end beings at Point Lobos Ave and extends to the Skyline Blvd. at the southern end where it connects with Route 35. In January 2011, San Francisco officials ordered both southbound lanes of the Great Highway near Sloat Blvd. closed until summer due to erosion occurring along the bluffs in this area.[19] The detour along Skyline Blvd. raises the question: can this become a permanent alternative route?
Since these erosion events are occurring every winter and climate change forecasts increased severity and frequency of winter storms, a more permanent solution needs to be implemented. Another alternative would be to reduce the number of lanes and convert the two lanes furthest away from the coast into a single lane in each direction (as per the previous recommendations set forth by the OBTF[12]). A transportation analysis would need to be conducted by the OBMP team to determine the impacts that such a reduction in lane-use would have on traffic.

The Lake Merced Wastewater Tunnel is another piece of infrastructure in this area which has been analyzed for relocation. The tunnel is located at the southern end of Ocean Beach where the worst of the erosion is occurring. The purpose of the tunnel is to store runoff and prevent overflows during storms when large amounts of water inundate the combined sewer-stormwater system. Local officials are concerned that untreated sewage could spill onto the beach and into the ocean if the tunnel becomes compromised due to damage from erosion. The San Francisco Department of Public Works has looked into the costs of relocating the tunnel and its associated structures but the figures are costly. Moving the tunnel alone would cost an estimated $110.46 million.[20] If the associated Southwest Ocean Outfall (SWOO) pipe and other pressurized pipes are moved as well the total cost would rise to almost $167 million.[20] Since the relocation costs are high, alternatives that protect the pipe rather than move it are being considered and evaluated. One option would be to strengthen the tunnel/pipe from within. By thickening its inner walls, the tunnel will lose storage capacity, however it will increase structural integrity. Another option is protecting the exposed tunnel with coastal armoring.

Similar to the Lake Merced Wastewater Tunnel, the Westside Transport Box acts as storage for the Oceanside Water Pollution Control Plant when this facility's capacity is overwhelmed. The transport box is a large rectangular tube that runs under the Great Highway from Lincoln Way to Sloat Blvd. Unlike the tunnel, the transport box is not in any immediate danger from erosion. Instead this section of the City's stormwater-sewage infrastructure may become a significant factor in shaping the beach and dunes as the coastline recedes.[4] If the coastline along Ocean Beach recedes past the current seawalls, the Westside Transport Box could act as a last line of defense to rising sea levels.

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External links

- California Coastal Records Project (http://www.californiacoastline.org/cgi-bin/timecompare.cgi?latdeg=37.726131&longdeg=122.505710&image=199300132016&flags=0&year=1993&hidden=0&oneimage=)
- GGNRA - Dog Management Draft Plant/DEIS (http://parkplanning.nps.gov/projectHome.cfm?projectId=11759)
- Ocean Beach Task Force Report (2005) (http://www.keepandshare.com/doc/1716706/obtaskforcestatusreport2005-pdf-january-29-2010-10-43-am-8-8-meg?)
- SPUR (http://spur.org)
- SPUR Report, 5/2011: Climate Change Hits Home: Adaptation Strategies for the San Francisco Bay Area (http://spur.org/files/policy-reports/SPUR_ClimateChangeHitsHome_0.pdf)
- Sunset Beacon (http://www.sunsetbeacon.com/), local newspaper
- Sunset District travel guide from Wikitravel
- Sunset District Events Calendar (http://www.sunsetdistrict.org/), local events calendar
- Surfrider Foundation's Save Sloat Campaign (http://www.surfrider.org/campaigns/entry/save-sloat)

- Western Neighborhoods Project (http://outsidelands.org/)

Orography

Orography (from the Greek *ὄρος*, hill, *γραφία*, to write) is the study of the formation and relief of mountains,[1] and can more broadly include hills, and any part of a region's elevated terrain.[2] Orography (also known as *oreography*, *orology* or *oreology*) falls within the broader discipline of geomorphology.

Uses

Orography has a major impact on global climate, for instance the orography of East Africa substantially determines the strength of the Indian monsoon.[3] In geoscientific models, such as general circulation models, orography defines the lower boundary of the model over land.

When a river's tributaries or settlements by the river are listed in 'orographic sequence', they are in order from the highest (nearest the source of the river) to the lowest or mainstem (nearest the mouth). This method of listing tributaries is similar to the Strahler Stream Order, where the headwater tributaries are listed as category = 1.

Precipitation

Orographic precipitation, also known as relief precipitation, is precipitation generated by a forced upward movement of air upon encountering a physiographic upland (see anabatic wind). This lifting can be caused by two mechanisms:

1. The upward deflection of large scale horizontal flow by the orography.
2. The anabatic or upward vertical propagation of moist air up an orographic slope caused by daytime heating of the mountain barrier surface.

Upon ascent, the air that is being lifted will expand and cool. This adiabatic cooling of a rising moist air parcel may lower its temperature to its dew point, thus allowing for condensation of the water vapor contained within it, and hence the formation of a cloud. If enough water vapor condenses into cloud droplets, these droplets may become large enough to fall to the ground as precipitation. In parts of the world subjected to relatively consistent winds (for example the trade winds), a wetter climate prevails on the windward side of a mountain than on the leeward (downwind) side as moisture is removed by orographic precipitation. Drier air (see katabatic wind) is left on the descending, generally warming, leeward side where a rain shadow is formed.

Terrain induced precipitation is a major factor for meteorologists as they forecast the local weather. Orography can play a major role in the type, amount, intensity and duration of precipitation events. Researchers have discovered that barrier width, slope steepness and updraft speed are major contributors for the optimal amount and intensity of orographic precipitation. Computer model simulations for these factors showed that narrow barriers and steeper slopes produced stronger updraft speeds which, in turn, enhanced orographic precipitation.

Orographic precipitation is well known on oceanic islands, such as the Hawaiian Islands or New Zealand, where much of the rainfall received on an island is on the windward side, and the leeward side tends to be quite dry, almost desert-like, by comparison. This phenomenon results in substantial local gradients of average rainfall, with coastal areas receiving on the order of 20 to 30 inches (510 to 760 mm) per year, and interior uplands receiving over 100 inches (2500 mm) per year. Leeward coastal areas are especially dry—less than 20 in (510 mm) per year at Waikiki—and the tops of moderately high uplands are especially wet—about 475 in (12100 mm) per year at Wai'ale'ale on Kaua'i.

Another well known area for orographic precipitation is the Pennines in the north of England where the west side of the Pennines receives more rain than the east because the clouds (generally arriving from the west) are forced up and over the hills and cause the rain to fall preferentially on the western slopes. This is particularly noticeable between

Manchester (West) and Leeds (East) where Leeds receives less rain due to a rain shadow of 12 miles from the Pennines.

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External links

- Map of the Orography of Europe (http://www.euratlas.com/Atlasphys/Orography.htm) from Euratlas.com

Palsa

Palsas are low, often oval, frost heaves occurring in polar and subpolar climates, which contain permanently frozen ice lenses. Like pingos, palsas consist of an ice core with overlying soil, but they are generally smaller than pingos, often occur in groups and may develop from ground water without additional hydrostatic pressure. Palsas are characteristically found in areas with discontinuous permafrost, and in such areas they may be the only reliable surface evidence of permafrost. Palsas need large quantities of water for the formation of their ice lenses, and for this reason they occur particularly in bogs.

A group of well developed palsas as seen from above

Genesis

Palsas may be initiated in areas of a moor or bog where the winter freezing front penetrates relatively faster than surrounding areas, perhaps due to an unusually thin cover of snow. The lack of thermal insulation provided by thick snow permits much deeper freezing in winter. This ice may then last through the summer with a persistent 'bump' of up to several cm due to frost heave. The elevated surface of a palsa will tend also to have thinner snow cover, allowing greater winter cooling, while in summer the surface material (especially if organic) will dry out and provide thermal insulation. Thus the interior temperature is consistently lower than that of adjacent ground. This contributes to the formation of an ice lens which grows by drawing up surrounding water. The expansion of the ice upon freezing exerts pressure on the surrounding soil, further forcing water out of its pore spaces which then accumulates on and increases the volume of the growing ice lens. A positive feedback loop develops. Changes in surface moisture and vegetation will then be such as to preserve the newly-formed permafrost.

The overlying soil layer is gradually lifted up by frost heaving.[1] In cross-section, the ice cores of a palsa show layering, which is caused by the successive winter freezing intervals. In case of palsas, the pressing out of water from the pores is not crucial, however, since the boggy soil is water-saturated and thus always provides enough

water for ice core growth.

Palsas appear to go through a developmental cycle that eventually leads to thawing and collapse. Open cracks that commonly accompany palsa growth and the water that tends to accumulate around palsas, probably as a result of their weight depressing the adjacent bog surface, are important factors in this process. The fact that palsas in various stages of growth and decay occur together shows that their collapse is not necessarily indicative of climatic change. All that is usually left after a palsa collapses is a depression surrounded by a rim.

Morphology

Palsa forms include mounds, moderately straight ridges, and winding ridges. Palsas in Iceland have been described as hump shaped, dike shaped, plateau shaped, ring shaped, and shield shaped, those in Norway as palsa plateaus, esker palsas, string palsas, conical ore dome-shaped palsas, and palsa complexes.

The Storflaket peat bog near Abisko in northern Sweden is a permafrost plateau. It shows some signs of collapse such as cracks at its borders

Widths are commonly 10–30 m, and lengths 15–150 m. However, lengths of up to 500 m have been reported for esker-like palsa ridges running parallel to the gradient of a bog. Heights range from less than 1 m to about 10 m at a maximum above the surrounding area. Large forms tend to be considerably less conical than small ones. In places, palsas combine to form complexes several hundred meters in extent. The permafrost core contains ice lenses no thicker than 2–3 cm, though locally lenses up to almost 40 cm thick have been described.

Palsas form in groups or "fields" and the individual palsa can show its age difference from the others.

Palsa surfaces are frequently traversed by open cracks, caused by doming (dilation cracking), frost cracking, or desiccation. The vegetation of a palsa may comprise low shrubs and lichen in addition to the sedges characterizing the peat. Also, the higher a palsa grows the dryer the peat covering the palsa becomes leading to more insulation which protects the inner core from melting.

There are two types of palsas, those with a peat core and those with a core of mineral soil, usually silt. The peat-core type is the most common, the other being regarded as exceptional by some, but more common than formerly thought.

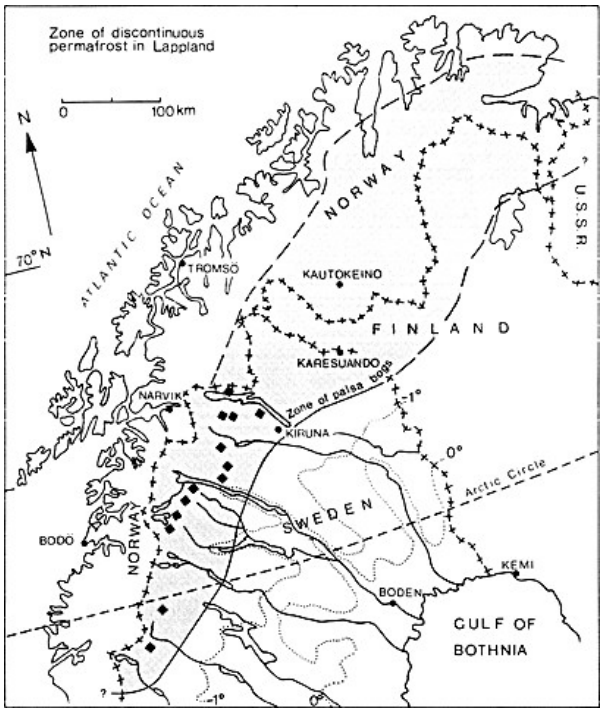
Permafrost plateau

Permafrost plateaus are structures of coalesced palsas that form a continuous elevated flatland area usually in a peat bog. Permafrost plateaus may have parts suffering decay while other growing at the same time. Permafrost plateaus are usually surrounded by wetlands but have often internal water pools during summer due to uneven relief, partial decay and thaw.

Geographic distribution

Palsas are typical forms of the discontinuous permafrost zone regions and are therefore found in Subarctic regions of northern Canada and Alaska, Siberia, northern Fennoscandia and Iceland.[2] They are almost exclusively associated with bogs and commonly occur in areas where the winters are long and the snow cover tends to be thin. In some places palsas extent into underlying permafrost; in others they rest on an unfrozen substratum.

In the southern hemisphere palsa remains from the last glacial maximum have been identified on the Argentine side of Isla Grande de Tierra del Fuego just north of Cami Lake.[3] Remainders of Ice-Age palsas are to be found also in Hochmooren of Central Europe, such as Hohen Venn in the German-Belgian border area.



Anders Rapp's map of the limit of palsas and discontinious permafrost in Fennoscandia.

Differences and commonalities between pingos and palsas

Palsas are morphologically and genetically similar to pingos, however with heights between approx. 0.5 and 2 m and lengths between approx. 5 and 25 m, palsas are significantly smaller than pingos. Both however are considered to be true perennial permafrost mounds since both occur in areas of continuous permafrost. Moreover, contrary to pingos which are usually isolated, palsas usually arise in groups with other palsas, such as in a so-called palsamoor. Unlike pingos, palsas do not require surrounding permafrost to grow, seeing as palsa are permafrost. Pingos also grow below the active layer, which is the depth that the annual freeze-thaw cycle occurs, and palsa grow in the active layer.

Both palsas and pingos result from freezing of water to an ice core. Palsas, however, do not necessarily require positive hydrostatic pressure (to inject water), since the boggy soil is water-saturated and therefore has sufficient supply for the growing ice core.

Terminology and synonyms

Palsa (plural: palsas or palsen) is a term from the Finnish language meaning "a hummock rising out of a bog with a core of ice," which in turn is a borrowing from Northern Sami, *balsa*.[4] As palsas particularly develop in moorlands they are therefore also named *palsamoors*. *Bugor* and *bulginniakhs* are general terms in the Russian language (the latter of Yakutian origin) for both palsas and pingos.

References

[1] De Schutter, Paul (2005-12-03), *Palsas & Lithalsas* (http://ougseurope.org/rockon/surface/palsas.asp), , retrieved 2010-03-10

[2] The Origin of Palsas. Matti Seppälä. 1986.

[3] The Late Cenozoic of Patagonia and Tierra del Fuego (http://books.google.se/books?id=Eq1W6eoUa_cC&pg=PA256&lpg=PA256&dq=palsa+patagonia&source=bl&ots=FC9h9sklVY&sig=cza4Waukm0rqC_BtWHag-5JbReY&hl=sv&ei=Law4SoigPI_Q-Qacq5SWAw&sa=X&oi=book_result&ct=result&resnum=5), retrieved 17 June 2009

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Further reading

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- Washburn, A.L. (1980). *Geocryology*. New York: John Wiley & Sons. ISBN 0470265825.
- Williams, Peter J.; Michael W. Smith (1989). *The frozen Earth*. New York: Cambridge University Press. ISBN 0521365341.

External links

Pictures of palsas and further information:

- Palsa, a [[Fennoscandian (http://www.isgs.illinois.edu/shilts/shilts-palsa.shtml)] term for a round or elongated hillock or mound, maximum height of about 10 m, composed of a peat layer overlying mineral soil.]
- William W. Shilts Geologic Image Gallery (Illinois State Geological Survey) (http://www.isgs.illinois.edu/shilts/shilts-gallery.shtml)
- Field trip guide on periglacial (cryogenic) geomorphology (html) (http://www.geo.wvu.edu/~kite/Geo321Lect19_2006Periglacial_files/frame.htm)
- Field trip guide on periglacial (cryogenic) geomorphology (pdf) (http://www.geo.wvu.edu/~kite/Geo321Lect17_2009Periglacial.pdf)
- Interpretation guide of natural geographic features: Palsa bog (index) (http://www.cits.rncan.gc.ca/site/eng/resoress/guide/palspals/index.html)
- Interpretation guide of natural geographic features: Palsa bog (aerial photographs) (http://www.cits.rncan.gc.ca/site/eng/resoress/guide/palspals/pg07.html)
- €U(RO)CK article from a 2005 issue (http://ougseurope.org/rockon/surface/palsas.asp)

Panhole

Example of **panholes**, which go by a variety of names, in Jura, France.

A **panhole** is a depressed, erosional feature found on flat or gently sloping rock. Panholes are the result of long-term weathering and are generally seen on bedrock or very large blocks of rock. Similar terms are **gnamma** (Australia), **opferkessel** (German, roughly “sacrificial basin”), “**armchair hollows**”, **weathering pans** (or **pits**) and **solution pans** (or **pits**). Other German names include **kamenitza** and **kamenica**. In Spanish they are **tinajita**.

In Namaqualand these features are called **!gau**[1]

These shallow solution basins, or closed depressions, tend to form on bare limestone or silicate rock. They are rarely found in granitic rocks. They are generally characterized by flat bottoms and sometimes by overhanging sides. The initial form may be a closed hollow created by a patch of humus. Diameters are rarely greater than 15 centimeters.

The Australian aboriginal term *gnamma*, in particular, implies a panhole capable of holding water at times.

A related concept is a "swirlhole": A hole in rock in a streambed eroded by eddying water, with or without sand or pebble abrasives. Swirlholes typically form at the bottoms of waterfalls.

Locations where panholes may be seen

- Beam Rocks, Forbes State Forest, Pennsylvania, USA
- Shenandoah National Park, Virginia, USA

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[1] "New species of ancient plant group discovered in South Africa" (http://www.kew.org/about-kew/press-media/press-releases-kew/new-species-south-africa/index.htm). Royal Botanic Gardens, Kew. May 8, 2009. . Retrieved 27 October 2010.

Patterned ground

Patterned ground is a term used to describe the distinct, and often symmetrical geometric shapes formed by ground material in periglacial regions. Typically found in remote regions of the Arctic, Antarctica, and the Australian outback, but also found anywhere that freezing and thawing of soil alternate,[2] the geometric shapes and patterns associated with patterned ground are often mistaken as artistic human creations. The nature of patterned ground puzzled scientists for ages. The introduction of computer-generated geological models in the past 20 years has allowed scientists to relate the formation of these features to phenomena associated with frost heaving, which refers to expansion that occurs when wet, fine-grained, and porous soils freeze.

The patterned ground below Mugi Hill on Mount Kenya is caused by frost heaving.[1]

Types of patterned ground

Patterned ground can be found in a variety of forms. Typically, the type of patterned ground in a given area is related to the amount of larger stones present in local soils and the frequency of freeze-thaw cycles.

Polygons

Polygons can form either in permafrost areas or in areas that are affected by seasonal frost. The rocks that make up these raised stone rings typically decrease in size with depth. In the northern reaches of the Canadian Boreal forests, when bogs reach a eutrophic climax and create a sedge mat, Tamarack Larch and Black Spruce are often the early colonists within such a polygonal climax sedge mat.[3]

Polygons on the Bridlicna mountain, Hruby Jesenik Mts, Czech republic

Circles

Circles range in size from a few centimeters to several meters in diameter. Circles can consist of both sorted and unsorted material, and generally occur with fine sediments in the center surrounded by a circle of larger stones. Unsorted circles are similar, but rather than being surrounded by a circle of larger stones, they are bounded by a circular margin of vegetation.

Partially melted and collapsed lithalsas (heaved mounds found in permafrost) have left circle-like structures on the Svalbard Archipelago

Steps

Steps can be developed from circles and polygons. This form of patterned ground is generally a terrace-like feature that has a border of either larger stones or vegetation on the downslope side, and can consist of either sorted or unsorted material.

Stripes

Stripes are lines of stones, vegetation, and/or soil that typically form from transitioning **steps** on slopes at angles between 2° and 7°. Stripes can consist of either sorted or unsorted material. Sorted stripes are lines of larger stones separated by areas of smaller stones, fine sediment, or vegetation. Unsorted stripes typically consist of lines of vegetation or soil that are separated by bare ground.

Formation of patterned ground

As water freezes, it expands by around 10% and takes up a larger volume. The expansion of water has proven strong enough to transform small highway cracks into potholes and to break apart enormous boulders along fractures in the rock through a process known as ice wedging. Pressures associated with ice wedging are known to reach nearly 30,000 lbf/in² (200 MPa), a pressure close to that required to crush granite.

In periglacial areas and areas affected by seasonal frost, repeated freezing and thawing of groundwater forces larger stones toward the surface as smaller soils flow and settle underneath larger stones. At the surface, areas that are rich in larger stones contain much less water than highly porous areas of finer grained sediments. These water saturated areas of finer sediments have a much greater ability to expand and contract as freezing and thawing occur, leading to lateral forces which ultimately pile larger stones into clusters and stripes. Through time, repeated freeze-thaw cycles smooth out irregularities and odd-shaped piles to form the common polygons, circular, and stripes of patterned ground.

Frost also sorts the sediments in the ground. Once the mantle has been weathered, finer particles tend to migrate away from the freezing front, and larger particles migrate through the action of gravity.

Patterned ground forms mostly within the active layer of permafrost. Water percolating through the soil builds up underneath blocks. When it freezes, blocks are pushed up towards the surface. When the soil thaws, the blocks do not return to their original location because finer particles fill in voids. The process continues until the blocks are completely unearthed.

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Footnotes

[1] Baker, B. H. (1967). *Geology of the Mount Kenya area; degree sheet 44 N.W. quarter (with coloured map)*. Nairobi: Geological Survey of Kenya.

[2] Patterned ground has also been observed on Mars. See: http://www.msss.com/mars_images/moc/polygons_5_02/.

[3] C. Michael Hogan. 2008. *Black Spruce: Picea mariana*, GlobalTwitcher.com, ed. N. Stromberg (http://globaltwitcher.auderis.se/artspec_information.asp?thingid=44751)

Pediment (geology)

A **pediment** is a gently inclined erosional surface carved into bedrock. It is thinly covered with fluvial gravel that has developed at the foot of mountains. It develops when running water erodes most of the mass of the mountain. It is typically a concave surface gently sloping away from mountainous desert areas.[1]

Processes responsible for carving pediments

- Lateral plantation or erosion by a stream [2]
- Sheetwash or sheet erosion-

  "The removal of thin layers of surface material more or less evenly from an extensive area of gently sloping land, by broad continuous sheets of running water rather than by stream flowing in well defined channels"[3]

- Rillwash or rill erosion-

  "The development fo numerous minute closely spaced channels resulting from the uneven removal of surface soil by running water that is concentrate in streamlets of sufficient discharge and velocity to generate cutting power"[3]

- Mountain-front retreating by weathering

History

In 1877 Grove Karl Gilbert first observed pediments in the Henry Mountains in Utah. He described the formation as "hills of planation cut across the upturned edges of tilted beds". Gilbert believed the origin of pediments in the Henry Mountains are due to stream plantation and active erosion of deserts. This theory was advocated by Paige (1912), Blackwelder (1931), and Johnson 1932. Johnson came up with three zones of pediments.[1]

Zones of formation

Three formational zones are recognized:[1]

- An inner most zone of mountainous uplands that have near vertical erosion
- An intermediate zone or degradation zone which is the pediment beyond the mountain front.
- An outer zone or aggradation zone which extends beyond the pediment and is a zone of deposition.

References

[1] Easterbrook, Don J. (1999) *Surface Processes and Landforms*, New Jersey, Prentice Hall
[2] Johnson, Douglas (1932) *Rock Planes of Arid Regions*, Geographical Review, Vol. 22, No. 4 (Oct., 1932), pp. 656–665
[3] Wilson, William E. (editor) (1998) *Glossary of Hydrology*, American Geological Institute

Pediplen

Pediplen (Engl. pediplain, from the Lat. pes, genitive case pedis - foot, foot and Eng. plain - plain) - the extensive slightly inclined denudation plain, which is formed under the conditions of arid and semiaridnogo climate on the spot is earlier than the existed mountain or hilly relief by the parallel retreat of slopes from the axis of valleys and connection of the separate vyrovnennykh sections - pediments. Relative to the mechanism of the formation of pediplena there is no unanimous opinion. It is considered that the main and necessary condition of forming pediplena is the long absence of the motions, which create inclines, and the fixed attitude of the basis of denudation, which determines the descending development of relief and levelling off under any climatic conditions.

Pedra da Galinha Choca

Pedra da Galinha Choca (Broody Hen's Stone) is the name given to one of the most famous monolith in the city of Quixadá, taking its name from its curious shape. It is located 5 km from the city center.[1] Until the early twentieth century was called the *Pedra da Arara* (Arara's Stone). It consists of a inselberg diorites and granites, which are igneous rocks, ie, formed from cooling magma. Like other monoliths of the region, the Pedra da Galinha Choca is on a crystalline ground, ie, consists of ancient and tough rocks that arose before the Cambrian era, what with the erosion of rain arose above the surface.

The Pedra da Galinha Chocar is a major tourist destination of Quixadá. Photo of the stone in the dry season.

In the vicinity was built the Açude do Cedro (Cedar's Dam), and together they form the best known quixadaense landscape.

References

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Peneplain

A **peneplain** is a low-relief plain representing the final stage of fluvial erosion during times of extended tectonic stability. The existence of peneplains, and peneplanation as a geomorphological process, is not without controversy, due to a lack of contemporary examples and uncertainty in identifying relic examples.[1]

Canisteo River Valley from Pinnacle State Park, New York. The distant peaks at the same elevation represent the remnants of a peneplain that was uplifted to form the Allegheny Plateau, which is a dissected plateau in southwestern New York. In this area, the sharp relief that is seen on some of the Allegheny Plateau has been rounded by glaciation.

After the streams in an area have reached "base level", lateral erosion is dominant as the higher areas between the streams are eroded. Finally, the upland is almost gone: the stream floodplains merge in an area of very low to no topographic relief. The resulting flat plain is the ultimate stage in the *cycle of erosion* or *geographical cycle*.

The streams within a peneplained region show extensive meandering and braiding. If the area is subsequently uplifted due to adjacent orogenic processes, without internal deformation within the peneplain, the streams will again begin downward erosion - creating incised meanders, water gaps, and other unique geomorphic features.

A peneplain can be mistaken for a depositional plain. However, the rocks beneath a peneplain have been folded and tilted by tectonic forces, while the rocks beneath a depositional plain lie in horizontal layers.

The peneplain concept was developed early in the 1900s by the geomorphologists, William Morris Davis and Walther Penck.

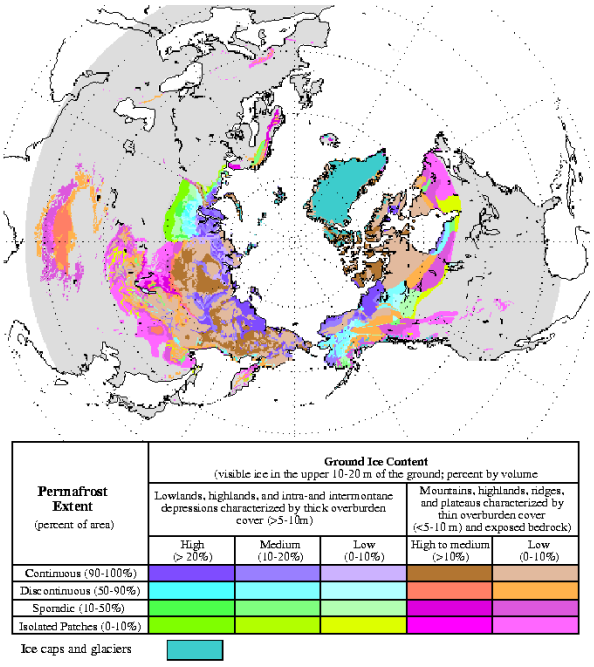
References

[1] Phillips, Jonathan D. (2002), "Erosion, isostatic response, and the missing peneplains" (http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V93-44HWRY2-2&_user=9002422&_coverDate=06/15/2002&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=9002422&md5=1158a725e452982fb62b8e4df18b0e22), *Geomorphology* (http://www.elsevier.com/wps/find/journaldescription.cws_home/503334/description#description), Vol. 45, No. 3-4. Elsevier (http://www.elsevier.com/wps/find/homepage.cws_home), 15 June 2002, pp. 225-241. doi:10.1016/S0169-555X(01)00156-8.

Permafrost

In geology, **permafrost**, **cryotic soil** or **permafrost soil** is soil at or below the freezing point of water (0 °C or 32 °F) for two or more years. Ice is not always present, as may be in the case of nonporous bedrock, but it frequently occurs and it may be in amounts exceeding the potential hydraulic saturation of the ground material. Most permafrost is located in high latitudes (i.e. land close to the North and South poles), but **alpine permafrost** may exist at high altitudes in much lower latitudes. Permafrost accounts for 0.022% of total water and exists in 24% of exposed land in the Northern Hemisphere.

The extent of permafrost can vary as the climate changes. Today, a considerable area of the Arctic is covered by permafrost (including discontinuous permafrost). Overlying permafrost is a thin *active layer* that seasonally thaws during the summer. Plant life can be supported only within the active layer since growth can occur only in soil that is fully thawed for some part of the year. Thickness of the active layer varies by year and location, but is typically 0.6–4 m (2.0–13 ft) thick. In areas of continuous permafrost and harsh winters the depth of the permafrost can be as much as 1493 m (4898 ft) in the northern Lena and Yana River basins in Siberia. Permafrost can also store carbon, both as peat and as methane. The most recent work investigating the permafrost carbon pool size estimates that 1400-1700 Gt of carbon is stored in permafrost soils worldwide. [1] . This large carbon pool represents more carbon than currently exists in all living things and twice as much carbon as exists in the atmosphere.



Map showing extent and types of permafrost in the Northern Hemisphere

Continuous and discontinuous permafrost

Permafrost will typically form in any climate where the mean annual air temperature is less than the freezing point of water. Exceptions are found in moist-wintered forest climates, such as in Northern Scandinavia and the North-Eastern part of European Russia west of the Urals, where snow acts as an insulating blanket. The bottoms of many glaciers can also be free of permafrost.

While these two men dig in Alaska to study soil, the hard permafrost requires the use of a jackhammer

Typically, the below-ground temperature will be less variable from season to season than the air temperature, with temperatures tending to increase with depth. Thus, if the mean annual air temperature is only slightly below 0 °C (32 °F), permafrost will form only in spots that are sheltered — usually with a northerly aspect. This creates what is known as *discontinuous permafrost*. Usually, permafrost will remain discontinuous in a climate where the mean annual soil surface temperature is between -5 and 0 °C (23 and 32 °F). In the moist-wintered areas mentioned before, there may not be even discontinuous permafrost down to −2 °C (28.4 °F). Discontinuous permafrost is often further divided into *extensive discontinuous permafrost*, where permafrost covers between 50 and 90 percent of the landscape and is usually found in areas with mean annual temperatures between -2 and -4 °C (28 and 25 °F), and *sporadic permafrost*, where permafrost cover is less than 50 percent of the landscape and typically occurs at mean annual temperatures between 0 and -2 °C (32 and 28 °F).

The Storflaket permafrost plateau bog near Abisko in northern Sweden shows cracks at its borders due to thawing of the permafrost.

In soil science, the sporadic permafrost zone is abbreviated **SPZ** and the extensive discontinuous permafrost zone **DPZ**.

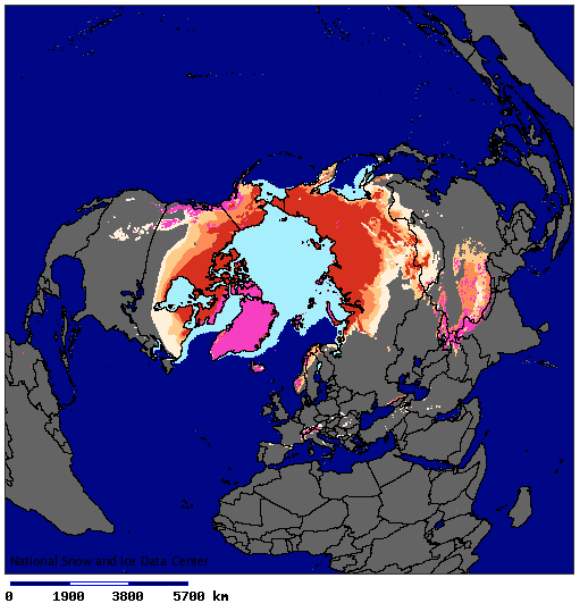
There are exceptions in *un-glaciated* Siberia and Alaska where the present depth of permafrost is a relic of climatic conditions during glacial ages where winters were up to 11 °C (20 °F) colder than those of today. At mean annual soil surface temperatures below −5 °C (23 °F) the influence of aspect can never be sufficient to thaw permafrost and a zone of *continuous permafrost* (abbreviated to **CPZ**) forms. There are also "fossil" cold anomalies in the Geothermal gradient in areas where deep permafrost developed during the Pleistocene that still persists down to several hundred metres. The Suwałki cold anomaly in Poland led to the recognition that similar thermal disturbances related to Pleistocene-Holocene climatic changes are recorded in boreholes throughout Poland. [2]

A **line of continuous permafrost** in the Northern Hemisphere (Frozen Ground 28, 2004, p5) is formed from the most northerly points at which permafrost sometimes thaws or is interrupted by regions without permafrost. North of

this line all land is covered by permafrost or glacial ice. The "line" of continuous permafrost lies further north at some longitudes than others and can gradually move northward or southward due to regional climatic changes. In the southern hemisphere, most of the equivalent line would fall within the Southern Ocean if there were land there. Most of the Antarctic continent is overlain by glaciers.

In the Andes at Atacama Desert permafrost extends down to an altitude of 4,400 metres and is continuous above 5,600 metres.

Changes in permafrost extent



Location of Permafrost in the Northern Hemisphere. Glaciers and the Greenland Ice Sheet are violet, and Arctic Sea Ice is light blue. from NSIDC

In Yukon, the zone of continuous permafrost might have moved 100 kilometres poleward since 1899, but accurate records only go back 30 years. It is thought that permafrost thawing could exacerbate global warming by releasing methane and other hydrocarbons, which are powerful greenhouse gases.[3] [4] [5] It also could encourage erosion because permafrost lends stability to barren Arctic slopes.

At the Last Glacial Maximum, continuous permafrost covered a much greater area than it does today, covering all of ice-free Europe south to about Szeged (southeastern Hungary) and the Sea of Azov (then dry land) and China south to Beijing. In North America, only an extremely narrow belt of permafrost existed south of the ice sheet at about the latitude of New Jersey through southern Iowa and northern Missouri. In the southern hemisphere, there is some evidence for former permafrost from this period in central Otago and Argentine Patagonia, but was probably discontinuous, and is related to the tundra.

Ecological consequences

Formation of permafrost has significant consequences for ecological systems, primarily due to constraints imposed upon rooting zones, but also due to limitations on den and burrow geometries for fauna requiring subsurface homes. Of course, there are secondary effects from species dependent on plants and animals whose habitat is constrained by the permafrost. One of the most widespread examples is the dominance of Black Spruce in extensive permafrost areas, since this species can tolerate rooting pattern constrained to the near surface.[6]

Patterned ground

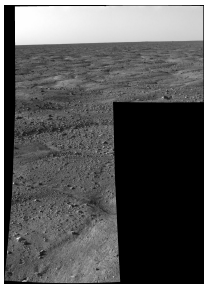
Patterned ground is a term used to describe the distinct, and often symmetrical geometric shapes formed by ground material in periglacial regions.

Polygons on the ground

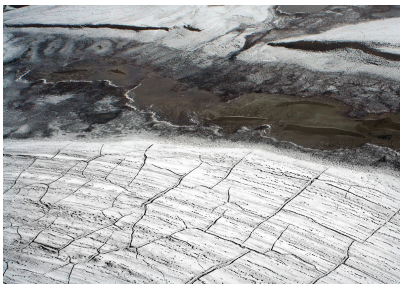
Stone rings on Spitsbergen

Ice wedges seen from top

Solifluction on Svalbard



Phoenix landing-day image near north pole of Mars showing flat terrain, containing what appears to be a polygonal pattern, stretching from the foreground to the horizon.



This image was taken from a helicopter in Canadian Arctic

Time to form deep permafrost

Time taken for permafrost to reach depth

Time (yr)	Permafrost depth
1	4.44 m (14.6 ft)
350	79.9 m (262 ft)
3,500	219.3 m (719 ft)
35,000	461.4 m (1514 ft)
100,000	567.8 m (1863 ft)
225,000	626.5 m (2055 ft)
775,000	687.7 m (2256 ft)

It has been calculated that the time required to form the deep permafrost underlying Prudhoe Bay, Alaska is 500,740 years. This time extends over several glacial and interglacial cycles of the Pleistocene and suggests that the present climate of Prudhoe Bay is probably considerably warmer than it has been on average over that period. Such warming

over the past 15,000 years is widely accepted. The table to the right shows that the first hundred metres of permafrost forms relatively quickly but that deeper levels take progressively longer.

Construction on permafrost

Utility lines in a permafrost zone must be above ground

Building on permafrost is difficult due to the heat of the building (or pipeline) thawing the permafrost and sinking. This problem has three common solutions: using foundations on wood piles; building on a thick gravel pad (usually 1–2 metres/3.3-6.6 feet thick); or using anhydrous ammonia heat pipes. The Trans-Alaska Pipeline System uses insulated heat pipes to prevent the pipeline from sinking. Qingzang railway in Tibet was built using a variety of methods to keep the ground cool.

At the *Permafrost Research Institute* in Yakutsk, it has been found that the sinking of large buildings into the ground (known to the Yakuts before Yakutsk was founded) can be prevented by using stilts extending down to about fifteen metres or more. At this depth the temperature does not change with the seasons, remaining at about -5 °C (23F).

References

[1] [Tarnocai, C., J. G. Canadell, E. A. G. Schuur, P. Kuhry, G. Mazhitova, and S. Zimov (2009), Soil organic carbon pools in the northern circumpolar permafrost region, Global Biogeochemical Cycles, 23]

[2] http://www.pgi.gov.pl/pgi_en/index.php?option=news&task=viewarticle&sid=107

[3] The Guardian (http://www.guardian.co.uk/climatechange/story/0,12374,1546824,00.html)

[4] The effect of permafrost thaw on old carbon release and net carbon exchange from tundra (http://www.nature.com/nature/journal/v459/n7246/full/nature08031.html)

[5] The Economist: Thaw point (http://www.economist.com/node/14119825)

[6] C. Michael Hogan, *Black Spruce: Picea mariana*, GlobalTwitcher.com, ed. Nicklas Stromberg, November, 2008 (http://globaltwitcher.auderis.se/artspec_information.asp?thingid=44751)

The Trans-Alaska Pipeline is largely constructed either on top of or beneath the permafrost. However, in this one brief section it is buried only a few feet below the Richardson Highway and a system of heat-diffusing pipes is used to stop the heat from the warm oil melting the permafrost

External links

- International Permafrost Association (IPA) (http://www.ipa-permafrost.org)
- What is Permafrost? (http://cgc.rncan.gc.ca/permafrost/whatis_e.php), Geological Survey of Canada
- How rapidly is permafrost changing? What are the impacts of these changes? (http://www.arctic.noaa.gov/essay_romanovsky.html) from * NOAA (http://www.arctic.noaa.gov/essays.html)
- Melting Russian Permafrost Could Accelerate Global Warming (http://www.keepmedia.com/pubs/EnvironmentNewsService/2006/09/07/1800717?ba=a&bi=17&bp=13) - ENS (7 September 2006)
- Mike W. Smith's page on permafrost in Canada (http://www.carleton.ca/~msmith2/current_pf.htm)
- Earth's permafrost starts to squelch (http://news.bbc.co.uk/2/hi/science/nature/4120755.stm) — BBC (29 December 2004)
- PERMAFROST: A Building Problem For Alaska (http://www.uaf.edu/coop-ext/publications/freepubs/HCM-00754.pdf)

- Permafrost Young Researchers Network (PYRN) (http://www.pyrn.org)
- United States Permafrost Association (USPA) (http://www.uspermafrost.org/)
- Air Conditioning Lubricant named PermaFrost (http://www.permafrost.bz/)
- Conversion Calculator (http://www.eustis.army.mil/weather/weather_products/wxconversions.htm)
- Permafrost Research in 1940s-1950s (http://pubs.aina.ucalgary.ca/arctic/Arctic7-3&4-153.pdf)
- Geophysical Institute Permafrost Lab (http://permafrost.gi.alaska.edu), University of Alaska Fairbanks

Physiographic province

A physiographic province is a geographic region with a specific geomorphology and often specific subsurface rock type or structural elements.

A continent may be subdivided into various physiographic provinces, each having a specific character, relief, and environment which contributes to its uniqueness.

Examples

In eastern North America, the Atlantic Coastal Plain, Piedmont, Blue Ridge Mountains, Ridge-and-Valley Appalachians, and Appalachian Plateau are specific physiographic provinces.[1]

In the Western United States of western North America: the Basin and Range Province, Cascade Range, Colorado Plateau, Rio Grande rift, Great Basin, Central Valley (California), Peninsular Ranges, Los Angeles Basin, and Transverse Ranges are physiographic province examples.

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[1] http://tapestry.usgs.gov/physiogr/physio.html A Tapestry of Time and Terrain, USGS

Pingo

A **pingo**, also called a **hydrolaccolith**, is a mound of earth-covered ice found in the Arctic and subarctic that can reach up to 70 metres (230 ft) in height and up to 600 m (2000 ft) in diameter. The term originated as the Inuvialuktun word for a small hill. A pingo is a periglacial landform, which is defined as a nonglacial landform or process linked to colder climates. They are essentially formed by ground ice which develops during the winter months as temperatures fall.[1] [2] [3] The plural form is "pingos".

Pingos near Tuktoyaktuk, Northwest Territories, Canada

Locations

Tuktoyaktuk in the Mackenzie Delta of the Northwest Territories has one of the highest concentrations of pingos, with some 1,350 examples. Pingo National Landmark protects eight of these features.[4] Other places with pingos include Nunavut[5] and Yukon in Canada, Alaska in the United States, Greenland, Siberia, and the Norwegian island of Spitsbergen.[1] Some old pingo ruins can be found in Norfolk, England (in the Breckland) and in the Netherlands, in Dantumadeel and Opsterland in the province of Friesland, and also in the provinces of Drenthe[6] and Groningen.

In Siberia, pingos are known as *bulganniakh*, from the Sakha language (Yakut language).[7]

Melting pingo and polygon wedge ice near Tuktoyaktuk, Northwest Territories, Canada

Types

Rounded tops are common for smaller pingos, but larger ones often have breaks in the ice at the top. These larger pingos can have craters that have cones resembling those from volcanoes. This is due to the ice breaking and from melting of the inner ice core. Beds will often dip outward from the center when they occur in stratified sand or silt, a lot like being adjacent to an intrusive body. Pingos that form in bedrock can show similar deformation. The ice in the core of pingos usually originates from segregation or injection of fluid water, and can be massive. Tension fractures are normal for the mound's summit, but pingo ice expansion is brief and rare. A small freshwater lake can occupy the summit where a crater has formed from the ice melting.

Pingos are generally classified as hydrostatic (closed-system) or hydraulic (open-system). Relict hydrostatic (closed-system) and hydraulic (open-system) pingos may be distinguished from each other by determining if lacustrine (lake) deposits are associated with the formation.

Formation

Pingos can only form in a permafrost environment. Evidence of collapsed pingos in an area suggests that there was once permafrost.

Pingos usually grow only a couple centimetres per year, with Ibyuk Pingo growing at a rate of 2 centimetres (0.79 in) a year,[4] and the largest take decades or even centuries to form. The process that creates pingos is believed to be closely related to frost heaving.

Hydrostatic (closed-system) pingos form as a result of hydrostatic pressure on water from permafrost, and commonly form in drained lakes or river channels. Permafrost rises to the drained body's former floor. Pore water is expelled in front of the rising permafrost, and the resulting pressure causes the frozen ground to rise and an ice core to form. The shape and size of a hydrostatic or closed system pingo is often similar to the body of water that it originated from. They can vary from symmetrical conical domes to asymmetric, elongate hills.

Hydraulic (open-system) pingos result from groundwater flowing from an outside source, i.e. subpermafrost or intrapermafrost aquifers. Hydrostatic pressure initializes the formation of the ice core as water is pushed up and subsequently freezes. Open-system pingos have no limitations to the amount of water available unless the aquifers freeze. They often occur at the base of slopes and are commonly known as Greenland type. The groundwater is put under artesian pressure and forces the ground up as it makes an expanding ice core. It is not the artesian pressure itself that forces the ground up, but rather the ice core that is being fed the water from the aquifer. These are often formed in a thin, discontinuous permafrost. These conditions allow an ice core to form, but also provide it with a supply of artesian ground water. These pingos are often oval or oblong shaped. It is still not entirely understood why open system or hydraulic pingos normally occur in unglaciated terrain.

History

The term *pingo* was first borrowed from the Inuvialuit by the Arctic botanist Alf Erling Porsild in 1938. Porsild Pingo in Tuktoyaktuk is named in his honor.[8]

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[4] Pingo Canadian Landmark (http://www.pc.gc.ca/docs/v-g/pingo/index_e.asp)
[5] A Pingo in the Mala River Valley, Baffin Island, Northwest Territories, Canada (http://pubs.aina.ucalgary.ca/arctic/Arctic38-3-244.pdf)
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External links

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Planation

Planation is a geomorphic process which creates nearly flat surfaces by fluvial (river), eolian (wind) and marine processes. The process is erosional and takes millions of years, and its legacy from the tertiary period (65-2Ma) is present in many of today's landscapes. It has been studied since the 1890's but many fundamental questions remain about this process.

Playfair's Law

In estimating erosion, **Playfair's Law** is an empirical relationship that relates the size of a stream to the valley it runs through. The role of the flow regiment requires subject attention; the relation acts fundamentally similar to the functionality of a glacial trough[1] . Since the relationship is case specific, it is a misleading description of the morphology of fluvial junctions and is better defined as a theory rather than law.

Gishron Stream, Israel. Showing the relationship; a large and deep stream in its proportionally sized valley.

Definition

The law states each stream cuts into its own valley[2] , that each valley is proportional in size to its stream and that the stream junctions in the valley are proportional in depth in accordance with the stream level. Although there are models, in the most basic sense it simply says that large, fast streams will be in large valleys and vice versa. This is because steady, heavy flow of water will tug surrounding soil and subsequently erode and deepen the valley it cuts through.

Playfair's law also states that at tributary junctions, tributaries will have the same slope as the main channels. This is referred to by saying that the junctions occur "at grade".

Equation

By modeling Playfair's Law in the following mathematical scheme, we can find the incision rate of the stream into the valley by following:

$$\dot{\varepsilon} = kA^m S^n$$ [3]

where

ε is the is erosion (or incision), and $\dot{\varepsilon}$ is therefore equal to the incision rate

k is an erosion parameter (see below)

A is the area drained by the stream

S is the local gradient of the channel

m, n stream parameters (see below)

In evaluating the case specific parameters, we regard k as a parameter that is dependent on the type of land or soil that the stream is penetrating. Also, m, n can be estimated by first assuming that at the junction the law holds over the distance used to determine S and taking their ratios (m/n) at different points, then substitution.

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[3] ""Wiley Interscience: Fundamentals"" (http://www3.interscience.wiley.com/journal/112716313/abstract). . Retrieved 2009-01-09.

Plunge pool

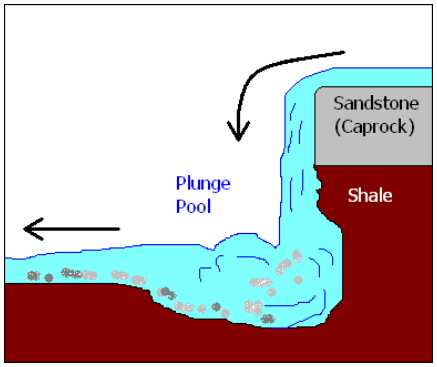
A **plunge pool** (or **plunge basin** or **waterfall lake**) can be a natural hydrologic fluvial landform feature or a constructed recreational garden feature. It is a stream pool, lake, or pond that is small in diameter, but deep.

Selandjafoss' plunge pool (Iceland)

Formation

Plunge pools are formed under the force of a natural source, such as a waterfall or rapids, but also as the result of scour from man-made objects such as spillways and bridge abutments. The swirling water, sometimes carrying rocks within it, erodes the riverbed into a basin, often featuring irregular and rough sides. Plunge pools can remain after the waterfall has ceased to exist or the stream has been diverted.

Plunge pools are erosional features which occur in the youthful stage of a river. When soft rock has been eroded back to a knickpoint, water constantly bombards its base. Because this rock is often less dense than surrounding strata, the water from the higher grade continues eroding downward.



Water going over the falls carries sand and pebbles that scour a plunge pool at its base.

Garden feature

A plunge pool, also known as a **cold plunge**, can be a recreational water feature in landscape design, and constructed in gardens. They can be small-diameter swimming pools used for wading in warmer climates or adjacent to saunas.

These plunge pools are built to the same codes and specifications as swimming pools in regards to structural engineering, sanitation and filtration requirements, safety and liability precautions, and building permits. They can be unheated in climates without seasonal freezing, since their purpose is not for active recreation or exercise. Their smaller surface and ease of covering reduce evaporative water losses, and need for potable water refilling. Their popularity has increased with concerns and needs for domestic water conservation, more sustainable landscaping design, and reduction of resource consumption with energy-efficient landscaping.

References

External links

- USGS: Stream Modeling website (http://smig.usgs.gov/SMIG/features_0300/otis_fs.html)

Point bar

A **point bar** is a depositional feature of streams. Point bars are found in abundance in mature or meandering streams. They are crescent-shaped and located on the inside of a stream bend, being very similar to, though often smaller than towheads, or river islands.

Point bars are composed of sediment that is well sorted and typically reflects the overall capacity of the stream. They also have a very gentle *slope* and an elevation very close to water level. Since they are low-lying, they are often overtaken by floods and can accumulate driftwood and other debris during times of high water levels. Due to their near flat topography and the fact that the water speed is slow in the shallows of the point bar they are popular rest stops for boaters and rafters. However, camping on a point bar can be dangerous as a flash flood that raises the stream level by as little as a few inches (centimetres) can overwhelm a campsite in moments.

A point bar is an area of deposition whereas a cut bank is an area of erosion.

Point bars are formed as the secondary flow of the stream sweeps and rolls sand, gravel and small stones laterally across the floor of the stream and up the shallow sloping floor of the point bar.

Cut bank erosion and point bar deposition as seen on the Powder River in Montana.

Formation

Any fluid, including water in a stream, can only flow around a bend in vortex flow.[1] In vortex flow the speed of the fluid is fastest where the radius is smallest, and slowest where the radius is greatest. (Tropical cyclones, tornadoes, and the spinning motion of water as it escapes down a drain are all visible examples of vortex flow.) In the case of water flowing around a bend in a stream the secondary flow in the boundary layer along the floor of the stream does not flow parallel to the banks of the stream but flows partly across the floor of the stream toward the inside of the stream (where the radius of curvature is smallest).[2] This movement of the boundary layer is capable of sweeping and rolling loose particles including sand, gravel, small stones and other submerged objects along the floor of the stream toward the point bar.[3]

This can be demonstrated at home. Partly fill a circular bowl or cup with water and sprinkle a little sand, rice or sugar into the water. Set the water in circular motion with a hand or spoon. The secondary flow will quickly sweep the solid particles into a neat pile in the center of the bowl or cup. The primary flow (the vortex) might be expected to sweep the solid particles to the perimeter of the bowl or cup, but instead the secondary flow along the floor of the bowl or cup sweeps the particles toward the center.

Where a stream is following a straight course the slower boundary layer along the floor of the stream is also following the same straight course. It sweeps and rolls sand, gravel and polished stones downstream, along the floor

of the stream. However, as the stream enters a bend and vortex flow commences as the primary flow, a secondary flow also commences and flows partly across the floor of the stream toward the convex bank (the bank with the smaller radius). Sand, gravel and polished stones that have travelled with the stream for a great distance where the stream was following a straight course may finally come to rest in the point bar of the first stream bend.

Due to the circular path of a stream around a bend the surface of the water is slightly higher near the concave bank (the bank with the larger radius) than near the convex bank. This slight slope on the water surface of the stream causes a slightly greater water pressure on the floor of the stream near the concave bank than near the convex bank. This pressure gradient drives the slower boundary layer across the floor of the stream toward the convex bank. The pressure gradient is capable of driving the boundary layer up the shallow sloping floor of the point bar, causing sand, gravel and polished stones to be swept and rolled up-hill!

The concave bank is often a cut bank and an area of erosion. The eroded material is swept and rolled across the floor of the stream by the secondary flow and may be deposited on the point bar only a small distance downstream from its original location in the concave bank.

The point bar typically has a gently sloping floor with shallow water. The shallow water is mostly the accumulated boundary layer and does not have a fast speed. However, in the deepest parts of the stream where the stream is flowing freely, vortex flow prevails and the stream is flowing fastest where the radius of the bend is smallest, and slowest where the radius is greatest. The shallows around the point bar can become treacherous when the stream is rising. As the water depth increases over the shallows of the point bar, the vortex flow can extend closer toward the convex bank and the water speed at any point can increase dramatically in response to only a small increase in water depth.

Fallacy regarding formation of point bars

An enduring fallacy exists regarding the formation of point bars and oxbow lakes. The fallacy suggests they are formed by the deposition of a stream's suspended load as the velocity and energy of the stream *decreases* in the bend. This fallacy relies on the erroneous notion that the speed of the water is slowest on the inside of the bend (where the radius is smallest) and fastest on the outside of the bend (where the radius is greatest).

If it were true that, around a bend in a stream, the difference between the speed of the water near one bank and the other was sufficient to cause deposition of suspended solids on one bank but not the other, the deposition would occur near the concave bank rather than the convex bank because vortex flow is slowest where the radius of curvature is greatest. Any fluid, including water in a stream, can only flow around a bend in vortex flow.

All point bars typically have a gently sloping floor with shallow water. The shallow depth of the water, and the fact that it is an accumulation of the boundary layer, prevent the water from reaching fast speed over the point bar. It is probably this observation which led early geographers to believe the slowest part of the stream is where the radius is smallest.

In a slow-flowing stream or river, the difference in speed between one bank and the other is not sufficient to provide a credible explanation as to why all the deposition occurs on one bank, and none on the other. Similarly, the fallacy has no explanation as to why all the deposition occurs at a stream bend, and little or none occurs where the stream is following a straight course. (The speed of water in a stream does not slow just because the stream enters a bend.)

In a mature, meandering stream or river the water speed is slow, turbulence is low, and the water is not capable of holding coarse sand and gravel in suspension. In contrast, point bars comprise coarse sand, gravel, polished stones and other submerged objects. These materials have not been carried in suspension and then dropped on the point bar – they have been swept and rolled into place by the secondary flow that exists across the floor of every stream in the vicinity of a stream bend.

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> In the absence of secondary flow, bend flow seeks to conserve angular momentum so that it tends to conform to that of a free vortex with high velocity at the smaller radius of the inner bank and lower velocity at the outer bank where radial acceleration is lower.

Hickin, Edward J. (2003), "Meandering Channels", in Middleton, Gerard V., *Encyclopedia of Sediments and Sedimentary Rocks*, New York: Springer, pp. 432 ISBN 1 402 008724

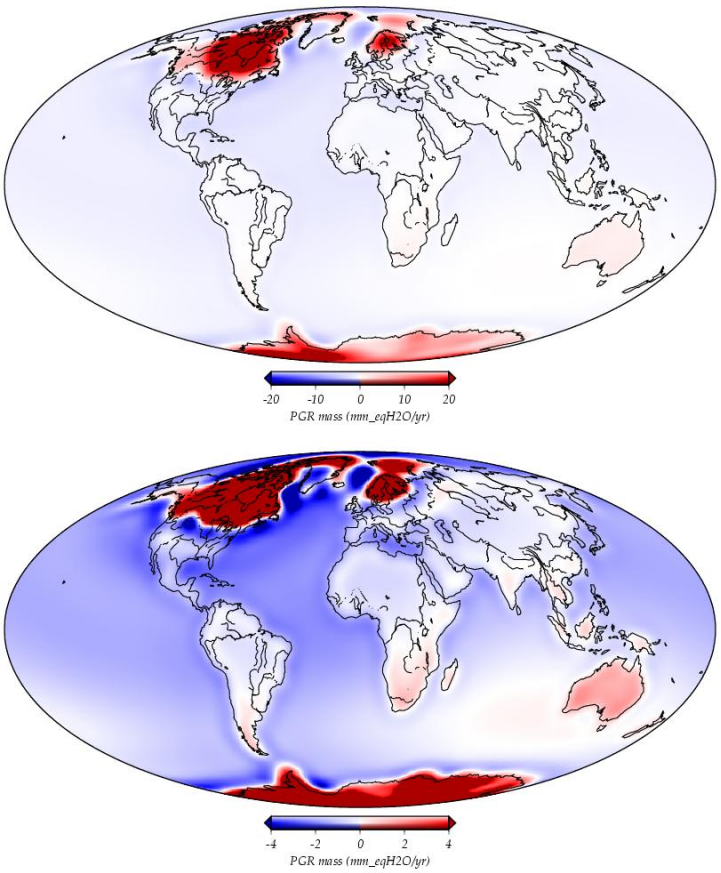
[2] Journal of Geophysical Research, Volume 107 (2002) (http://www.agu.org/pubs/crossref/2002/2001JC001082.shtml)

> One of the important consequences of helical flow in meanders is that sediment eroded from the outside of a meander bend tends to be moved to the inner bank or point bar of the next downstream bend.

Hickin, Edward J. (2003), "Meandering Channels", in Middleton, Gerard V., *Encyclopedia of Sediments and Sedimentary Rocks*, New York: Springer, pp. 432 ISBN 1 402 008724

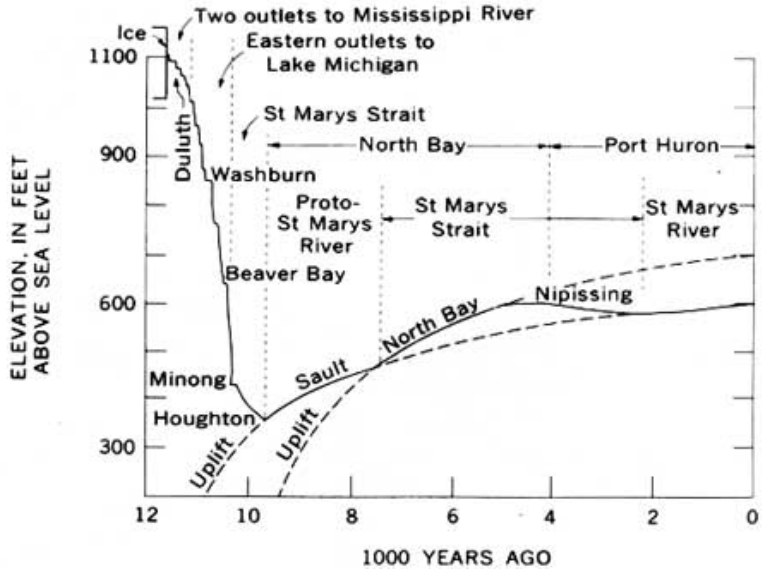
Post-glacial rebound

Post-glacial rebound (sometimes called **continental rebound**, **glacial isostatic adjustment**) is the rise of land masses that were depressed by the huge weight of ice sheets during the last glacial period, through a process known as isostasy. It affects northern Europe (especially Scotland, Fennoscandia and northern Denmark), Siberia, Canada, the Great Lakes of Canada and the United States, parts of Patagonia, and Antarctica.



A model of present-day surface elevation change due to post-glacial rebound and the reloading of the ocean basins with seawater. Red areas are rising due to the removal of the ice sheets. Blue areas are falling due to the re-filling of the ocean basins when the ice sheets melted and because of the collapse of the forebulges around the ice sheets.

Overview

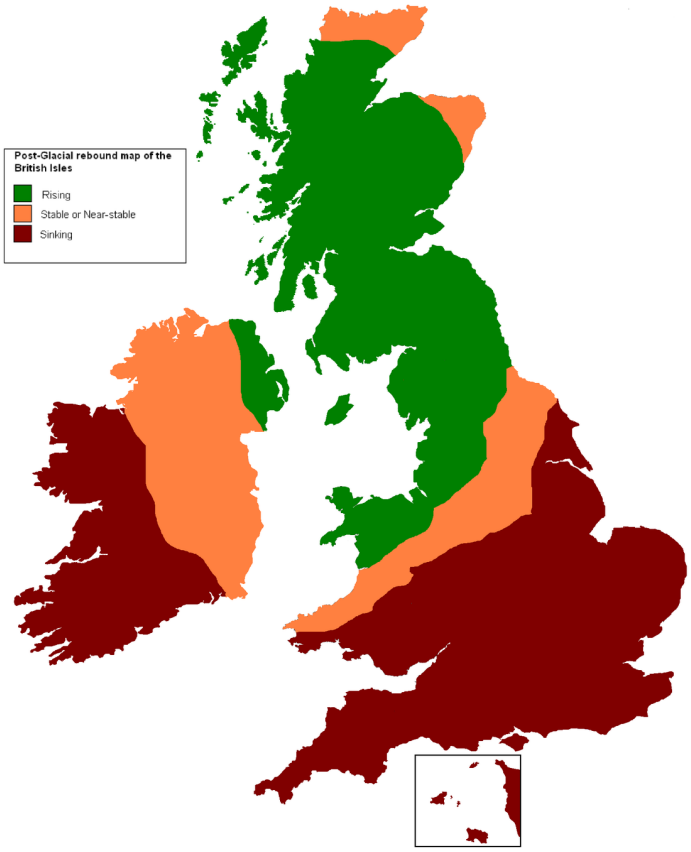


Changes in the elevation of Lake Superior due to glaciation and post-glacial rebound

During the last glacial period, much of northern Europe, Asia, North America, Greenland and Antarctica were covered by ice sheets. The ice was as thick as three kilometres during the last glacial maximum about 20,000 years ago. The enormous weight of this ice caused the surface of the Earth's crust to deform and warp downward, forcing the fluid mantle material to flow away from the loaded region. At the end of the ice age when the glaciers retreated, the removal of the weight from the depressed land led to slow (and still ongoing) uplift or rebound of the land and the return flow of mantle material back under the deglaciated area. Due to the extreme viscosity of the mantle, it will take many thousands of years for the land to reach an equilibrium level.

Studies have shown that the uplift has taken place in two distinct stages. The initial uplift following deglaciation was rapid (called "elastic"), and took place as the ice was being unloaded. After this "elastic" phase, uplift proceeded by "slow viscous flow" so the rate decreased exponentially after that. Today, typical uplift rates are of the order of 1 cm/year or less. In northern Europe, this is clearly shown by the GPS data obtained by the BIFROST GPS network.[1] Studies suggest that rebound will continue for about at least another 10,000 years. The total uplift from the end of deglaciation depends on the local ice load and could be several hundred metres near the centre of rebound.

Recently, the term **post-glacial rebound** is gradually being replaced by the term **glacial isostatic adjustment**. This is in recognition that the response of the Earth to glacial loading and unloading is not limited to the upward rebound movement, but also involves downward land movement, horizontal crustal motion,[1] [2] changes in global sea levels,[3] the Earth's gravity field,[4] induced earthquakes [5] and changes in the rotational motion.[6]



Map of Post Glacial Rebound effects upon the land-level of the British Isles.

Effects

Post-glacial rebound (or glacial isostatic adjustment) produces measurable effects on vertical crustal motion, global sea levels, horizontal crustal motion, gravity field, Earth's rotational motion and state of stress and earthquakes. Studies of glacial rebound give us information about the flow law of mantle rocks and also past ice sheet history. The former is important to the study of mantle convection, plate tectonics and the thermal evolution of the Earth. The latter is important to glaciology, paleoclimate and changes in global sea level. Understanding postglacial rebound is also important to our ability to monitor recent global change.

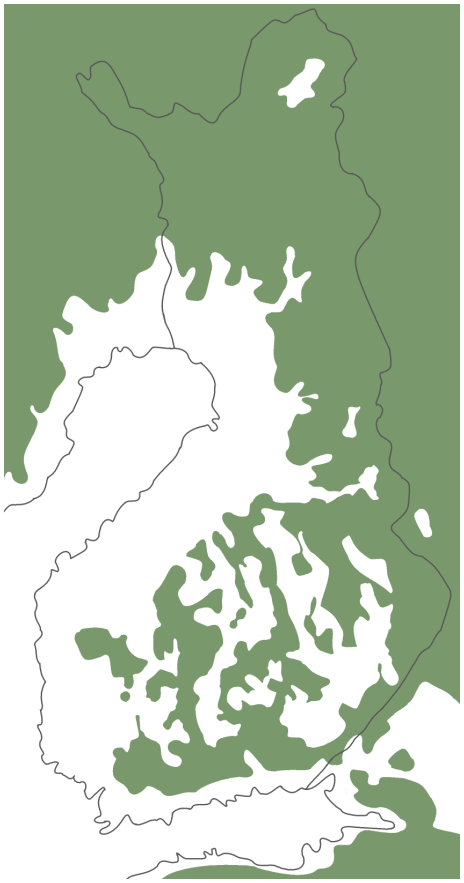
Vertical crustal motion

Erratic boulders, U-shaped valleys, drumlins, eskers, kettle lakes, bedrock striations are among the common signatures of the Ice Age. In addition, post-glacial rebound has caused numerous significant changes to coastlines and landscapes over the last several thousand years, and the effects continue to be significant.

In Sweden, Lake Mälaren was formerly an arm of the Baltic Sea, but uplift eventually cut it off and led to its becoming a freshwater lake in about the 12th century, at the time when Stockholm was founded at its outlet. Marine seashells found in Lake

This sign in Turku illustrates the sea level in 2,000 BCE.

Ontario sediments imply a similar event in prehistoric times. Other pronounced effects can be seen on the island of Öland, Sweden, which has little topographic relief due to the presence of the very level Stora Alvaret. The rising land has caused the Iron Age settlement area to recede from the Baltic Sea, making the present day villages on the west coast set back unexpectedly far from the shore. These effects are quite dramatic at the village of Alby, for example, where the Iron Age inhabitants were known to subsist on substantial coastal fishing.



Much of modern Finland is former seabed or archipelago: illustrated are sea levels immediately after the last ice age.

As a result of post-glacial rebound, the Gulf of Bothnia is predicted to eventually close up at Kvarken. The Kvarken is a UNESCO World Natural Heritage Site, selected as a "type area" illustrating the effects of post-glacial rebound and the holocene glacial retreat.

In several other Nordic ports, like Tornio and Pori (formerly at Ulvila), the harbour has had to be relocated several times. Place names in the coastal regions also illustrate the rising land: there are inland places named 'island', 'skerry', 'rock', 'point' and 'sound'. For example, Oulunsalo "island of Oulujoki"[7] is a peninsula, with inland names such as *Koivukari* "Birch Rock", *Santaniemi* "Sandy Cape", and *Salmioja* "the ditch of the Sound". (Compare [8] and [9].)

In Great Britain, glaciation affected Scotland but not Southern England, and the post-glacial rebound of northern Great Britain is causing a corresponding downward movement of the southern half of the island.[10] This is leading to an increased risk of floods, particularly in the areas surrounding the lower River Thames. Along with rising sea levels caused by global warming, the post-glacial sinking of southern England is likely to seriously compromise the effectiveness of the Thames Barrier, London's most important flood defence, after about 2030.

The combination of horizontal and vertical motion changes the tilt of the surface. That is, locations farther north rise faster. This effect is seen in lakes, where land rises at the northern end and sinks at the southern end. The Great Lakes of North America lie approximately on the 'pivot' line between rising and sinking land. Lake Superior was formerly part of a much larger lake together with Lake Michigan and Lake Huron, but post-glacial rebound raised land dividing the three lakes about 2100 years ago.[11] Today, southern shorelines of the lakes continue to experience rising water levels while northern shorelines see falling levels.

Since the glacial isostatic adjustment process causes the land to move relative to the sea, ancient shorelines are found to lie above present day sea level in areas that were once glaciated. On the other hand, places in the peripheral bulge area which was uplifted during glaciation now begins to subside. Therefore ancient beaches are found below present day sea level in the bulge area. The “relative sea level data”, which consists of height and age measurements of the ancient beaches around the world, tells us that glacial isostatic adjustment proceeded at a higher rate near the end of deglaciation than today.

The present-day uplift motion in northern Europe is also monitored by a GPS network called BIFROST.[1] [12] [13] Results of GPS data shows a peak rate of about 11 mm/year in the north part of the Gulf of Bothnia, but this uplift rate decreases away and becomes negative outside the former ice margin.

In the near field outside the former ice margin, the land sinks relative to the sea. This is the case along the east coast of the United States, where ancient beaches are found submerged below present day sea level and Florida is expected

to be submerged in the future.[3] GPS data in North America also confirms that land uplift becomes subsidence outside the former ice margin.[2]

Global sea levels

To form the ice sheets of the last Ice Age, water from the oceans evaporated, condensed as snow and was deposited as ice in high latitudes. Thus global sea level fell during glaciation.

The ice sheets at the last glacial maximum were so massive that global sea level fell by about 120 metres. Thus continental shelves were exposed and many islands became connected with the continents through dry land. This was the case between the British Isles and Europe, or between Taiwan, the Indonesian islands and Asia. Most important is the existence of a sub-continent between Siberia and Alaska that allowed the migration of people and animals during last glacial maximum.[3]

The fall in sea level also affects the circulation of ocean currents and thus has important impact on climate during the Ice Age.

During deglaciation, the melted ice water returns to the oceans, thus sea level in the ocean increases again. However, geological records of sea level changes show that the redistribution of the melted ice water is not the same everywhere in the oceans. In other words, depending upon the location, the rise in sea level at a certain site may be more than that at another site. This is due to the gravitational attraction between the mass of the melted water and the other masses, such as remaining ice sheets, glaciers, water masses and mantle rocks[3] and the changes in centrifugal potential due to Earth's variable rotation.[14]

Horizontal crustal motion

Accompanying vertical motion is the horizontal motion of the crust. The BIFROST GPS network[13] shows that the motion diverges from the centre of rebound.[1] However, the largest horizontal velocity is found near the former ice margin.

The situation in North America is less certain; this is due to the sparse distribution of GPS stations in northern Canada, which is rather inaccessible.[2]

Gravity field

Ice, water and mantle rocks have mass, and as they move around, they exert a gravitational pull on other masses towards them. Thus, the gravity field, which is sensitive to all mass on the surface and within the Earth, is affected by the redistribution of ice/melted water on the surface of the Earth and the flow of mantle rocks within.

Today, more than 6000 years after the last deglaciation terminated, the flow of mantle material back to the glaciated area causes the overall shape of the Earth to become less oblate. This change in the topography of Earth's surface affects the long-wavelength components of the gravity field.

The changing gravity field can be detected by repeated land measurements with absolute gravimeters and recently by the GRACE satellite mission.[15] The change in long-wavelength components of Earth's gravity field also perturbs the orbital motion of satellites and has been detected by LAGEOS satellite motion.[16]

Vertical datum

The vertical datum is a theoretical reference surface for altitude measurement and plays vital roles in many human activities, including land surveying and construction of buildings and bridges. Since postglacial rebound continuously deforms the crustal surface and the gravitational field, the vertical datum needs to be redefined repeatedly through time.

Earth's rotation

Examination of ancient Chinese and Babylonian eclipse records reveals that the Earth's rotation rate is not constant. For example, if the rotation rate were constant, then the shadow path of an ancient Babylonian eclipse would lie somewhere across western Europe and the ancient eclipse could not have been observed at the recorded time in Babylon. It is well known that tidal interaction between Earth and the Moon (tidal friction or tidal dissipation) causes the Earth's rotation to slow. But taking into account the tidal interaction alone over-corrects the eclipse path which would lie east of Babylon.[17] To have the shadow path pass through Babylon at the recorded time, we need to take into account the effect of glacial isostatic adjustment on Earth's rotational motion.

To understand how glacial isostatic adjustment affects Earth's rotation rate, we note that the movement of mass on and beneath the Earth's surface affects the moment of inertia of the Earth; by the conservation of angular momentum, the rotational motion must also change. This is illustrated by a rotating ice skater: as she extends her arms above her head, her moment of inertia decreases, and she spins faster. On the other hand, as she extends her arms horizontally, her moment of inertia increases and her spin slows.

During glaciation, water is taken from the oceans, whose average position is nearer the equator, and deposited as ice over the higher latitudes closer to the poles, which is closer to the rotational axis. This causes the moment of inertia of the Earth–ice–water system to decrease and just like the rotating figure skater bringing her arms closer to her body, the earth should spin faster. During deglaciation, the melted ice water returns to the oceans – farther from the rotational axis – causing the Earth's spin to slow down. The mantle rocks flow in a direction opposite to that of the water, but the rate is much slower. After the end of deglaciation, the dominant mass movement is from the return flow of the mantle rocks back to the glaciated areas at high latitude, making the shape of the Earth less oblate. This process would, in isolation, lead to an increase in the rotation speed of the Earth and therefore to a decrease of the length of day. Lambeck estimated that the isolated effect of post-glacial rebound on the length of the day would be a decrease of about 0.7 milliseconds per century.[18] This process of nontidal acceleration of the rotation of the earth is corroborated by observations of the satellite LAGEOS[16] and is generally attributed to glacial isostatic adjustment.[6]

In addition to the changes in the Earth's rotation rate, the changes in the moment of inertia due to glacial isostatic adjustment also cause the rotational axis to move from the current position near the North Pole towards the center of the ice masses at glacial maximum (polar wander); thus it is moving towards eastern Canada at a rate of about 1 degree per million years.[6] [19]

This drift of the Earth's rotational axis in turn affects the centrifugal potential on the surface of the earth, and thus also affects sea levels.[14]

State of stress and intraplate earthquakes

According to the theory of plate tectonics, plate-plate interaction results in earthquakes near plate boundaries. However, large earthquakes are found in intraplate environment like eastern Canada (up to M7) and northern Europe (up to M5) which are far away from present-day plate boundaries. An important intraplate earthquake was the magnitude 8 New Madrid earthquake that occurred in mid-continental USA in the year 1811.

Glacial loads have provided more than 30 MPa of vertical stress in northern Canada and more than 20 MPa in northern Europe during glacial maximum. This vertical stress is supported by the mantle and the flexure of the lithosphere. Since the mantle and the lithosphere continuously respond to the changing ice and water loads, the state of stress at any location continuously changes in time. The changes in the orientation of the state of stress is recorded in the postglacial faults in southeastern Canada.[20] When the postglacial faults formed at the end of deglaciation 9000 years ago, the horizontal principal stress orientation was almost perpendicular to the former ice margin, but today the orientation is in the northeast-southwest, along the direction of seafloor spreading at the Mid-Atlantic Ridge. This shows that the stress due to postglacial rebound had played an important role at deglacial time, but has gradually relaxed so that tectonic stress has become more dominant today.

According to the Mohr-Coulomb Theory of rock failure, large glacial loads generally suppress earthquakes, but rapid deglaciation promotes earthquakes. According to Wu & Hasagawa, the rebound stress that is available to trigger earthquakes today is of the order of 1 MPa.[21] This stress level is not large enough to rupture intact rocks but is large enough to reactivate pre-existing faults that are close to failure. Thus, both postglacial rebound and past tectonics play important roles in today's intraplate earthquakes in eastern Canada and southeast USA. Generally postglacial rebound stress could have triggered the intraplate earthquakes in eastern Canada and may have played some role in triggering earthquakes in eastern USA including the New Madrid earthquakes of 1811.[5] The situation in northern Europe today is complicated by the current tectonic activities nearby and by coastal loading and weakening.

Recent global warming

Recent global warming has caused mountain glaciers and the ice sheets in Greenland and Antarctica to melt and global sea level to rise. Therefore, monitoring sea level rise and the mass balance of ice sheets and glaciers allows us to understand more about global warming.

Recent rise in sea levels has been monitored by tide gauges and Satellite Altimetry (e.g. TOPEX/Poseidon). In addition to the addition of melted ice water from glaciers and ice sheets, recent sea level changes are also affected by the thermal expansion of sea water due to global warming, sea level change due to deglaciation of the last Ice Age (postglacial sea level change), deformation of the land and ocean floor and other factors. Thus, to understand global warming from sea level change, one must be able to separate all these factors, especially postglacial rebound, since it is one of the leading factors.

Mass changes of ice sheets can be monitored by measuring changes in the ice surface height, the deformation of the ground below and the changes in the gravity field over the ice sheet. Thus ICESat, GPS and GRACE satellite mission are useful for such purpose.[22] However, glacial isostatic adjustment of the ice sheets affect ground deformation and the gravity field today. Thus understanding glacial isostatic adjustment is important in monitoring recent global warming.

One of the possible impacts of global warming-triggered rebound may be more volcanic activity in previously ice-capped areas such as Iceland.[23]

Applications

The speed and amount of postglacial rebound is determined by two factors: the viscosity or rheology (i.e., the flow) of the mantle, and the ice loading and unloading histories on the surface of Earth.

The viscosity of the mantle is important in understanding mantle convection, plate tectonics, dynamical processes in Earth, the thermal state and thermal evolution of Earth. However viscosity is difficult to observe because creep experiments of mantle rocks take thousands of years to observe and the ambient temperature and pressure conditions are not easy to attain for a long enough time. Thus, the observations of postglacial rebound provide a natural experiment to measure mantle rheology. Modelling of glacial isostatic adjustment addresses the question of how viscosity changes in the radial[3] [24] [25] and lateral directions[26] and whether the flow law is linear or nonlinear.[27]

Ice thickness histories are useful in the study of paleoclimatology, glaciology and paleo-oceanography. Ice thickness histories are traditionally deduced from the three types of information: First, the sea level data at stable sites far away from the centers of deglaciation give an eastimate of how much water entered the oceans or equivalently how much ice was locked up at glacial maximum. Secondly, the location and dates of terminal moraines tell us the areal extent and retreat of past ice sheets. Physics of glaciers gives us the theoretical profile of ice sheets at equilibrium, it also says that the thickness and horizontal extent of equilibrium ice sheets are closely related to the basal condition of the ice sheets. Thus the volume of ice locked up is proportional to their instantaneous area. Finally, the heights of ancient beaches in the sea level data and observed land uplift rates (e.g. from GPS or VLBI) can be used to constrain local ice thickness. A popular ice model deduced this way is the ICE5G model.[28] Because the response of the Earth to changes in ice height is slow, it cannot record rapid fluctuation or surges of ice sheets, thus the ice sheet profiles deduced this way only gives the "average height" over a thousand years or so.[29]

Glacial isostatic adjustment also plays an important role in understanding recent global warming and climate change.

Discovery

Before the 18th century, it was thought in Sweden that sea levels were falling. On the initiative of Anders Celsius a number of marks were made in rock on different locations along the Swedish coast. In 1765 it was possible to conclude that it was not a lowering of sea levels but an uneven rise of land. In 1865 Thomas Jamieson came up with a theory that the rise of land was connected with the ice age that had been first discovered in 1837. The theory was accepted after investigations by Gerard De Geer of old shorelines in Scandinavia published in 1890.

Legal status

In areas where the rising of land is seen, it is necessary to define the exact limits of property. In Finland, the "new land" is legally the property of the owner of the water area, not any land owners on the shore. Therefore, if the owner of the land wishes to build a pier over the "new land", he needs the permission of the owner of the (former) water area. The landowner of the shore may redeem the new land at market price.[30]

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External links

- BIFROST GPS System (http://www.oso.chalmers.se/~hgs/Bifrost_01/)
- (http://www.gfz-potsdam.de/pb1/op/grace/index_GRACE.html) GRACE Gravity Mission from GPZ, Potsdam
- (http://cfa-www.harvard.edu/space_geodesy/BIFROST/radial_rates.html) BIFROST GPS results from Harvard

Pressure ridge (ice)

A **pressure ridge** is an ice formation typically found on large frozen lakes or sea ice during the winter. In the most basic sense, a pressure ridge is a long crack in the ice that occurs because of repeated heating and cooling on the surface of the lake.

Pressure ridge in Antarctica with Mount Erebus, Ross Island in the background

In cases of extreme cold, ice will shrink in volume like any other solid, opening up cracks in the surface of lakes that are completely frozen over. The cracks quickly fill with water and freeze again, but when the temperature rises later, the ice expands and forces itself upward along the lines of the crack, in much the same fashion that plate tectonics creates mountain ranges, albeit on a much smaller scale. Pressure ridges can sometimes extend for miles, making an ice road impassable for truckers hauling freight to far northern locations.

Pressure ridges also develop on lava flows when the solid colder top layer is deformed by movements of the underflowing hotter lava.

External links

- Pressure ridges on hawaiian an icelandic lava flows (in french) [1]

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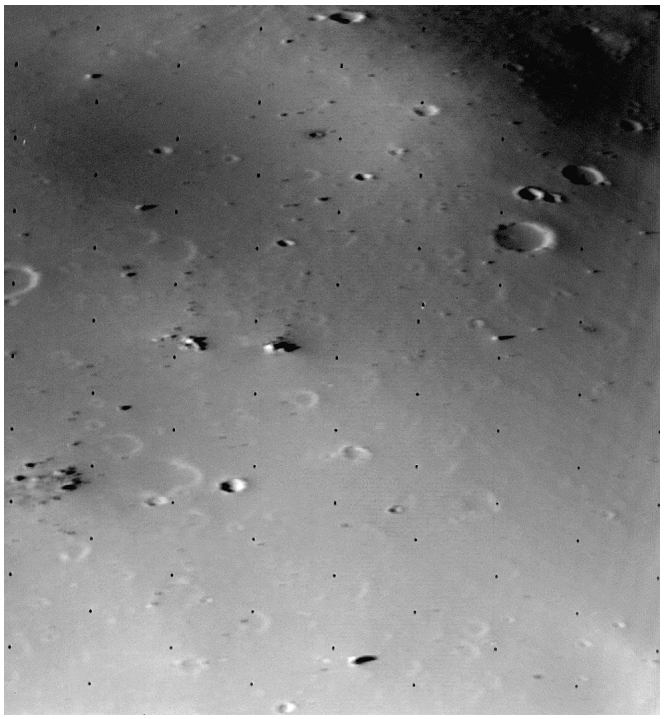
Regolith

Regolith is a layer of loose, heterogeneous material covering solid rock. It includes dust, soil, broken rock, and other related materials and is present on Earth, the Moon, some asteroids, and other planets.



The surface of Deimos, a moon of Mars, seen from a height of 30 km (19 mi) is covered by a layer of regolith estimated to be 50 m (160 ft) thick

Etymology

The term *regolith* combines two Greek words: *rhegos* (ῥῆγος), "blanket", and *lithos* (λίθος), "rock". George P. Merrill first defined the term in 1897, writing:

> In places this covering is made up of material originating through rock-weathering or plant growth *in situ*. In other instances it is of fragmental and more or less decomposed matter drifted by wind, water or ice from other sources. This entire mantle of unconsolidated material, whatever its nature or origin, it is proposed to call the regolith.
>
> —[1]

Earth

Earth's regolith[2] [3] [4] comprises the following subdivisions and components:

- soil or pedolith
- alluvium and other transported cover, including that transported by aeolian, glacial, marine, and gravity flow processes.
- *saprolith*, generally divided into the
  - *upper saprolite*: completely oxidised bedrock
  - *lower saprolite*: chemically reduced partially weathered rocks
  - *saprock*: fractured bedrock with weathering restricted to fracture margins.
- volcanic ash and lavas
- duricrust, formed by cementation of soils, saprolith and transported material by clays, silicates, iron oxides and oxyhydroxides, carbonates and sulfates, as well as less common agents, into indurated layers resistant to weathering and erosion.
- groundwater- and water-deposited salts.
- biota and organic components derived from it.

Regolith can vary from being essentially absent to hundreds of metres in thickness. Its age can vary from instananeous, for an ash fall or alluvium just deposited, to hundreds of millions of years old. Regolith of Precambrian age has been found in parts of Australia.[5]

Regolith on Earth originates from weathering and biological processes; if it contains a significant proportion of biological compounds it is more conventionally referred to as soil. People also call various types of earthly regolith by such names as dirt, dust, gravel, sand, and (when wet) mud.

On Earth, the presence of regolith is one of the important factors for most life, since few plants can grow on or within solid rock and animals would be unable to burrow or build shelter without loose material.

Regolith is also important to engineers constructing buildings,roads and other civil works. The mechanical properties of regolith vary considerably and need to be documented if the construction is to withstand the rigors of use.

Many mineral deposits are hosted in regolith, for example mineral sands, calcrete uranium, and lateritic nickel deposits, among others. Elsewhere, understanding regolith properties, especially geochemical composition, is critical to geochemical and geophysical exploration for mineral deposits beneath it.[6] [7] The regolith is also an important source of construction material, including sand, gravel, crushed stone, lime, and gypsum.

The regolith is the zone through which aquifers are recharged and through which aquifer discharge occurs. Many aquifers, such as alluvial aquifers, occur entirely within regolith. The composition of the regolith can also strongly influence water composition through the presence of salts and acid-generating materials.

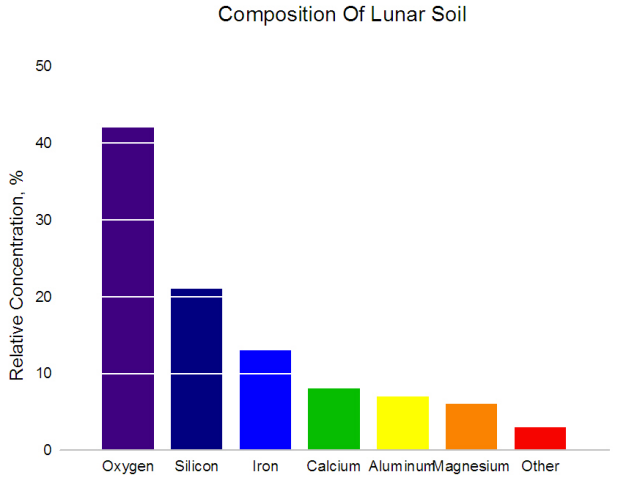
Moon

Nearly the entire lunar surface is covered with regolith, bedrock being exposed only on very steep-sided crater walls and the occasional lava channel. This regolith has been formed over the last 4.6 billion years by the impact of large and small meteoroids and the steady bombardment of micrometeoroids and solar and galactic charged particles breaking down surface rocks.

This famous image taken during Apollo 11 shows the fine and powdery texture of lunar soil.

The impact of micrometeoroids, sometimes travelling faster than 60,000 mph (96,000 km/h), generates enough heat to melt or partially vaporize dust particles. This melting and refreezing welds particles together into glassy, jagged-edged *agglutinates*,[8] reminiscent of tektites found on Earth.

The regolith is generally from 4 to 5 meters thick in mare areas and from 10 to 15 meters in the older highland regions.[9] Below this true regolith is a region of blocky and fractured bedrock created by larger impacts, which is often referred to as the "megaregolith".



Relative Concentration Of Various Elements On The Lunar Surface

The term lunar soil is often used interchangeably with "lunar regolith" but typically refers to the finer fraction of regolith, that which is composed of grains one centimeter in diameter or less. Some have argued that the term "soil" is not correct in reference to the Moon because soil is defined as having organic content, whereas the Moon has none. However, standard usage among lunar scientists is to ignore that distinction. "Lunar dust" generally connotes even finer materials than lunar soil, the fraction which is less than 30 micrometers in diameter. The average chemical composition of regolith might be estimated from the relative concentration of elements in lunar soil.

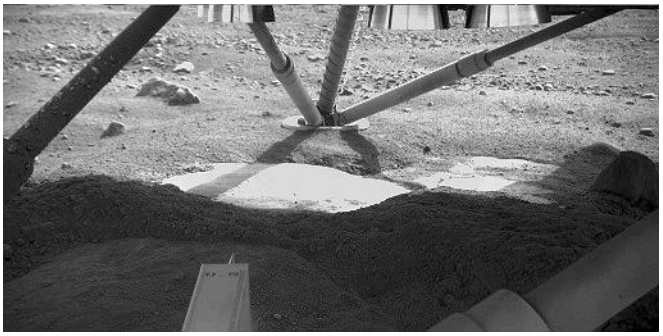
The physical and optical properties of lunar regolith are altered through a process known as space weathering, which darkens the regolith over time, causing crater rays to fade and disappear.

During the early phases of the Apollo Moon landing program, Thomas Gold of Cornell University and part of President's Science Advisory Committee raised a concern that the thick dust layer at the top of the regolith would not support the weight of the lunar module and that the module might sink beneath the surface. However, Joseph Veverka (also of Cornell) pointed out that Gold had miscalculated the depth of the overlying dust,[10] which was only a couple of centimeters thick. Indeed, the regolith was found to be quite firm by the robotic Surveyor spacecraft that preceded Apollo, and during the Apollo landings the astronauts often found it necessary to use a hammer to drive a core sampling tool into it.

Mars

Mars is covered with vast expanses of sand and dust and its surface is littered with rocks and boulders. The dust is occasionally picked up in vast planet-wide dust storms. Mars dust is very fine and enough remains suspended in the atmosphere to give the sky a reddish hue. The sand is believed to move only slowly in the martian winds due to the very low density of the atmosphere in the present epoch. In the past, liquid water flowing in gullies and river valleys may have shaped the martian regolith. Mars researchers are studying whether groundwater sapping is shaping the martian regolith in the present epoch, and whether carbon dioxide hydrates exist on Mars and play a role. It is believed that large quantities of water and carbon

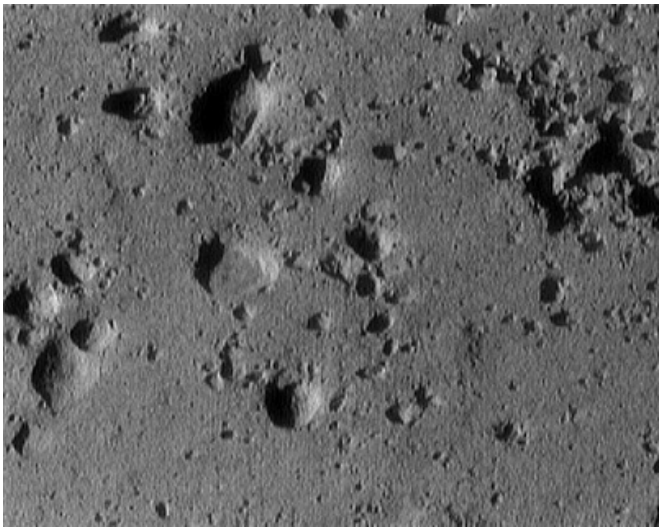
Martian sand and boulders photographed by NASA's Mars Exploration Rover *Spirit*



Regolith beneath NASA's Phoenix Mars Lander, where the descent thrusters have apparently cleared away several patches of soil to expose the underlying ice.

dioxide ices remain frozen within the regolith in the equatorial parts of Mars and on its surface at higher latitudes.

Asteroids

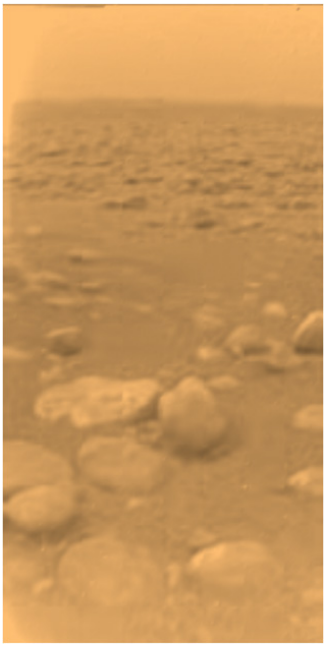


Taken from just 250 m above the surface of Eros as the NEAR Shoemaker spacecraft was landing, this image shows an area that is only 12 m across

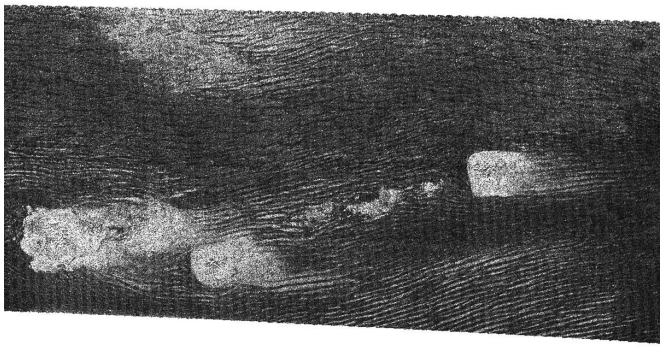
Asteroids have regoliths developed by meteoroid impact. The final images taken by the NEAR Shoemaker spacecraft of the surface of Eros are the best images we have of an asteroidal regolith. The recent Japanese Hayabusa mission also returned spectacular and surprising images of an asteroidal regolith on an asteroid so small it was thought that gravity was too low to develop and maintain a regolith.

Titan

Titan is known to have extensive fields of dunes, though the origin of the material forming the dunes is not known - it could be small fragments of water ice eroded by flowing methane, or possibly particulate organic matter that formed in Titan's atmosphere and rained down on the surface. Scientists are beginning to call this loose icy material *regolith* because of the mechanical similarity with regolith on other bodies, although traditionally (and etymologically) the term had been applied only when the loose layer was composed of mineral grains like quartz or plagioclase or rock fragments that were in turn composed of such minerals. Loose blankets of ice grains were not considered to be regolith because when they appear on Earth in the form of snow they behave differently than regolith, the grains melting and fusing with only small changes in pressure or temperature. The idea of an ice-regolith complete with erosion and aeolian and/or sedimentary processes is unique to Titan because of its thermodynamic environment.



Pebbles on Titan's surface, imaged from a height of about 85 cm by the Huygens spacecraft



Dunes on Titan's surface in a radar image taken by the Cassini spacecraft of a region approximately 160 by 325 kilometers (99 by 202 miles)

The Huygens probe used a penetrometer on landing to characterize the mechanical properties of the local regolith. The surface itself was reported to be a clay-like "material which might have a thin crust followed by a region of relative uniform consistency." Subsequent analysis of the data suggests that surface consistency readings were likely caused by *Huygens* displacing a large pebble as it landed, and that the surface is better described as a 'sand' made of ice grains.[11] The images taken after the probe's landing show a flat plain covered in pebbles. The pebbles, which may be made of water ice, are somewhat rounded, which may indicate the action of fluids on them.[12]

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External links

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- The Regolith Glossary: Surficial Geology, Soils and Landscapes, Richard A Eggleton, Editor (http://crcleme.org.au/Pubs/Monographs/RegolithGlossary.pdf)

Rejuvenation (river)

A river is said to be **rejuvenated** when the base level that it is flowing down to is lowered. This can happen through various causes.

Signs

Rejuvenated terrains usually have complex landscapes because remnants of older landforms are locally preserved. Parts of floodplains may be preserved as terraces along the downcutting stream channels. Meandering streams often become entrenched, so a product of older river systems is found with steep, very pronounced "V" shaped valleys - often seen with younger systems.

Example

One example of rejuvenation is the Nile, which was rejuvenated when the Mediterranean Sea dried up in the late Miocene. Its base level dropped from sea level to over 2 miles below sea level. It cut its bed down to several hundred feet below sea level at Aswan and 8000 feet below sea level at Cairo. After the Mediterranean re-flooded, those gorges gradually filled with silt.

Causes

Rejuvenation may result from causes which are dynamic, eustatic or isostatic in nature. All of these cause the river suddenly to erode its bed vertically (downcutting) faster as it gains gravitational potential energy. That causes effects such as meanders cut down as gorges, steps where the river suddenly starts flowing faster, and fluvial terraces derived from old floodplains.

Dynamic rejuvenation

A region may be uplifted at any stage. This lowers the base level and streams begin active downward erosion again.

Dynamic rejuvenation may be caused by the epeirogenic uplift of a land mass. These movements are either associated with neighboring orogenic movements or may be world wide in nature. Warping or faulting of a drainage basin will steepen the stream gradient followed by the downcutting. The effect of seaward tilting can be felt immediately only when the direction of that stream is parallel to the direction of tilting.

Eustatic rejuvenation

Eustatic rejuvenation results from the causes which bring worldwide decrease in sea level, and two types of such rejuvenation are recognized. Diastrophic eustatism is the change in sea level due to variation in capacity of ocean basins, whereas glacio-eustatism is the change in sea level due to withdrawal or return of water into the oceans, occupying the accumulation or melting of successive ice sheet.

Eustatic rejuvenation rejuvenates the mouth of the stream. Regrading of a stream toward a new base level will precede upvalley. The result may be an interrupted profile with the point of intersection of the old and new base levels.

Static rejuvenation

Three changes may bring static rejuvenation, to the stream.

1. decrease in load
2. increase in runoff because of increased rainfall
3. increase in stream volume through acquisition of new drainage by stream diversion

Rejuvenation due to decrease in load took place during post-glacial times along many valleys that formerly received large quantities of glacial outwash. With change to no glacier conditions stream load decreased and valley deepening ensued.

Rift

For an example for rejuvenation due to rift, see Amazon-Congo.

Either way, rejuvenation results in a "knickpoint", as it appears on a river's long profile, which often turns out to be a waterfall, such as Seljalandsfoss in Southern Iceland, where isostatic (dynamic) uplift has occurred as a result of both construction and deglaciation.

Riffle-pool sequence

In a flowing stream, a **riffle-pool sequence** (also known as a pool-riffle sequence) develops as a stream's hydrological flow structure alternates from areas of relatively shallow to deeper water. This sequence is present only in streams carrying gravel or coarser sediments. Riffles are formed in shallow areas by coarser materials such as gravel deposits over which water flows. Pools are deeper and calmer areas whose bed load (in general) is made up of finer material such as silt. [1] Streams with only sand or silt laden beds do not develop the feature. The sequence within a stream bed commonly occurs at intervals of from 5 to 7 stream widths. Meandering streams with relatively coarse bed load tend to develop a riffle-pool sequence with pools in the outsides of the bends and riffles in the *crossovers* between one meander to the next on the opposite margin of the stream. The pools are areas of active erosion and the material eroded tends to be deposited in the riffle area between.

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Rill

A **Rill** can be a:

- 1.) natural fluvial topographic feature;
- 2.) functional constructed channel to carry a water supply from a water source some distance away;
- 3.) aesthetic garden water feature.

Natural

In fluvial geomorphology, a **rill** is a narrow and shallow incision into topsoil layers, resulting from erosion by overland flow or surface runoff. Rills are most common on slopes of unvegetated ground and agricultural land. However, they can occur on a variety of surfaces. Rills may even be found on the surface of certain soluble rocks like limestone[1] . Rills are often seen as the first signs of major soil erosion, and if left to grow, may evolve into larger fluvial features like gullies, streams, or rivers.

A natural Fluvial **Rill**
flowing through a grassland in Holford Combe.

Formation of Rills

Rills are created when water erodes the topsoil on hillsides, and so, are significantly affected by seasonal weather patterns. They tend to appear more often in rainier months[2] . Rills begin to form when the runoff shear stress, the ability of surface runoff to detach soil particles, overcomes the soil's shear strength, the ability of soil to resist force working parallel to the soil's surface. This begins the erosion process as water breaks soil particles free and carries them down the slope[3] . These forces explain why sandy, loamy soils are especially susceptible to the formation of rills, whereas dense clays tend to resist rill formation[4] .

Rills cannot form on every surface, and their formation is intrinsically connected to the steepness of the hillside slope. Gravity determines the force of the water, which provides the power required to start the erosional environment necessary to create rills. Therefore, the formation of rills is primarily controlled by the slope of the hillside. Slope controls the depth of the rills, while the length of the slope and the soil's permeability control the number of incisions in an area. Each type of soil has a threshold value, a slope angle below which water velocity cannot produce sufficient force to dislodge enough soil particles for rills to form[5] . For instance, on many non-cohesive slopes, this threshold value hovers around an angle of 2 degrees with a shear velocity between 3 and 3.5 cm/s[6] .

After rills begin forming, they are subjected to variety of other erosional forces which may increase their size and output volume. Up to 37% of erosion in a rill-ridden area may derive from mass movement, or collapse, of rill sidewalls. As water flows through a rill, it will undercut into the walls, triggering collapse. Also, as water seeps into the soil of the walls, they weaken, amplifying the chance of wall collapse. The erosion created by these forces increases the size of the rill while also swelling its output volume[7] .

Significance of Rill Erosion

Although rills are small, they transport significant amounts of soil each year. Some estimates claim rill flow has a carrying capacity of nearly ten times that of non-rill, or interrill, areas. In a moderate rainfall, rill flow can carry rock fragments up to 9 cm in diameter downslope. In 1987, scientist J. Poesen conducted an experiment on the Huldenberg field in Belgium which revealed that during a moderate rainfall, rill erosion removed as much as much as 200 kg (in submerged weight) of rock[8] .

Unfortunately, the considerable effect rills have on landscapes often negatively impact human activity. Rills have been observed washing away archaeological sites[9] . They are also very common in agricultural areas because sustained agriculture depletes the soil of much of its organic content, increasing the erodibility of the soil. Agricultural machines, such as tractors, compact the soil to the point where water flows over the surface rather than seeping into the soil. Tractor wheel impressions often channel water, providing a perfect environment for the generation of rills. If left alone, these rills may erode considerable amounts of arable soil[10] .

Luckily, rills are small and are easily repaired by tilling the soil. This will prevent, for a time at least, the rills from growing and eroding the landscape more rapidly with time[11] .

Functional

A constructed functional **rill** is a small canal; of stone, brick, concrete, or other lining material; usually rectilinear in cross section; for water transportation from a source such as a river-creek, spring, reservoir, qanat, or aqueduct; for domestic consumption or agricultural irrigation of crop land uses.

Rills were traditionally used in Middle Eastern and Mediterranean climate cultures of ancient and historical eras; and other climates and continents worldwide. They are distinguished from a 'water ditch' by being lined to reduce absorption losses and to increase durability. The *Falaj* irrigation system at the Al Ain Oasis, in present day Abu Dhabi Emirate, uses rills as part of its qanat water system. Sometimes in the Spanish language they are called *Acequias*.

A functional **Rill**, part of the *Falaj* water transportation system, at Al Ain Oasis, in the Abu Dhabi Emirate.

Aesthetic

A **Rill** may also refer to narrow channels of water inset into the pavement of a garden, as linear water features, and often tiled and part of a fountain design.

The historical origins are from paradise garden religious images that first translated into ancient Persian Gardens. Rills were later exceptionally developed in the Moorish (Spanish) Gardens of Al-andalus, such as at the Alhambra in Granada; and also in other Islamic gardens, cultures, and countries. Early 20th century examples are in the Maria Louisa Park gardens in Seville, Spain; and at the Casa del Herrero gardens in Montecito, California.

Other

A rill may also refer to the groove in a vinyl record where the information is stored in analog form for playback.

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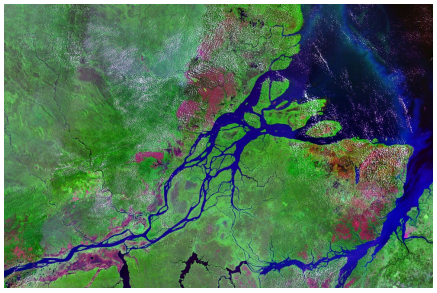
River

A **river** is a natural watercourse,[1] usually freshwater, flowing towards an ocean, a lake, a sea, or another river. In a few cases, a river simply flows into the ground or dries up completely before reaching another body of water. Small rivers may also be called by several other names, including stream, creek, brook, rivulet, tributary and rill; there is no general rule that defines what can be called a river, although in some countries or communities a stream may be defined by its size. Many names for small rivers are specific to geographic location; one example is "burn" in Scotland and northeast England. Sometimes a river is said to be larger than a creek,[2] but this is not always the case, because of vagueness in the language.[3]

Melting toe of Athabasca Glacier, Jasper National Park, Alberta, Canada.

A river is part of the hydrological cycle. Water within a river is generally collected from precipitation through a drainage basin from surface runoff and other sources such as groundwater recharge, springs, and the release of stored water in natural ice and snowpacks (e.g., from glaciers). Potamology is the scientific study of rivers.



A false-color satellite photograph of the Amazon River in Brazil.

Topography

The water in a river is usually confined to a channel, made up of a stream bed between banks. In larger rivers there is also a wider floodplain shaped by flood-waters over-topping the channel. Flood plains may be very wide in relation to the size of the river channel. This distinction between river channel and floodplain can be blurred especially in urban areas where the floodplain of a river channel can become greatly developed by housing and industry.h The term upriver refers to the direction leading to the source of the river, which is against the direction of flow. Likewise, the term downriver describes the direction towards the mouth of the river, in which the current flows.

The river channel typically contains a single stream of water, but some rivers flow as several interconnecting streams of water, producing a braided river. Extensive braided rivers are now found in only a few regions worldwide, such as the South Island of New Zealand. They also occur on peneplains and some of the larger river deltas. Anastamosing rivers are similar to braided rivers and are also quite rare. They have multiple sinuous channels carrying large volumes of sediment.

A river flowing in its channel is a source of energy which acts on the river channel to change its shape and form. According to Brahm's law (sometimes called Airy's law), the mass of objects that may be carried away by a river is proportional to the sixth power of the river flow speed. Thus, when the speed of flow increases two times, it can transport 64 times larger (i.e., more massive) objects.[4] In mountainous torrential zones this can be seen as erosion channels through hard rocks and the creation of sands and gravels from the destruction of larger rocks. In U-shaped glaciated valleys, the subsequent river valley can often easily be identified by the V-shaped channel that it has carved. In the middle reaches where the river may flow over flatter land, meanders may form through erosion of the river banks and deposition on the inside of bends. Sometimes the river will cut off a loop, shortening the channel and forming an oxbow lake or billabong. Rivers that carry large amounts of sediment may develop conspicuous deltas at their mouths, if conditions permit. Rivers whose mouths are in saline tidal waters may form estuaries.

Nile River delta, as seen from Earth orbit. The Nile is an example of a wave-dominated delta that has the classic Greek delta (Δ) shape after which River deltas were named.

Throughout the course of the river, the total volume of water transported downstream will often be a combination of the free water flow together with a substantial contribution flowing through sub-surface rocks and gravels that underlie the river and its floodplain (called the hyporheic zone). For many rivers in large valleys, this unseen component of flow may greatly exceed the visible flow.

Subsurface streams

Most but not all rivers flow on the surface. Subterranean rivers flow underground in caves or caverns. Such rivers are frequently found in regions with limestone geologic formations. Subglacial streams are the braided rivers that flow at the beds of glaciers and ice sheets, permitting meltwater to be discharged at the front of the glacier. Because of the gradient in pressure due to the overlying weight of the glacier, such streams can even flow uphill.

Permanence of flow

An *intermittent river* (or ephemeral river) only flows occasionally and can be dry for several years at a time. These rivers are found in regions with limited or highly variable rainfall, or can occur because of geologic conditions such as having a highly permeable river bed. Some ephemeral rivers flow during the summer months but not in the winter. Such rivers are typically fed from chalk aquifers which recharge from winter rainfall. In the UK these rivers are

called *Bournes* and give their name to place such as Bournemouth and Eastbourne

Classification

River have been classified by many criteria including their topography, their biotic status, their relevance to white water or canoeing activities.

Topographical classification

Rivers can generally be classified as either alluvial, bedrock, or some mix of the two. Alluvial rivers have channels and floodplains that are self-formed in unconsolidated or weakly-consolidated sediments. They erode their banks and deposit material on bars and their floodplains. Bedrock rivers form when the river downcuts through the modern sediments and into the underlying bedrock. This occurs in regions that have experienced some kind of uplift (thereby steepening river gradients) or in which a particular hard lithology causes a river to have a steepened reach that has not been covered in modern alluvium. Bedrock rivers very often contain alluvium on their beds; this material is important in eroding and sculpting the channel. Rivers that go through patches of bedrock and patches of deep alluvial cover are classified as mixed bedrock-alluvial.

Alluvial rivers can be further classified by their channel pattern as meandering, braided, wandering, anastomose, or straight. The morphology of an alluvial river reach is controlled by a combination of sediment supply, substrate composition, discharge, vegetation, and bed aggradation.

The work of William Morris Davis at the turn of the 20th century used a classification based of river “age” as a way to characterise rivers.

- **Youthful river**: A river with a steep gradient that has very few tributaries and flows quickly. Its channels erode deeper rather than wider. Examples include the Brazos, Trinity and Ebro rivers.
- **Mature river**: A river with a gradient that is less steep than those of youthful rivers and flows more slowly. A mature river is fed by many tributaries and has more discharge than a youthful river. Its channels erode wider rather than deeper. Examples include the Mississippi, Saint Lawrence, Danube, Ohio, Thames and Paraná rivers.
- **Old river**: A river with a low gradient and low erosive energy. Old rivers are characterized by flood plains. Examples include the Yellow, Ganges, Tigris, Euphrates, Indus and Nile rivers.
- **Rejuvenated river**: A river with a gradient that is raised by tectonic uplift.

The way in which a river's characteristics vary between the upper course and lower course of a river are summarized by the Bradshaw model. Power-law relationships between channel slope, depth, and width are given as a function of discharge by "river regime".

Biotic classification

There are very many systems of classification based on biotic conditions typically assigning classes from the most oligotrophic or unpolluted through to the most eutrophic or polluted.[5] Other systems are based on a whole eco-system approach such as developed by the New Zealand Ministry for the Environment.[6] In Europe, the requirements of the Water Framework Directive has let to the development of a wide range of classification methods including classifications based on fishery status [7] A system of river zonation used in francophone communities [8] [9] divides rivers into three primary zones:

- The *crenon* is the uppermost zone at the source of the river. It is further divided into the eucrenon (spring or boil zone) and the hypocrenon (brook or headstream zone). These areas are characterized by low temperatures, reduced oxygen content and slow moving water.
- The *rhithron* is the upstream portion of the river that follows the crenon. It is characterized by relatively cool temperatures, high oxygen levels, and fast, turbulent flow.

- The *potamon* is the remaining downstream stretch of river. It is characterized by warmer temperatures, lower oxygen levels, slow flow and sandier bottoms.

Whitewater classification

The International Scale of River Difficulty is used to rate the challenges of navigation—particularly those with rapids. Class I is the easiest and Class VI is the hardest.

Stream order classification

The Strahler Stream Order ranks rivers based on the connectivity and hierarchy of contributing tributaries. Headwaters are first order while the Amazon River is twelfth order. Approximately 80% of the rivers and streams in the world are of the first and second order.

Uses

Rivers have been used as a source of water, for obtaining food, for transport, as a defensive measure, as a source of hydropower to drive machinery, for bathing, and as a means of disposing of waste.

Rivers have been used for navigation for thousands of years. The earliest evidence of navigation is found in the Indus Valley Civilization, which existed in northwestern Pakistan around 3300 BC.[10] Riverine navigation provides a cheap means of transport, and is still used extensively on most major rivers of the world like the Amazon, the Ganges, the Nile, the Mississippi, and the Indus. Since river boats are often not regulated, they contribute a large amount to global greenhouse gas emissions, and to local cancer due to inhaling of particulates emitted by the transports.[11] [12]

Leisure activities on the River Avon at Avon Valley Country Park, Keynsham, United Kingdom. A boat giving trips to the public passes a moored private boat.

In some heavily forested regions such as Scandinavia and Canada, lumberjacks use the river to float felled trees downstream to lumber camps for further processing, saving much effort and cost by transporting the huge heavy logs by natural means.

Rivers have been a source of food since pre-history.[13] They can provide a rich source of fish and other edible aquatic life, and are a major source of fresh water, which can be used for drinking and irrigation. It is therefore no surprise to find most of the major cities of the world situated on the banks of rivers. Rivers help to determine the urban form of cities and neighbourhoods and their corridors often present opportunities for urban renewal through the development of foreshoreways such as Riverwalks. Rivers also provide an easy means of disposing of waste-water and, in much of the less developed world, other wastes.

Fast flowing rivers and waterfalls are widely used as sources of energy, via watermills and hydroelectric plants. Evidence of watermills shows them in use for many hundreds of years such as in Orkney at Dounby click mill. Prior to the invention of steam power, water-mills for grinding cereals and for processing wool and other textiles were common across Europe. In the 1890s the first machines to generate power from river water were established at places such as Cragside in Northumberland and in recent decades there has been a significant increase in the development of large scale power generation from water, especially in wet mountainous regions such as Norway

The coarse sediments, gravel and sand, generated and moved by rivers are extensively used in construction. In parts of the world this can generate extensive new lake habitats as gravel pits re-fill with water. In other circumstances it can destabilise the river bed and the course of the river and cause severe damage to spawning fish populations which rely on stable gravel formations for egg laying.

In upland rivers, rapids with whitewater or even waterfalls occur. Rapids are often used for recreation, such as whitewater kayaking.

Rivers have been important in determining political boundaries and defending countries. For example, the Danube was a long-standing border of the Roman Empire, and today it forms most of the border between Bulgaria and Romania. The Mississippi in North America and the Rhine in Europe are major east-west boundaries in those continents. The Orange and Limpopo Rivers in southern Africa form the boundaries between provinces and countries along their routes.

Ecosystem

The organisms in the riparian zone respond to changes in river channel location and patterns of flow. The ecosystem of rivers is generally described by the River continuum concept, which has some additions and refinements to allow for spatial (dams, waterfalls) and temporal (extensive flooding). The basic idea is that the river can be described as a system that is continuously changing along its length in the physical parameters, the availability of food particles and the composition of the ecosystem. The food (energy) that is the leftover of the upstream part is being utilized downstream.

The general pattern is that the first order streams contain particulate matter (decaying leaves from the surrounding forests), which is processed there by shredders like Plecoptera larvae. The leftovers of the shredders are utilized by collectors as Hydropsyche and furter downstream algae that create the primary production become the main foodsource of the organisms. All changes are gradual and the distribution of each species can be described as a normal curve with the highest density where the conditions are optimal. In rivers succession is virtually absent and the composition of the ecosystem stays fixed in time.

Chemistry

The chemistry of rivers is complex and depends on inputs from the atmosphere, the geology through which it travels and the inputs from man's activities. The chemistry of the water has a large impact on the ecology of that water for both plants and animals and it also affects the uses that may be made of the river water. Understanding and characterising river water chemistry requires a well designed and managed programme of sampling and analysis

Like many other Aquatic ecosystems, rivers too are under increasing threat of pollution. According to a study of the WWF's Global Freshwater Programme, the 10 most polluted rivers are: Ganges, Indus, Yangtze, Salween-Nu, Mekong-Lancang, Rio Grande/Rio Bravo, La Plata, Danube, Nile-Lake Victoria, and the Murray-Darling.[14]

Brackish water

Some rivers generate brackish water by having their river mouth in the ocean. This, in effect creates a unique environment in which certain species are found.

Flooding

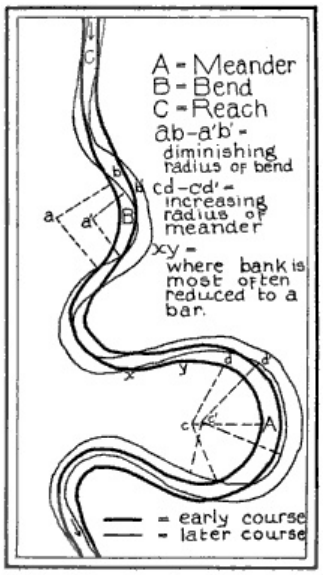
Flooding is a natural part of a river's cycle. The majority of the erosion of river channels and the erosion and deposition on the associated floodplains occur during flood stage. In many developed areas, human activity has changed river channel form, altering different magnitudes and frequencies of flooding. Some examples of this are the building of levees, the straightening of channels, and the draining of natural wetlands. In many cases human activities in rivers and floodplains have dramatically increased the risk of flooding. Straightening rivers allows water to flow more rapidly downstream increasing the risk of flooding places further downstream. Building on flood plains removes flood storage which again exacerbates downstream flooding. The building of levees may only protect the area behind the levees and not those further downstream. Levees and flood-banks can also increase flooding upstream because of back-water pressure as the upstream water has to squeeze between the levees.

Flow

Studying the flows of rivers is one aspect of hydrology.[15]

Direction

A common misconception is that most, or even all, rivers flow from north to south.[16] [17] [18] Rivers in fact flow downhill regardless of compass direction. Sometimes downhill is from north to south, but equally it can be from south to north, and usually is a complex meandering path involving all directions of the compass.[19] [20] [21] Three of the ten longest rivers in the world - the Nile, Yenisei, and Ob - flow north, as do other major rivers such as the Rhine, Mackenzie, and Nelson.



River meandering course

Rivers flowing downhill, from river source to river mouth, do not necessarily take the shortest path. For alluvial streams, straight and braided rivers have very low sinuosity and flow directly down hill, while meandering rivers flow from side to side across a valley. Bedrock rivers typically flow in either a fractal pattern, or a pattern that is determined by weaknesses in the bedrock, such as faults, fractures, or more erodible layers.

Rate

Volumetric flow rate, also called discharge, volume flow rate, and rate of water flow, is the volume of water which passes through a given cross-section of the river channel per unit time. It is typically measured in cubic meters per second (cumec) or cubic feet per second (cfs), where 1 m^3/s = 35.51 ft^3/s; it is sometimes also measured in litres or gallons per second.

Volumetric flow rate can be thought of as the mean velocity of the flow through a given cross-section, times that cross-sectional area. Mean velocity can be approximated through the use of the Law of the Wall. In general, velocity increases with the depth (or hydraulic radius) and slope of the river channel, while the cross-sectional area scales with the depth and the width: the double-counting of depth shows the importance of this variable in determining the discharge through the channel.

Management

Rivers are often managed or controlled to make them more useful, or less disruptive, to human activity.

- Dams or weirs may be built to control the flow, store water, or extract energy.
- Levees, known as dikes in Europe, may be built to prevent river water from flowing on floodplains or floodways.
- Canals connect rivers to one another for water transfer or navigation.
- River courses may be modified to improve navigation, or straightened to increase the flow rate.

River bank repair

River management is a continuous activity as rivers tend to 'undo' the modifications made by people. Dredged channels silt up, sluice mechanisms deteriorate with age, levees and dams may suffer seepage or catastrophic failure.

The benefits sought through managing rivers may often be offset by the social and economic costs of mitigating the bad effects of such management. As an example, in parts of the developed world, rivers have been confined within channels to free up flat flood-plain land for development. Floods can inundate such development at high financial cost and often with loss of life.

Rivers are increasingly managed for habitat conservation, as they are critical for many aquatic and riparian plants, resident and migratory fishes, waterfowl, birds of prey, migrating birds, and many mammals.

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River bifurcation

River bifurcation (from Latin: *furca*, fork) occurs when a river flowing in a single stream separates into two or more separate streams (called distributaries) which continue downstream. Some rivers form complex networks of distributaries, especially in their deltas. If the streams eventually merge again or empty into the same body of water, then the bifurcation forms an island.

Bifurcation in Hövelhof, Germany

River bifurcation may be temporary or semi-permanent, depending on the strength of the material which separates the distributaries. For example, a mid-stream island of soil or silt in a delta is most likely temporary. A location where a river divides around a rock fin, e.g. a volcanically formed Dike, or a mountain, may be more lasting. A bifurcation may also be man-made, for example when two streams are separated by a long bridge pier.

River deltas such as the pictured delta of the Salween River in Myanmar often show bifurcations. The water flows in from the lower section of the image and passes on both sides of the large island in the center.

Examples

One example of a natural bifurcation is the Casiquiare canal that links the Orinoco River with the Amazon.

Another occurrence of a river bifurcation was in Serbia[1] [2] [3] [4] [5] , Europe in the Nerodimka River. The Nerodime Bifurcation was a hydrological curiosity: separate streams flowed into the Aegean and the Black Seas. The Bifurcation was located in the southern part of the Kosovo territory of Uroševac Municipality. The Bifurcation of Nerodimka was the first hydrological protected object in Serbia (1979). The Nerodimka Bifurcation is a strict wildlife sanctuary, category I according to (IUCN), with an area of 13.0 ha (about 32 acres). This bifurcation is considered to be an artificial phenomenon, but created under extremely favorable natural conditions.

In the past, the small Kalaus River in south-western Russia, when reaching the thalweg of the Kuma-Manych Depression at 45°43′N 44°06′E, would split, the two distributaries becoming the headwaters of the West and East Manych Rivers. The former flows west into the Don River and eventually into the Sea of Azov, while the latter flows east, and is lost in the steppe before ever reaching the Caspian Sea. However a dam was built, preventing water from flowing from the Kalaus into the East Manych; thus the Kalaus is now the source of the West Manych only.[6]

The Bahr Yussef is a channel which splits off the west side of the Nile and drains into the Birket Qarun, an inland sea in the Fayum Depression. Originally a natural bifurcation for flood waters, its flow was increased by canalisation in the 12th Dynasty (about 1900 BC). Around 230BC, the channel of the Nile from which it came (itself a bifurcation) dried up, but has since been fed by a new canal to allow water again to make it from the Nile to Al Fayyum. The entire waterway is over 300km long, consisting of modern canals taking Nile water from Asyut to Dairut[7] , the old Nile channel then runs alongside the Nile for over 150km to Lahun, then the Ancient Egyptian canal carries the water into the Fayum Depression.

Torne River has a distributary called the Tärendö River, which on average transports 57% of the water of the Torne River into the Kalix River.[8]

Goat Island just above Niagara Falls separates the Niagara River into two parts, creating the American and Canadian Falls, but this is too small to be considered a bifurcation.

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River channel migration

River channel migration is the lateral motion of an alluvial river channel across its floodplain due to processes of erosion of and deposition on its banks and bars. In meandering streams, channel migration typically takes place by erosion of the cut bank and deposition on the point bar. In braided streams, channel change occurs due to sediment transport and the motion of barforms through the channel.

Channel migration is an important engineering problem, as it can undercut and damage transportation infrastructure.[1]

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River island

A **river island** or **river archipelago** is any landmass or fluvial landform within a river.

Regional variations

- An islet is a very small island, which could be surrounded by a river.
- The term "*towhead*" implies a small islet or sandbar within a river (most often the Mississippi River) having a grouping or thicket of trees, and is often used in the Midwestern United States. Many rivers, if wide enough, can house considerably large islands. The term "towhead" was popularised by Mark Twain's *Adventures of Huckleberry Finn*.
- In England, a river island in the Thames is referred to as an "*ait*".

In terms of real estate, river islands are often viewed as being considerably cheaper purchases as private islands than ones situated in lakes or oceans.

Lists of river islands

Largest river islands in the world

This list is incomplete.

- *Note: Including some river islands which "**bordered with sea and Ocean**".*

Name	Area (km²)	Country	River
Ilha do Bananal	19,162	Brazil	Tocantins River
Tupinambarana	11,850	Brazil	Amazon River
Ilha Grande do Gurupá	4864	Brazil	Amazon River/ Xingu River
Mompox Island	2,832 [1]	Colombia	Magdalena River
Veľký Žitný ostrov	1,885.2 [2]	Slovakia	Danube
Richards Island	2165	Canada	Yukon River
Hatiya Island	1508.23	Bangladesh	Meghna River
Letea Island	1480	Romania	Danube River
Camargue	1453	France	Grand Rhone, Petit Rhone
Bhola Island	1441	Bangladesh	Meghna River
Ile a Mofil	1250	Senegal	Senegal River
Zhongshan Dao	1055.42	China	Pearl River
Chongming Island	1,041.21	China	Yangtze River
Sandwip Island	762.42	Bangladesh	Meghna River
Great Brăila Island	720.2	Romania	Danube
Sumba Island	500 [3]	Democratic Republic of Congo	Congo River
Majuli	421.65	India	Brahmaputra River
Szigetköz / Malý Žitný ostrov	375	Hungary, Slovakia	Danube
Manpura Island	373	Bangladesh	Meghna
Inhacamba	340	Mozambique	Zambezi

Hoeksche Waard	323.74	Netherlands	Oude Maas, Nieuwe Maas
Ilha de Maracá	300	Brazil	Amazon River
Csepel Island	257	Hungary	Danube
Voorne-Putten	220	Netherlands	Oude Maas, Nieuwe Maas
Mosquiero	212	Brazil	Amazon River
Mbamou Island	180	Congo-Brazzaville [3]	Congo River
IJsselmonde	105.3	Netherlands	Oude Maas, Nieuwe Maas
Hengqin New Area	96	China	Pearl River
Haizhu Island	90.5	China	Pearl River
Changxing Island	88.54	China	Yangtze River
Sauvie Island	84.82	USA	Columbia River, Willamette River, Multnomah Channel
Dordrecht Island	79.53	Netherlands	Oude Maas, Hollands Diep
Grand Island	73.8	USA	Niagara River
Ostrvo	60	Serbia	Danube
Manhattan Island	59	USA	Hudson River/East River
Hengsha Island	55.74	China	Yangtze River
Wilhelmsburg	35.3	Germany	Elbe
Isla Teja	15	Chile	Cau-Cau River/Cruces River/Valdivia River

Most populous river islands

This list is incomplete.

Name	Population	Area [km²]	Country	City	River
Manhattan Island	1,634,795 (2008)	59	USA	New York City	Hudson River/East River
Montreal	1,854,442	499	Canada	Montreal	St. Lawrence River
Veľký Žitný ostrov	226,446 (2001)	1,885	Slovakia	several	Danube
Vasilievsky Island	202,650 (2002)	?	Russia	St. Petersburg	Bolshaya Neva/Malaya Neva
Lulu Island	168,162	?	Canada	Richmond	Fraser
Majuli	140,000	422	India		Brahmaputra River
Csepel Island	>65,148	257	Hungary	diverse	Danube
Wilhelmsburg	49,132 (2006)	35.3	Germany	Hamburg	Elbe

Notable river islands

This list is incomplete.

Name	Area [km²]	Country	Notable for
Abagaitu Islet	?	China/Russia	Border disputes
Ada	2.7	Serbia	Belgrade recreational area/tourism
Blood Island	?	USA	Duels
Boblo Island	1.1	Canada	Boblo Island Amusement Park
Donauinsel	~4	Austria	Vienna recreational area
Hajógyári Island	1.08	Hungary	Sziget Festival
Île de la Cité	?	France	Part of Paris' city centre
Spreeinsel	?	Germany	Part of Berlin's city centre, Museum Island (*Museumsinsel*) in the northern part
Tiber Island	?	Italy	Part of Rome's city centre
U Thant Island	?	USA	New York's smallest island, 100 ft x 200 ft
Vasilievsky Island	0.74	China	Border disputes and war between China and Russia in 1969
Zhenbao Island			

Other river islands

Name	Area [km²]	Country
Ackerman Island	?	USA
Barnston Island	?	Canada
Flint River Towhead	?	?
Isla del Rey	?	Chile
Mancera Island	?	Chile
McGibbon Island	?	?
Peche Island	?	Canada
Pippin Towhead	?	?
Raghopur	?	India
Witten Towhead	?	USA

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River morphology

The terms **river morphology** and its synonym fluvial geomorphology are used to describe the shapes of river channels and how they change over time. The morphology of a river channel is a function of a number of processes and environmental conditions, including the composition and erodibility of the bed and banks (e.g., sand, clay, bedrock); vegetation and the rate of plant growth; the availability of sediment; the size and composition of the sediment moving through the channel; the rate of sediment transport through the channel and the rate of deposition on the floodplain, banks, bars, and bed; and regional aggradation or degradation due to subsidence or uplift.

The study of river morphology is accomplished in the field of fluvial geomorphology.

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External links

- River Morphology at Delft University of Technology [2]
- River Engineering and Morphology at WL | Delft Hydraulics [3]
- River morphology in Delft Cluster [4]

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[4] http://www.delftcluster.nl/website/nl/page393.asp

Rock veneer

A **rock veneer** is a geomorphic formation in which rock fragments (clasts) of gravel or cobble size form a thin cover over a surface or hillslope. Rock veneers are typically one or two clasts thick and may partially or fully cover the ground surface.[1] Veneers typically form in semiarid and arid regions where chemical weathering rates and the potential for mass wasting are low. Other names for a rock veneer are rock-fragment cover (RFC), stone pavement, desert pavement, stony mantle, hammada and reg.

Formation

Rock veneers commonly arise from the weathering of resistant rocks of quartzite, felsic granites, coarse granites, and dense basalts. As these larger rocks are deposited on a surface, smaller sands either are removed by wind or water erosion, or settle and form a fine-grained layer beneath the larger veneer rocks. The larger clasts then rearrange and settle to form the rock veneer.[2]

Rock veneers form a variety of ways, with two major types; *in situ* veneers form in place by means of weathering, fluvial erosion, deflation (the removal of loose, fine-grained particles) or accretion; other veneers are transported via soil creep, sheet flooding or gully gravure (described below).[3] Rock veneers are typically distinguished through six variables: particle size, particle density, stability characteristics, potential for storing mobile sediments, degree of abrasion, and varnishing.[4]

Gully Gravure

Gully gravure is a transportation process by which rock veneers can be formed. Valleys formed of gullies and rills are made and coarse rock fragments are deposited in side channels. As the side channels fill in, water forms new, less resistant channels down the borders of the coarse channels and finer gullies and rills. These channels build up, and the process happens again, resulting in a reversal of rills and gullies, with coarser clasts on the surface.

Root Throw

Root throw is the process that occurs when a tree topples, raising its rootwad and the rock fragments in it. Fine sediment falls back into the rootwad pit or travels downstream, but coarse sediments form a local rock veneer around the rootwad. This local rock veneer is larger than the pit of the rootwad, as falling clasts extend the area of veneer. In a study of rootwads in Westcliffe, Colorado, it was estimated that root throw could have created a rock veneer over 90% of the surface during the Holocene.

Root throw produces a rock veneer when there are a large number of clasts near the surface, where there are: a slow rate of chemical weathering, insufficient precipitation to move the large clasts, high velocity winds, conditions favorable to shallow-rooted trees, and trees large enough to embed coarse rock in their roots.

Effects

Hillslopes with a rock veneer are more stable than those without and have lower erosion rates. Rock veneers form a rocky armor on the hillslope which prevents the erosion of smaller sediments and stabilizes the slope. Rock veneers, forming when influx and outflux sediment rates are equal, indicate a hillslope in equilibrium, partly due to their protective cover on the slope. Erosion rates on veneered hillslopes are low to moderate.

Notes

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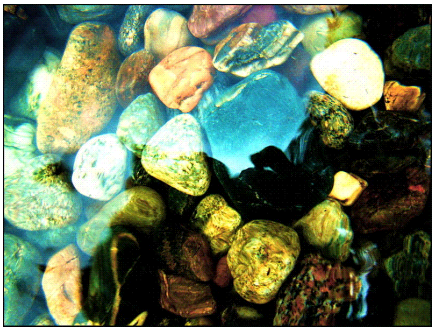
Roundness (geology)

Roundness is the degree of smoothing due to abrasion of sedimentary particles. It is expressed as the radius of the average radius of curvature of the edges or corners to the radius of curvature of the maximum inscribed sphere.



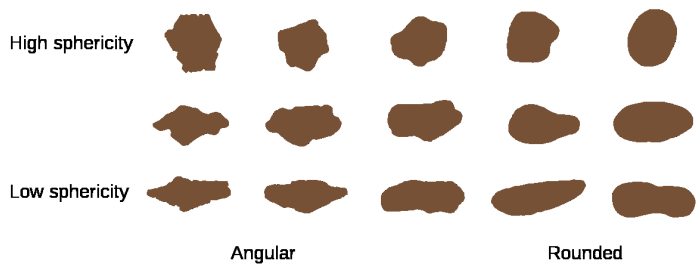
Rounded pebbles in a streambed

Well-rounded cobble from the beach on Teletskoe Lake, Altai Republic

Granite erratic middle-rounded boulders on Teletskoe Lake, Altai Republic

Measure of roundness

Rounding, roundness or angularity are terms used to describe the shape of the corners on a particle (or clast) of sediment.[1] Such a particle may be a grain of sand, a pebble, cobble or boulder. Although roundness can be numerically quantified, for practical reasons geologists typically use a simple visual chart with up to six categories of roundness:



Schematic representation of difference in grain shape. Two parameters are shown: sphericity (vertical) and rounding (horizontal).

- Very angular: corners sharp and jagged
- Angular
- Sub-angular
- Sub-rounded
- Rounded
- Well-rounded: corners completely rounded

Rounding of sediment particles can indicate the distance and time involved in the transportation of the sediment from the source area to where it is deposited.

Speed of rounding will depend on composition, hardness and mineral cleavage. For example, a soft claystone pebble will obviously round much faster, and over a shorter distance of transport, than a more resistant quartz pebble. The rate of rounding is also affected by the grain size and energy conditions.

Abrasion

Abrasion occurs in natural environments such as beaches, sand dunes, river or stream beds by the action of current flow, wave impact, glacial action, wind, gravitational creep and other erosive agents.

Paleogeographic value of determining the degree of roundness of clastic material

Roundness is an important indicator of the genetic affiliation of a clastic rock. The degree of roundness points to the range and mode of transport of clastic material, and can also serve as a search criterion in mineral exploration, especially for placer deposits.

Alluvial debris in major rivers tend to exhibit a high degree of roundness. Alluvium from small rivers is less rounded. Deposits of ephemeral streams exhibit little rounding with angular clasts.

Clast rounding in non-sedimentary environments

Pebble dikes are dikelike bodies found in intrusive environments which contain variably rounded fragments. The clasts originate in deeper formations and have been brought up by diatreme or intrusive breccias. The fragments have been rounded due to either *milling* action or corrosion by hydrothermal fluids.[2] [3] The ore deposits of Tintic mining district, Utah; Ouray, Colorado; Silver Bell; and Bisbee, Arizona and the Kiruna iron deposit in Sweden contain these pebble dikes.[3]

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Rouse number

The **Rouse number** is a non-dimensional number in fluid dynamics which is used to define a concentration profile of suspended sediment and which also determines how sediment will be transported in a flowing fluid. It is a ratio between the sediment fall velocity w_s and the upwards velocity on the grain as a product of the von Kármán constant κ and the shear velocity u_*.

$$P = \frac{w_s}{\kappa u_*}$$

It is named after the American fluid dynamicist Hunter Rouse. It is a characteristic scale parameter in the Rouse Profile of suspended sediment concentration with depth in a flowing fluid. The concentration of suspended sediment with depth goes as the power of the negative Rouse number. It also is used to determine how the particles will move in the fluid. The required Rouse numbers for transport as bed load, suspended load, and wash load, are given below.

Mode of Transport	Rouse Number
Bed load	>2.5
Suspended load: 50% Suspended	>1.2, <2.5
Suspended load: 100% Suspended	>0.8, <1.2
Wash load	<0.8

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Sag (geology)

In geology a **sag** is a former river bed which has been partially filled with debris from glaciation or other natural processes but which is still visible in the surface terrain. Sags formed by the former river beds of large rivers often become the valleys of smaller streams after a change of course by the main river.

Examples of sags include the former continuations of the Grand, Moreau and White rivers in South Dakota in the United States. Before the last ice age these rivers continued eastward past their current confluences with the present course of Missouri River. The sags are prominently visible on the plateau of the Coteau du Missouri, allowing small streams to drain into the Missouri from its eastern side.

Sag pond

A **sag pond** is a body of water, which forms as water collects in the lowest parts of the depression that forms between two strands of an active strike-slip fault. The relative motion of the two fault strands results in a stretching of the land between them, causing the land between them to sink.

External links

- Glossary at Wallace Creek [1]

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Salt pan (geology)

Dry lakes are ephemeral lakebeds, or a remnant of an endorheic lake. Such flats consist of fine-grained sediments infused with alkali salts. Dry lakes are also referred to as **alkali flats**, **sabkhas**, **playas** or **mud flats**. If the surface is primarily salt then they are called **salt pans**, **pans**, **hardpan** or **salt flats**. (remnants of **salt lakes**)

Devil's Golf Course in Death Valley National Park, western United States

Terminology

The Spanish word *playa* (pronounced [ˈplaʝa]) literally means "beach". Dry lakes are known by this name in some parts of Mexico and the western United States. This term is also used on the Llano Estacado and other parts of the Southern High Plains.

In South America, the usual term for a dry lake is **salar**, Spanish for "salt pan".

Pan is the term used in most of South Africa. These may include the small round highveld pans, typical of the Chrissiesmeer area, to the extensive pans of the Northern Cape province, which are sometimes employed for land speed record attempts. It is also used in Australia. Distinguished are **salt pans** and **clay pans**.

Black Rock Desert lakebed (Nevada, United States)

Hardpan is a dry terminus of an internally drained basin in a dry climate, typically used in the Great Basin of the western US.

In Arabic, an alkali flat is called a *sabkha* (also spelled *sabkhah*, *subkha* or *sebkha*) or *shott* (*chott*).

In Central Asia, a similar "cracked mud" salt flat is known as a takyr.

In Iran salt flats are called **kavir**.

Formation

The surface of a dry lake is typically dry, hard and rough during the dry season, but wet and very soft in the rainy season. Dry lakes are generally small, round depressions in the surface of the landscape.

A playa lake is formed when rain fills a round depression in the landscape, creating a small lake. The water is generally freshwater, When all of the water evaporates, a playa is formed. The playa appears as a flat bed of clay, generally encrusted with precipitated salts. These evaporate minerals are a concentration of weathering products that have been left behind. Some examples of evaporite minerals are sodium carbonate, borax, and other salts. Playas are often found in bajadas, a depositional landform of desert environments.[1]

The rarely-flooded Badwater Basin after the exceptionally wet winter and spring of 2005, Death Valley National Park.

Dry lakes can also form when the water table intersects the surface and water seeps into them.

Dry lakes are typically formed in semi-arid to arid regions of the world. The largest concentration of dry lakes in the world (nearly 22,000) is in the southern High Plains of Texas and eastern New Mexico.

Most dry lakes are small, however Salar de Uyuni in Bolivia, near Potosí, the largest salt flat in the world is of 4,085 square miles (10,582 square km).

Many dry lakes contain shallow water during the rainy season, especially during wet years. If the layer of water is thin and is moved around the dry lake by wind, an exceedingly hard and smooth surface may develop. Thicker layers of water may result in a "cracked-mud" surface and "teepee" structure desiccation features. Very little water can result in dune formation.

Ecology

While the dry lake itself will be devoid of vegetation, they are commonly ringed by shadscale, saltbrush and other salt-tolerant plants that provide critical winter fodder for livestock and other herbivores.

Threats to dry lakes include pollution from concentrated animal feeding operations such as cattle feedlots and dairies, erosion, fertilizer, pesticide and sediment runoff from farms, and overgrazing.

Human use

The extremely flat, smooth and hard surfaces of dry lakes make them ideal for motor vehicles and bicycles. Furthermore, large-sized dry lakes are excellent spots for pursuing land speed records, as the smoothness of the surface allows low-clearance vehicles to travel very fast without any risk of disruption by surface irregularities, and the path traveled has no obstacles to avoid. The dry lakes at Bonneville Salt Flats in Utah and Black Rock Desert in Nevada have both been used for setting land speed records. Dry lake beds that do not fill with water at any time are sometimes used as locations for air bases, for similar reasons. Examples include Area 51 in Nevada, and Edwards Air Force Base (originally known as Muroc Dry Lake) in California.

The Mosaic Company chemical plant processes brines from Searles Dry Lake to make such products as trona

Brines from the subsurface of dry lakes are often exploited for valuable minerals in solution. See, for example Searles Dry Lake and Lithium resources.

United States regulation

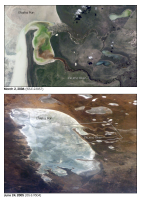
Under United States law, a "playa lake" may be considered isolated wetlands, and may be eligible to enroll in the new wetlands component of the Conservation Reserve Program, enacted in the 2002 farm bill(P.L. 107-171, Sec. 2101).[2]

Gallery

The dry lake and shore of Lake Hart, an endorheic desert lake in South Australia.

Salt harvesting in Salar de Uyuni, Bolivia, the world's largest salt flat.

A closeup photograph of salt growths on the crust of a dry lake.



Etosha Pan in northern Namibia

References

[1] Grotzinger, John, Thomas H. Jordan, Frank Press and Raymond Siever; *Understanding Earth,* Freeman, 5th Ed., 2006, ISBN 978-0716766827

[2] "CRS Report for Congress: Agriculture: A Glossary of Terms, Programs, and Laws, 2005 Edition - Order Code 97-905" (http://ncseonline.org/nle/crsreports/05jun/97-905.pdf). . Retrieved November 30, 2009. "A temporary lake created in the lowest elevation of a basin in an arid area that has no surface drain into another water body, such as a perennial stream or river. Lake water is removed either by evaporation into the air or seepage into the ground."

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- Briere, Peter R. (May 2002). "Playa, playa lake, sabkha: Proposed definitions for old terms". *Journal of Arid Environments* (Elsevier) **45** (1): 1–7. doi:10.1006/jare.2000.0633.
- John H. Wellington, "Southern Africa: a geographical study", Chapter 16 LAKES AND PANS

Schmidt hammer

A **Schmidt hammer**, also known as a **Swiss hammer** or a rebound hammer, is a device to measure the elastic properties or strength of concrete or rock, mainly surface hardness and penetration resistance.

It was invented by Ernst Schmidt, a Swiss engineer.

Original Schmidt Concrete Test Hammer

The hammer measures the rebound of a spring loaded mass impacting against the surface of the sample. The test hammer will hit the concrete at a defined energy. Its rebound is dependent on the hardness of the concrete and is measured by the test equipment. By reference to the conversion chart, the rebound value can be used to determine the compressive strength. When conducting the test the hammer should be held at right angles to the surface which in turn should be flat and smooth. The rebound reading will be affected by the orientation of the hammer, when used in a vertical position (on the underside of a suspended slab for example) gravity will increase the rebound distance of the mass and vice versa for a test conducted on a floor slab. The Schmidt hammer is an arbitrary scale ranging from 10 to 100. Schmidt hammers are available from their original manufacturers in several different energy ranges. These include: (i) Type L-0.735 Nm impact energy, (ii) Type N-2.207 Nm impact energy; and (iii) Type M-29.43 Nm impact energy.

The test is also sensitive to other factors:

- Local variation in the sample. To minimize this it is recommended to take a selection of readings and take an average value.
- Water content of the sample, a saturated material will give different results from a dry one.

Prior to testing, the Schmidt hammer should be calibrated using a calibration test anvil supplied by the manufacturer for that purpose. 12 readings should be taken, dropping the highest and lowest, and then take the average of the ten remaining. Using this method of testing is classed as indirect as it does not give a direct measurement of the strength of the material. It simply gives an indication based on surface properties, it is only suitable for making comparisons between samples.

This test method for testing concrete is governed by ASTM C805. ASTM D5873 describes the procedure for testing of rock.

External links

- More information on the SilverSchmidt [1]
- *Savoie Maintenance Service revendeur et réparateur SCHMIDT Hammer* [2] (in French)
- *Schmidt und Partner* [3] (in German)

References

[1] http://www.silverschmidt.com/home.html?L=0/
[2] http://www.sms-labo.fr/
[3] http://www.schmidtundpartner.ch/pages/firmenportrait.html

Schrofen

Schrofen terrain

Schrofen is a German mountaineering term that refers to steep terrain, strewn with rocks and rock outcrops, that is laborious to cross, but whose rock ledges (*Schrofen*) offer many good steps and hand holds. It is usually rocky terrain on which grass has established itself, but it can also refer to purely rocky slopes. Schrofen are found especially where the rock has broken off against its angle of dip.

Schrofen differs from trackless terrain in that hands are needed in order to negotiate it. Often there are route markings that only indicate a rough direction.[1]

Schrofen terrain requires at least surefootedness and is typical of grade I climbing routes. In wet weather Schrofen can become very dangerous because of the increased risk of slipping, particularly in the descent. In addition, the risk of falling in Schrofen terrain is often underestimated.

In keeping with the base meaning of the word ("rock spikes"), *Schrofen* also forms part of the name of numerous mountains in the Northern Limestone Alps. Alpine farms near a Schrofen are often named after it, as are their access roads, e.g.: *Ob dm Schrofa, Schrofaweg*. The word is linked to the German adjective *schroff* which means rugged, steep or craggy.

References

[1] *So gehen Sie sicher im Schrofengelände* (http://www.alpin.de/onlinekurse/news/07731f61-386f-4f55-9076-c582698e89e4) at www.alpin.de. Accessed on 31 Dec 2010

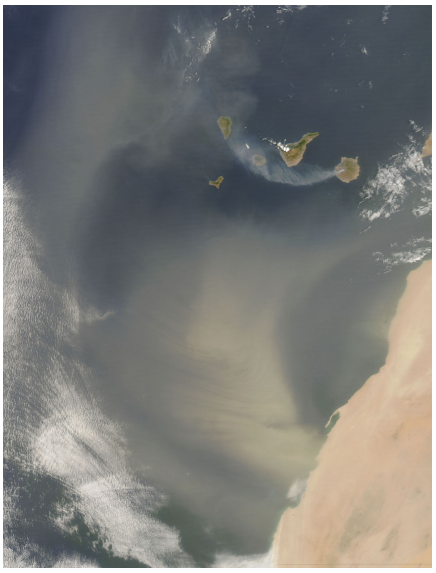
External links

- Negotiating Schrofen terrain (http://www.alpin.de/onlinekurse/news/07731f61-386f-4f55-9076-c582698e89e4) **(German)**

Sediment transport

Sediment transport is the movement of solid particles (sediment), typically due to a combination of the force of gravity acting on the sediment, and/or the movement of the fluid in which the sediment is entrained. An understanding of sediment transport is typically used in natural systems, where the particles are clastic rocks (sand, gravel, boulders, etc.), mud, or clay; the fluid is air, water, or ice; and the force of gravity acts to move the particles due to the sloping surface on which they are resting. Sediment transport due to fluid motion occurs in rivers, the oceans, lakes, seas, and other bodies of water, due to currents and tides; in glaciers as they flow, and on terrestrial surfaces under the influence wind. Sediment transport due only to gravity can occur on sloping surfaces in general, including hillslopes, scarps, cliffs, and the continental shelf—continental slope boundary.

Sediment transport is important in the fields of sedimentary geology, geomorphology, civil engineering and environmental engineering (see applications, below). Knowledge of sediment transport is most often used to know whether erosion or deposition will occur, the magnitude of this erosion or deposition, and the time and distance over which it will occur.



A plume of dust blows off of the Sahara Desert and sails over Atlantic Ocean towards the Canary Islands.

Mesquite Dunes, Death Valley, California. Ripples and dunes form as a natural self-organizing response to sediment transport.

Mechanisms

Aeolian

Sand blowing off a crest in the Kelso Dunes of the Mojave Desert, California.

Aeolian or *eolian* (depending on the parsing of æ) is the term for sediment transport by wind. This process results in the formation of ripples and sand dunes. Typically, the size of the transported sediment is fine sand (<1 mm) and smaller, because air is a fluid with low density and viscosity, and can therefore not exert very much shear on its bed.

Aeolian sediment transport is common on beaches and in the arid regions of the world, because it is in these environments that vegetation does not prevent the presence and motion of fields of sand.

Wind-blown very fine-grained dust is capable of entering the upper atmosphere and moving across the globe. Dust from the Sahara deposits on the Canary Islands and islands in the Caribbean,[1] and dust from the Gobi desert has deposited on the western United States.[2] This sediment is important to the soil budget and ecology of several islands.

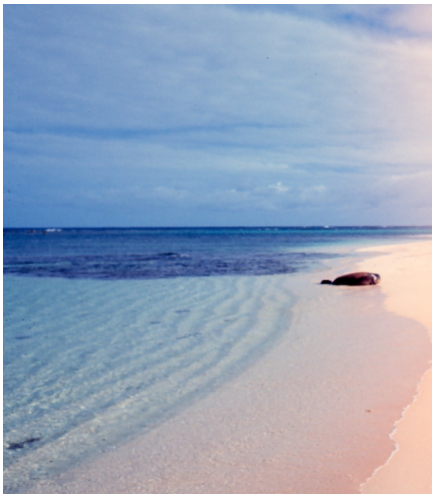
Deposits of fine-grained wind-blown glacial sediment are called loess.

Toklat River, East Fork, Polychrome overlook, Denali National Park, Alaska. This river, like other braided streams, rapidly changes the positions of its channels through processes of erosion, sediment transport, and deposition.

Fluvial

In geology, physical geography, and sediment transport, fluvial processes relate to flowing water in natural systems. This encompasses rivers, streams, periglacial flows, flash floods and glacial lake outburst floods. Sediment moved by water can be larger than sediment moved by air because water has both a higher density and viscosity. In typical rivers the largest carried sediment is of sand and gravel size, but larger floods can carry cobbles and even boulders.

Fluvial sediment transport can result in the formation of ripples and dunes, in fractal-shaped patterns of erosion, in complex patterns of natural river systems, and in the development of floodplains.



Sand ripples, Laysan Beach, Hawaii. Coastal **sediment transport** results in these evenly spaced ripples along the shore. Monk seal for scale.

Coastal

Coastal sediment transport takes place in near-shore environments due to the motions of waves and currents. At the mouths of rivers, coastal sediment and fluvial sediment transport processes mesh to create river deltas.

Coastal sediment transport results in the formation of characteristic coastal landforms such as beaches, barrier islands, and capes.[3]

Glacial

As glaciers move over their beds, they entrain and move material of all sizes. Glaciers can carry the largest sediment, and areas of glacial deposition often contain a large number of glacial erratics, many of which are several meters in diameter. Glaciers also pulverize rock into "glacial flour", which is so fine that it is often carried away by winds to create loess deposits thousands of kilometers afield. Sediment entrained in glaciers often moves approximately along the glacial flowlines, causing it to appear at the surface in the ablation zone.

A glacier joining the Gorner Glacier, Zermatt, Switzerland. These glaciers transport sediment and leave behind lateral moraines.

Hillslope

In hillslope sediment transport, a variety of processes move regolith downslope. These include:

- Soil creep
- Tree throw
- Movement of soil by burrowing animals
- Slumping and landsliding of the hillslope

These processes generally combine to give the hillslope a profile that looks like a solution to the diffusion equation, where the diffusivity is a parameter that relates to the ease of sediment transport on the particular hillslope. For this reason, the tops of hills generally have a parabolic concave-up profile, which grades into a convex-up profile around valleys.

As hillslopes steepen, however, they become more prone to episodic landslides and other mass wasting events. Therefore, hillslope processes are better described by a nonlinear diffusion equation in which classic diffusion dominates for shallow slopes and erosion rates go to infinity as the hillslope reaches a critical angle of repose.[4]

Debris flow

Large masses of material are moved in debris flows, hyperconcentrated mixtures of mud, clasts that range up to boulder-size, and water. Debris flows move as granular flows down steep mountain valleys and washes. Because they transport sediment as a granular mixture, their transport mechanisms and capacities scale differently than those of fluvial systems.

Applications

Sediment transport is applied to solve many environmental, geotechnical, and geological problems.

Suspended sediment from a stream emptying into a fjord (Isfjorden, Svalbard, Norway).

Movement of sediment is important in providing habitat for fish and other organisms in rivers. Therefore, managers of highly regulated rivers, which are often sediment-starved due to dams, are often advised to stage short floods to refresh the bed material and rebuild bars. This is also important, for example, in the Grand Canyon of the Colorado River, to rebuild shoreline habitats also used as campsites.

Sediment discharge into a reservoir formed by a dam forms a reservoir delta. This delta will fill the basin, and eventually, either the reservoir will need to be dredged or the dam will need to be removed. Knowledge of sediment transport can be used to properly plan to extend the life of a dam.

Geologists can use inverse solutions of transport relationships to understand flow depth, velocity, and direction, from sedimentary rocks and young deposits of alluvial materials.

Flow in culverts, over dams, and around bridge piers can cause erosion of the bed. This erosion can damage the environment and expose or unsettle the foundations of the structure. Therefore, good knowledge of the mechanics of sediment transport in a built environment are important for civil and hydraulic engineers.

When suspended sediment transport is increased due to human activities, causing environmental problems including the filling of channels, it is called siltation after the grain-size fraction dominating the process.

Initiation of motion

Stress balance

For a fluid to begin transporting sediment that is currently at rest on a surface, the boundary (or bed) shear stress τ_b exerted by the fluid must exceed the critical shear stress τ_c for the initiation motion of grains at the bed. This basic criterion can be for the initiation of motion can be written as:

$$\tau_b = \tau_c .$$

This is typically represented by a comparison between a dimensionless shear stress (τ_b*)and a dimensionless critical shear stress (τ_c*). The nondimensionalization is in order to compare the driving forces of particle motion (shear stress) to the resisting forces that would make it stationary (particle density and size). This dimensionless shear stress, $\tau*$, is called the Shields parameter and defined as:

$$\tau* = \frac{\tau}{(\rho_s - \rho)(g)(D)}.$$

And the new equation to solve becomes:

$$\tau_b* = \tau_c* .$$

The equations included here describe sediment transport for clastic, or granular sediment. They do not work for clays and muds because these types of floccular sediments do not fit the geometric simplifications in these equations, and

also interact thorough electrostatic forces. The equations were also designed for fluvial sediment transport of particles carried along in a liquid flow, such as that in a river, canal, or other open channel.

Only one size of particle is considered in this equation. However, river beds are often formed by a mixture of sediment of various sizes. In case of partial motion where only a part of the sediment mixture moves, the river bed becomes enriched in large gravel as the smaller sediments are washed away. The smaller sediments present under this layer of large gravel have a lower possibility of movement and total sediment transport decreases. This is called armouring effect.[5]

Critical shear stress

The Shields diagram empirically shows how the dimensionless critical shear stress required for the initiation of motion is a function of a particular form of the particle Reynolds number, Re_p or Reynolds number related to the particle. This allows us to rewrite the criterion for the initiation of motion in terms of only needing to solve for a specific version of the particle Reynolds number, which we call Re_p*.

$$\tau_b* = f\left(Re_p*\right)$$

This equation can then be solved by using the empirically derived Shields curve to find τ_c* as a function of a specific form of the particle Reynolds number called the boundary Reynolds number.

Particle Reynolds Number

In general, a particle Reynolds Number has the form:

$$Re_p = \frac{U_p D}{\nu}$$

Where U_p is a characteristic particle velocity, D is the grain diameter (a characteristic particle size), and ν is the kinematic viscosity, which is given by the dynamic viscosity, μ, divided by the fluid density, ρ.

$$\nu = \frac{\mu}{\rho}$$

The specific particle Reynolds number of interest is called the boundary Reynolds number, and it is formed by replacing the velocity term in the Particle Reynolds number by the shear velocity, u_*, which is a way of rewriting shear stress in terms of velocity.

$$u_* = \sqrt{\frac{\tau_b}{\rho_w}} = \kappa z \frac{\partial u}{\partial z}$$

where τ_b is the bed shear stress (described below), and κ is the von Kármán constant, where

$$\kappa = 0.407.$$

The particle Reynolds number is therefore given by:

$$Re_p* = \frac{u* D}{\nu}$$

Bed shear stress

The boundary Reynolds number can be used with the Shields diagram to empirically solve the equation

$$\tau_c* = f\left(Re_p*\right),$$

which solves the right-hand side of the equation

$$\tau_b* = \tau_c* .$$

In order to solve the left-hand side, expanded as

$$\tau_b* = \frac{\tau_b}{(\rho_s - \rho)(g)(D)},$$

we must find the bed shear stress, τ_b . There are several ways to solve for the bed shear stress. First, we develop the simplest approach, in which the flow is assumed to be steady and uniform and reach-averaged depth and slope are used. Due to the difficulty of measuring shear stress *in situ*, this method is also one of the most-commonly used. This method is known as the depth-slope product.

Depth-slope product

For a river undergoing approximately steady, uniform equilibrium flow, of approximately constant depth *h* and slope θ over the reach of interest, and whose width is much greater than its depth, the bed shear stress is given by some momentum considerations stating that the gravity force component in the flow direction equals exactly the friction force.[6] For a wide channel, it yields:

$$\tau_b = \rho g h \sin(\theta)$$

For shallow slopes, which are found in almost all natural lowland streams, the small-angle formula shows that $\sin(\theta)$ is approximately equal to $\tan(\theta)$, which is given by S, the slope. Rewritten with this:

$$\tau_b = \rho g h S$$

Shear velocity, velocity, and friction factor

For the steady case, by extrapolating the depth-slope product and the equation for shear velocity:

$$\tau_b = \rho g h S$$

$$u_* = \sqrt{\left(\frac{\tau_b}{\rho}\right)},$$

We can see that the depth-slope product can be rewritten as:

$$\tau_b = \rho u_*^2 .$$

$u*$ is related to the mean flow velocity, $\bar{u}$, through the generalized Darcy-Weisbach friction factor, C_f, which is equal to the Darcy-Weisbach friction factor divided by 8 (for mathematical convenience).[7] Inserting this friction factor,

$$\tau_b = \rho C_f \left(\bar{u}\right)^2 .$$

Unsteady flow

For all flows that cannot be simplified as a single-slope infinite channel (as in the depth-slope product, above), the bed shear stress can be locally found by applying the Saint-Vennant equations for continuity, which consider accelerations within the flow.

Solution

Set-up

The criterion for the initiation of motion, established earlier, states that

$$\tau_b* = \tau_c* .$$

In this equation,

$\tau* = \frac{\tau_b}{(\rho_s - \rho)(g)(D)}$, and therefore

$$\frac{\tau_b}{(\rho_s - \rho)(g)(D)} = \frac{\tau_c}{(\rho_s - \rho)(g)(D)}.$$

τ_c* is a function of boundary Reynolds number, a specific type of particle Reynolds number.

$$\tau_c* = f\left(Re_p*\right).$$

For a particular particle Reynolds number, τ_c* will be an emprical constant given by the Shields Curve or by another set of empirical data (depending on whether or not the grain size is uniform).

Therefore, the final equation that we seek to solve is:

$$\frac{\tau_b}{(\rho_s - \rho)(g)(D)} = f\left(Re_p*\right).$$

Solution

We make several assumptions to provide an example that will allow us to bring the above form of the equation into a solved form.

First, we assume that the a good approximation of reach-averaged shear stress is given by the depth-slope product. We can then rewrite the equation as

$$\rho g h S = 0.06(\rho_s - \rho)(g)(D).$$

Moving and re-combining the terms, we obtain:

$$hS = \frac{(\rho_s - \rho)}{\rho}(D)\left(f\left(Re_p*\right)\right) = RD\left(f\left(Re_p*\right)\right)$$

where R is the submerged specific gravity of the sediment.

We then make our second assumption, which is that the particle Reynolds number is high. This is typically applicable to particles of gravel-size or larger in a stream, and means that the critical shear stress is a constant. The Shields curve shows that for a bed with a uniform grain size,

$$\tau_c* = 0.06.$$

Later researchers have shown that this value is closer to

$$\tau_c* = 0.03$$

for more uniformly sorted beds. Therefore, we will simply insert

$$\tau_c* = f\left(Re_p*\right)$$

and insert both values at the end.

The equation now reads:

$$hS = RD\tau_c*$$

This final expression shows that the product of the channel depth and slope is equal to the Shield's criterion times the submerged specific gravity of the particles times the particle diameter.

For a typical situation, such as quartz-rich sediment $\left(\rho_s = 2650\frac{kg}{m^3}\right)$ in water $\left(\rho = 1000\frac{kg}{m^3}\right)$, the submerged specific gravity is equal to 1.65.

$$R = \frac{(\rho_s - \rho)}{\rho} = 1.65$$

Plugging this into the equation above,

$$hS = 1.65(D)\tau_c*.$$

For the Shield's criterion of $\tau_c* = 0.06$. 0.06 * 1.65 = 0.099, which is well within standard margins of error of 0.1. Therefore, for a uniform bed,

$$hS = 0.1(D).$$

For these situations, the product of the depth and slope of the flow should be 10% of the diameter of the median grain diameter.

The mixed-grain-size bed value is $\tau_c* = 0.03$, which is supported by more recent research as being more broadly applicable because most natural streams have mixed grain sizes. Using this value, and changing D to D_50 ("50" for the 50th percentile, or the median grain size, as we are now looking at a mixed-grain-size bed), the equation becomes:

$$hS = 0.05(D_{50})$$

Which means that the depth times the slope should be about 5% of the median grain diameter in the case of a mixed-grain-size bed.

Modes of entrainment

The sediments entrained in a flow can be transported along the bed as bed load in the form of sliding and rolling grains, or in suspension as suspended load advected by the main flow.[6] Some sediment materials may also come from the upstream reaches and be carried downtream in the form of wash load.

Rouse number

The location in the flow in which a particle is entrained is determined by the Rouse number, which is determined by the density ϱ_s and diameter d of the sediment particle, and the density ϱ and kinematic viscosity ν of the fluid, determine in which part of the flow the sediment particle will be carried.[8]

$$P = \frac{w_s}{\kappa u_*}$$

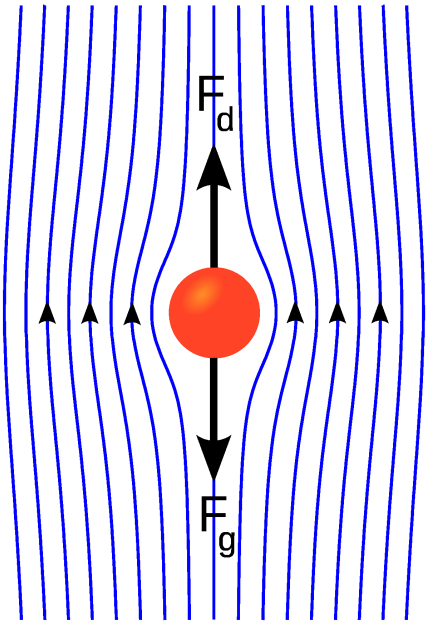
Here, the Rouse number is given by P. The term in the numerator is the (downwards) sediment the sendiment settling velocity w_s, which is discussed below. The upwards velocity on the grain is given as a product of the von Kármán constant, $\kappa = 0.4$, and the shear velocity, u_*.

The following table gives the approximate required Rouse numbers for transport as bed load, suspended load, and wash load.[8] [9]

Mode of Transport	Rouse Number
Initiation of motion	>7.5
Bed load	>2.5, <7.5
Suspended load: 50% Suspended	>1.2, <2.5
Suspended load: 100% Suspended	>0.8, <1.2
Wash load	<0.8

Settling velocity

The settling velocity (also called the "fall velocity" or "terminal velocity") is a function of the particle Reynolds number. Generally, for small particles (laminar approximation), it can be calculated with Stokes' Law. For larger particles (turbulent particle Reynolds numbers), fall velocity is calculated with the turbulent drag law. Dietrich (1982) compiled a large amount of published data to which he empirically fit settling velocity curves.[10] Ferguson and Church (2006) analytically combined the expressions for Stokes flow and a turbulent drag law into a single equation that works for all sizes of sediment, and successfully tested it against the data of Dietrich.[11] Their equation is



Streamlines around a sphere falling through a fluid. This illustration is accurate for laminar flow, in which the particle Reynolds number is small. This is typical for small particles falling through a viscous fluid; larger particles would result in the creation of a turbulent wake.

$$w_s = \frac{RgD^2}{C_1\nu + (0.75C_2RgD^3)^{(0.5)}}.$$

In this equation w_s is the sediment settling velocity, g is acceleration due to gravity, and D is mean sediment diameter. ν is the kinematic viscosity of water, which is approximately 1.0 x 10^{-6} m^2/s for water at 20°C.

C_1 and C_2 are constants related to the shape and smoothness of the grains.

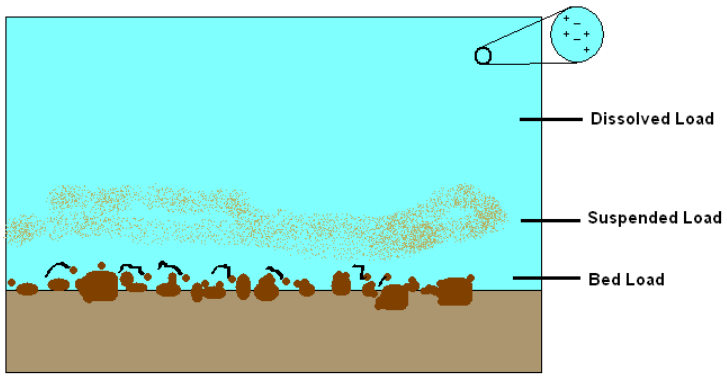
Constant	Smooth Spheres	Natural Grains: Sieve Diameters	Natural Grains: Nominal Diameters	Limit for Ultra-Angular Grains
C_1	18	18	20	24
C_2	0.4	1.0	1.1	1.2

The expression for fall velocity can be simplified so that it can be solved only in terms of D. We use the sieve diameters for natural grains, $g = 9.8$, and values given above for ν and R. From these parameters, the fall velocity is given by the expression:

$$w_s = \frac{16.17D^2}{1.8 \cdot 10^{-5} + (12.1275D^3)^{(0.5)}}$$

Transport rate

Formulas to calculate sediment transport rate exist for sediment moving in several different parts of the flow. These formulas are often segregated into bed load, suspended load, and wash load. They may sometimes also be segregated into bed material load and wash load.



A schematic diagram of where the different types of sediment load are carried in the flow. Dissolved load is not sediment: it is composed of disassociated ions moving along with the flow. It may, however, constitute a significant proportion (often several percent, but occasionally greater than half) of the total amount of material being transported by the stream.

Bed Load

Bed load moves by rolling, sliding, and hopping (or saltating) over the bed, and moves at a small fraction of the fluid flow velocity. Bed load is generally thought to constitute 5-10% of the total sediment load in a stream, making it less important in terms of mass balance. However, the bed material load (the bed load plus the portion of the suspended load which comprises material derived from the bed) is often dominated by bed load, especially in gravel-bed rivers. This bed material load is the only part of the sediment load that actively interacts with the bed. As the bed load is an important component of that, it plays a major role in controlling the morphology of the channel.

Bed load transport rates are usually expressed as being related to excess dimensionless shear stress raised to some power. Excess dimensionless shear stress is a nondimensional measure of bed shear stress about the threshold for motion.

$$(\tau_b^* - \tau_c^*),$$

Bed load transport rates may also be given by a ratio of bed shear stress to critical shear stress, which is equivalent in both the dimensional and nondimensional cases. This ratio is called the "transport stage" $(T_s \text{ or } \phi)$ and is an important in that it shows bed shear stress as a multiple of the value of the criterion for the initiation of motion.

$$T_s = \phi = \frac{\tau_b}{\tau_c}$$

When used for sediment transport formulae, this ratio is typically raised to a power.

The majority of the published relations for bedload transport are given in dry sediment weight per unit channel width, b ("breadth"):

$$q_s = \frac{Q_s}{b}.$$

Due to the difficulty of estimating bed load transport rates, these equations are typically only suitable for the situations for which they were designed.

Notable bed load transport formulae

Meyer-Peter Müller and derivatives

The transport formula of Meyer-Peter and Müller, originally developed in 1948,[12] was designed for well-sorted fine gravel at a transport stage of about 8.[8] The formula uses the above nondimensionalization for shear stress,[8]

$$\tau* = \frac{\tau}{(\rho_s - \rho)(g)(D)},$$

and Hans Einstein's nondimensionalization for sediment volumetric discharge per unit width[8]

$$q_s* = \frac{q_s}{D\sqrt{\frac{\rho_s - \rho}{\rho} g D}} = \frac{q_s}{Re_p \nu}.$$

Their formula reads:

$$q_s* = 8\left(\tau* - \tau*_c\right)^{3/2}.$$ [8]

Their experimentally determined value for $\tau*_c$ is 0.047, and is the third commonly used value for this (in addition to Parker's 0.03 and Shields' 0.06).

Because of its broad use, some revisions to the formula have taken place over the years that show that the coefficient on the left ("8" above) is a function of the transport stage:[8] [13] [14] [15]

$$T_s \approx 2 \rightarrow q_s* = 5.7\left(\tau* - 0.047\right)^{3/2}$$ [13]

$$T_s \approx 100 \rightarrow q_s* = 12.1\left(\tau* - 0.047\right)^{3/2}$$ [14] [15]

The variations in the coefficient were later generalized as a function of dimensionless shear stress:[8] [16]

$$\begin{cases} q_s* = \alpha_s\left(\tau* - \tau_c*\right)^n \\ n = \frac{3}{2} \\ \alpha_s = 1.6\ln(\tau*) + 9.8 \approx 9.64\tau*^{0.166} \end{cases}$$ [16]

Wilcock and Crowe

In 2003, Peter Wilcock and Joanna Crowe (now Joanna Curran) published a sediment transport formula that works with multiple grain sizes across the sand and gravel range.[17] Their formula works with surface grain size distributions, as opposed to older models which use subsurface grain size distributions (and thereby implicitly infer a surface grain sorting).

Their expression is more complicated than the basic sediment transport rules (such as that of Meyer-Peter and Müller) because it takes into account multiple grain sizes: this requires consideration of reference shear stresses for each grain size, the fraction of the total sediment supply that falls into each grain size class, and a "hiding function".

The "hiding function" takes into account the fact that, while small grains are inheriently more mobile than large grains, on a mixed-grain-size bed, they may be trapped in deep pockets between large grains. Likewise, a large grain on a bed of small particles will be stuck in a much smaller pocket than if it were on a bed of grains of the same size. In gravel-bed rivers, this can cause "equal mobility", in which small grains can move just as easily as large ones.[18] As sand is added to the system, it moves away from the "equal mobility" portion of the hiding function to one in which grain size again matters.[17]

Their model is based on the transport stage, or ratio of bed shear stress to critical shear stress for the initiation of grain motion. Because their formula works with several grain sizes simultaneously, they define the critical shear

stress for each grain size class, τ_{c,D_i}, to be equal to a "reference shear stress", τ_{ri}.[17]

They express their equations in terms of a dimensionless transport parameter, W_i^* (with the " $*$ " indicating nondimensionality and the " i " indicating that it is a function of grain size):

$$W_i^* = \frac{Rgq_{bi}}{F_i u*^3}$$

q_{bi} is the volumetric bed load transport rate of size class i per unit channel width b. F_i is the proportion of size class i that is present on the bed.

They came up with two equations, depending on the transport stage, ϕ. For $\phi < 1.35$:

$$W_i^* = 0.002\phi^{7.5}$$

and for $\phi \geq 1.35$:

$$W_i^* = 14\left(1 - \frac{0.894}{\phi^{0.5}}\right)^{4.5}.$$

This equation asymptotically reaches a constant value of W_i^* as ϕ becomes large.

Suspended load

Suspended load is carried in the lower to middle parts of the flow, and moves at a large fraction of the mean flow velocity in the stream.

A common characterization of suspended sediment concentration in a flow is given by the Rouse Profile. This characterization works for the situation in which sediment concentration c_0 at one particular elevation above the bed z_0 can be quantified. It is given by the expression:

$$\frac{c_s}{c_0} = \left[\frac{z\,(h - z_0)}{z_0\,(h - z)}\right]^{-P/\alpha}$$

Here, z is the elevation above the bed, c_s is the concentration of suspended sediment at that elevation, h is the flow depth, P is the Rouse number, and α relates the eddy viscosity for momentum K_m to the eddy diffusivity for sediment, which is approximately equal to one.[19]

$$\alpha = \frac{K_s}{K_m} \approx 1$$

Experimental work has shown that α ranges from 0.93 to 1.10 for sands and silts.[20]

The Rouse profile characterizes sediment concentrations because the Rouse number includes both turbulent mixing and settling under the weight of the particles. Turbulent mixing results in the net motion of particles from regions of high concentrations to low concentrations. Because particles settle downward, for all cases where the particles are not neutrally buoyant or sufficiently light that this settling velocity is negligible, there is a net negative concentration gradient as one goes upward in the flow. The Rouse Profile therefore gives the concentration profile that provides a balance between turbulent mixing (net upwards) of sediment and the downwards settling velocity of each particle.

Bed material load

Bed material load comprises the bed load and the portion of the suspended load that is sourced from the bed.

Three common bed material transport relations are the "Ackers-White",[21] "Engelund-Hansen", "Yang" formulae. The first is for sand to granule-size gravel, and the second and third are for sand[22] though Yang later expanded his formula to include fine gravel. That all of these formulae cover the sand-size range and two of them are exclusively for sand is that the sediment in sand-bed rivers is commonly moved simultaneously as bed and suspended load.

Engelund-Hansen

The bed material load formula of Engelund and Hansen is the only one to not include some kind of critical value for the initiation of sediment transport. It reads:

$$q_s* = \frac{0.05}{c_f}\tau*^{2.5}$$

where q_s* is the Einstein nondimensionalization for bed shear stress, c_f is a friction factor, and $\tau*$ is the Shields stress. The Engelund-Hansen formula is one of the few sediment transport formulae in which a threshold "critical shear stress" is absent.

Wash load

Wash load is carried within the water column as part of the flow, and therefore moves with the mean velocity of main stream. Wash load concentrations are approximately uniform in the water column, and are perfectly uniform for the endmember case in which the Rouse number is equal to 0.

Total load

Some authors have attempted formulations for the total sediment load carried in water.[23] [24]

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Shear velocity

Shear velocity, also called **friction velocity**, is a form by which a shear stress may be re-written in units of velocity. It is useful as a method in fluid mechanics to compare true velocities, such as the velocity of a flow in a stream, to a velocity that relates shear between layers of flow.

Shear velocity is used to describe shear-related motion in moving fluids. It is used to describe:

- Diffusion and dispersion of particles, tracers, and contaminants in fluid flows
- The velocity profile near the boundary of a flow (see Law of the wall)
- Transport of sediment in a channel

Shear velocity also helps in thinking about the rate of shear and dispersion in a flow. Shear velocity scales well to rates of dispersion and bedload sediment transport. A general rule is that the shear velocity is about 1/10 of the mean flow velocity.

$$u_\star = \sqrt{\frac{\tau}{\rho}}$$

Where τ is the shear stress in an arbitrary layer of fluid and ρ is the density of the fluid.

Typically, for sediment transport applications, the shear velocity is evaluated at the lower boundary of an open channel:

$$u_\star = \sqrt{\frac{\tau_b}{\rho}}$$

Where τ_b is the shear stress given at the boundary.

Shear velocity can also be defined in terms of the local velocity and shear stress fields (as opposed to whole-channel values, as given above).

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Shen Kuo

Shen Kuo 沈括	
 Modern artist's impression of Shen Kuo	
Born	1031Qiantang
Died	1095Runzhou
Residence	Hangzhou, Xiamen, Kaifeng, Zhenjiang
Fields	Geology, Astronomy, Archaeology, Mathematics, Pharmacology, Magnetics, Optics, Hydraulics, Metaphysics, Meteorology, Climatology, Geography, Cartography, Botany, Zoology, Architecture, Agriculture, Economics, Military strategy, Ethnography, Music, Divination
Institutions	Hanlin Academy
Known for	Geomorphology, Climate change, Atmospheric refraction, True north, Retrogradation, Camera obscura, Raised-relief map, fixing the position of the pole star, correcting lunar and solar errors

This is a Chinese name; the family name is Shen.

Shen Kuo or **Shen Gua** (Chinese: 沈括; pinyin: *Shěn Kuò*; Wade–Giles: Shen K'uo) (1031–1095), style name **Cunzhong** (存中) and pseudonym **Mengqi** (now usually given as **Mengxi**) **Weng** (夢溪翁),[1] was a polymathic Chinese scientist and statesman of the Song Dynasty (960–1279). Excelling in many fields of study and statecraft, he was a mathematician, astronomer, meteorologist, geologist, zoologist, botanist, pharmacologist, agronomist, archaeologist, ethnographer, cartographer, encyclopedist, general, diplomat, hydraulic engineer, inventor, academy chancellor, finance minister, governmental state inspector, poet, and musician. He was the head official for the Bureau of Astronomy in the Song court, as well as an Assistant Minister of Imperial Hospitality.[2] At court his political allegiance was to the Reformist faction known as the New Policies Group, headed by Chancellor Wang Anshi (1021–1086).

In his *Dream Pool Essays* (夢溪筆談; *Mengxi Bitan*) of 1088, Shen was the first to describe the magnetic needle compass, which would be used for navigation (first described in Europe by Alexander Neckam in 1187).[3] [4] Shen discovered the concept of true north in terms of magnetic declination towards the north pole,[4] with experimentation of suspended magnetic needles and "the improved meridian determined by Shen's [astronomical] measurement of the distance between the polestar and true north".[5] This was the decisive step in human history to make compasses more useful for navigation, and may have been a concept unknown in Europe for another four hundred years (evidence of German sundials made circa 1450 show markings similar to Chinese geomancer compasses in regards to declination).[6] [7]

Alongside his colleague Wei Pu, Shen planned to map the orbital paths of the Moon and the planets in an intensive five-year project involving daily observations, yet this was thwarted by political opponents at court.[8] To aid his work in astronomy, Shen Kuo made improved designs of the armillary sphere, gnomon, sighting tube, and invented a

new type of inflow water clock. Shen Kuo devised a geological hypothesis for land formation (geomorphology), based upon findings of inland marine fossils, knowledge of soil erosion, and the deposition of silt.[9] He also proposed a hypothesis of gradual climate change, after observing ancient petrified bamboos that were preserved underground in a dry northern habitat that would not support bamboo growth in his time. He was the first literary figure in China to mention the use of the drydock to repair boats suspended out of water, and also wrote of the effectiveness of the relatively new invention of the canal pound lock. Although Ibn al-Haytham (965–1039) was the first to describe camera obscura, Shen was the first in China to do so, several decades later. Shen wrote extensively about movable type printing invented by Bi Sheng (990–1051), and because of his written works the legacy of Bi Sheng and the modern understanding of the earliest movable type has been handed down to later generations.[10] Following an old tradition in China, Shen created a raised-relief map while inspecting borderlands. His description of an ancient crossbow mechanism which he himself unearthed proved to be a Jacob's staff, a surveying tool which wasn't known in Europe until described by Levi ben Gerson in 1321.

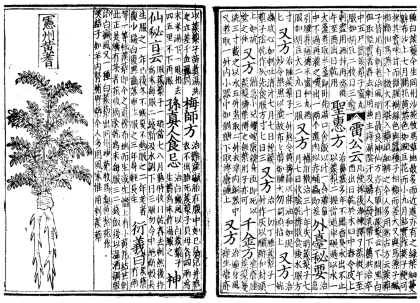
Shen Kuo wrote several other books besides the *Dream Pool Essays*, yet much of the writing in his other books has not survived. Some of Shen's poetry was preserved in posthumous written works. Although much of his focus was on technical and scientific issues, he had an interest in divination and the supernatural, the latter including his vivid description of unidentified flying objects from eyewitness testimony. He also wrote commentary on ancient Daoist and Confucian texts.

Life

Birth and youth

Shen Kuo was born in Qiantang (modern-day Hangzhou) in the year 1031. His father Shen Zhou (沈周; 978–1052) was a somewhat lower-class gentry figure serving in official posts on the provincial level; his mother was from a family of equal status in Suzhou, with her maiden name being Xu (許).[11] Shen Kuo received his initial childhood education from his mother, which was a common practice in China during this period.[11] [a][›] She was very educated herself, teaching Kuo and his brother Pi (披) the military doctrines of her own elder brother Xu Tang (許洞; 975–1016).[11] Since Shen was unable to boast of a prominent familial clan history like many of his elite peers born in the north, he was forced to rely on his wit and stern determination to achieve in his studies to enter the challenging and sophisticated life of an exam-drafted state bureaucrat.[11]

From about 1040, Shen's family moved around Sichuan province and finally to the international seaport at Xiamen, where Shen's father accepted minor provincial posts in each new location.[12] Shen Zhou also served several years in the prestigious capital judiciary, the equivalent of a federal supreme court.[11] Shen Kuo took notice of the various towns and rural features of China as his family traveled, while he became interested during his youth in the diverse topography of the land.[12] He also observed the intriguing aspects of his father's engagement in administrative governance and the managerial problems involved; these experiences had a deep impact on him as he later became a government official.[12] Since he often became ill as a child, Shen Kuo also developed a natural curiosity about medicine and pharmaceutics.[12]



The *Bencao* on traditional Chinese medicine; printed with woodblock in 1249; Shen grew ill often as a child, and so developed an interest in medicinal cures.

Shen Zhou died in the late winter of 1051 (or early 1052), when his son Shen Kuo was 21 years old. Shen Kuo grieved for his father, and following Confucian ethics, remained inactive in a state of mourning for three years until 1054 (or early 1055).[13] As of 1054, Shen began serving in minor local governmental posts. However, his natural abilities to plan, organize, and design were proven early in life; one example is his design and supervision of the

hydraulic drainage of an embankment system, which converted some one hundred thousand acres (400 km²) of swampland into prime farmland.[13] Shen Kuo noted that the success of the silt fertilization method relied upon the effective operation of sluice gates of irrigation canals.[14]

Official career

In 1063 Shen Kuo successfully passed the Imperial examinations, the difficult national-level standard test that every high official was required to pass in order to enter the governmental system.[13] He not only passed the exam however, but was placed into the higher category of the best and brightest students.[13] While serving at Yangzhou, Shen's brilliance and dutiful character caught the attention of Zhang Chu (張蓴; 1015–1080), the Fiscal Intendant of the region. Shen made a lasting impression upon Zhang, who recommended Shen for a court appointment in the financial administration of the central court.[13] Shen would also eventually marry Zhang's daughter, who became his second wife.

Shen's confidant, Emperor Shenzong of Song (r. 1067–1085), a Song era portrait painting.

In his career as a scholar-official for the central government, Shen Kuo was also an ambassador to the Western Xia Dynasty and Liao Dynasty,[15] a military commander, a director of hydraulic works, and the leading chancellor of the Hanlin Academy.[16] By 1072, Shen was appointed as the head official of the Bureau of Astronomy.[13] With his leadership position in the bureau, Shen was responsible for projects in improving calendrical science,[10] and proposed many reforms to the Chinese calendar alongside the work of his colleague Wei Pu.[8] With his impressive skills and aptitude for matters of economy and finance, Shen was appointed as the Finance Commissioner at the central court.[17]

As written by Li Zhiyi, a man married to Hu Wenrou (granddaughter of Hu Su, a famous minister of the Song Dynasty), Shen Kuo was Li's mentor while Shen served as an official.[18] According to Li's epitaph for his wife, Shen would sometimes relay questions via Li to Hu when he needed clarification for his mathematical work, as Hu Wenrou was esteemed by Shen as a remarkable female mathematician.[18] Shen lamented: "if only she were a man, Wenrou would be my friend."[18]

While employed by the central government, Shen Kuo was also sent out with others to inspect the granary system of the empire, investigating problems of illegal collections, negligence, ineffective disaster relief, and inadequate water-conservancy projects.[19] While Shen was appointed as the regional inspector of Zhejiang in 1073, the Emperor requested that Shen pay a visit to the famous poet Su Shi (1037–1101), then an administrator in Hangzhou.[20] Shen took advantage of this meeting to copy some of Su's poetry, which he presented to the Emperor indicating that it expressed "abusive and hateful" speech against the Song court; these poems were later politicized by Li Ding and Shu Dan in order to level a court case against Su.[20] With his demonstrations of loyalty and ability, Shen Kuo was awarded the honorary title of a State Foundation Viscount by Emperor Shenzong of Song (r. 1067–1085), who placed a great amount of trust in Shen Kuo.[17] He was even made 'companion to the heir apparent' (太子中允; 'Taizi zhongyun').[1]

Portrait painting of Wang Anshi.

At court Shen was a political favorite of the Chancellor Wang Anshi (1021–1086), who was the leader of the political faction of Reformers, also known as the New Policies Group (新法, Xin Fa).[21] b[›] Shen Kuo had a previous history with Wang Anshi, since it was Wang who had composed the funerary epitaph for Shen's father, Zhou.[22] Shen Kuo soon impressed Wang Anshi with his skills and abilities as an administrator and government agent. In 1072, Shen was sent to supervise Wang's program of surveying the building of silt deposits in the Bian Canal outside the capital city. Using an original technique, Shen successfully dredged the canal and demonstrated the formidable value of the silt gathered as a fertilizer.[22] He gained further reputation at court once he was dispatched as an envoy to the Khitan Liao Dynasty in the summer of 1075.[22] The Khitans had made several aggressive negotiations of pushing their borders south, while manipulating several incompetent Chinese ambassadors who conceded to the Liao Kingdom's demands.[22] In a brilliant display of diplomacy, Shen Kuo came to the camp of the Khitan monarch at Mt. Yongan (near modern Pingquan, Hebei), armed with copies of previously archived diplomatic negotiations between the Song and Liao dynasties.[22] Shen Kuo refuted Emperor Daozong's bluffs point for point, while the Song reestablished their rightful border line.[22] In regards to the Lý Dynasty of Đại Việt (in modern northern Vietnam), Shen demonstrated in his *Dream Pool Essays* that he was familiar with the key players (on the Vietnamese side) in the prelude to the Sino-Vietnamese War of 1075–1077.[23] With his reputable achievements, Shen became a trusted member of Wang Anshi's elite circle of eighteen unofficial core political loyalists to the New Policies Group.[22]

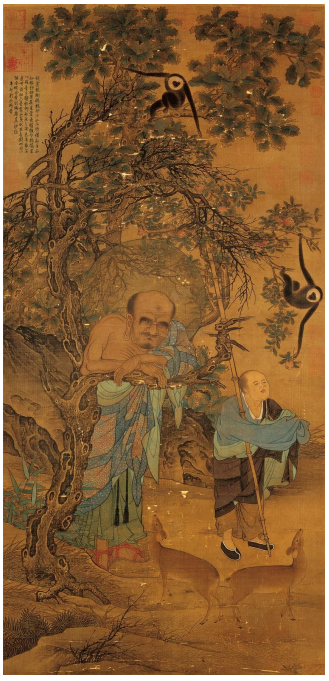
Boundaries of the Northern Song Dynasty, the Liao Dynasty, and the Western Xia.

Although much of Wang Anshi's reforms outlined in the New Policies centered around state finance, land tax reform, and the Imperial examinations, there were also military concerns. This included policies of raising militias to lessen the expense of upholding a million soldiers,[24] putting government monopolies on saltpetre and sulphur production and distribution in 1076 (to ensure that gunpowder solutions would not fall into the hands of enemies),[25] [26] and aggressive military policy towards China's northern rivals of the Western Xia and Liao dynasties.[27] A few years after Song Dynasty military forces had made victorious territorial gains against the Tanguts of the Western Xia, in 1080 Shen Kuo was entrusted as a military officer in defense of Yanzhou (modern-day Yan'an, Shaanxi province).[28] During the autumn months of 1081, Shen was successful in defending Song Dynasty territory while capturing several fortified towns of the Western Xia.[17] The Emperor Shenzong of Song rewarded Shen with numerous titles for his merit in these battles, and in the sixteen months of Shen's military campaign, he received 273 letters from the Emperor.[17] However, Emperor Shenzong trusted an arrogant military officer who disobeyed the emperor and Shen's proposal for strategic fortifications, instead fortifying what Shen considered useless strategic locations. Furthermore, this officer expelled Shen from his commanding post at the main citadel, so as to deny him any glory in chance of victory.[17] The result of this was nearly catastrophic, as the forces of the arrogant officer were decimated;[17] Xinzhong Yao states that the death toll was 60,000.[1] Nonetheless, Shen was successful in defending his fortifications and the only possible Tangut invasion-route to Yanzhou.[17]

Impeachment and later life

The new Chancellor Cai Que (蔡確; 1036–1093) held Shen responsible for the disaster and loss of life.[17] Along with abandoning the territory which Shen Kuo had fought for, Cai ousted Shen from his seat of office.[17] Shen's life was now forever changed, as he lost his once reputable career in state governance and the military.[17] Shen was then put under probation in a fixed residence for the next six years. However, as he was isolated from governance, he decided to pick up the quill and dedicate himself to intensive scholarly studies. After completing two geographical atlases for a state-sponsored program, Shen was rewarded by having his sentence of probation lifted, allowing him to live in a place of his choice.[17] Shen was also pardoned by the court for any previous faults or crimes that were claimed against him.[17]

In his more idle years removed from court affairs, Shen Kuo enjoyed pastimes of the Chinese gentry and literati that would indicate his intellectual level and cultural taste to others.[30] As described in his *Dream Pool Essays*, Shen Kuo enjoyed the company of the "nine guests" (*jiuke*), a figure of speech for the Chinese zither, the older 17x17 line variant of Weiqi (known today as Go), Zen Buddhist meditation, ink (calligraphy and painting), tea drinking, alchemy, chanting poetry, conversation, and drinking wine.[29] These nine activities were an extension to the older so-called Four Arts of the Chinese Scholar.



Painting of a Buddhist luohan, by Liu Songnian, painted in 1207; Shen Kuo not only listed literati painting as one of his cherished pastimes, but also Buddhist meditation.[29]

According to Zhu Yu's book *Pingzhou Table Talks* (萍洲可談; *Pingzhou Ketan*) of 1119, Shen Kuo had two marriages; the second wife was the daughter of Zhang Chu (張蓴), who came from Huainan. Lady Zhang was said to be overbearing and fierce, often abusive to Shen Kuo, even attempting at one time to pull off his beard. Shen Kuo's children were often upset over this, and prostrated themselves to Lady Zhang to quit this behavior. Despite this, Lady Zhang went as far as to drive out Shen Kuo's son from his first marriage, expelling him from the household. However, after Lady Zhang died, Shen Kuo fell into a deep depression and even attempted to jump into the Yangtze River to drown himself. Although this suicide attempt failed, he would die a year later.[31]

In the 1070s, Shen had purchased a lavish garden estate on the outskirts of modern-day Zhenjiang, Jiangsu province, a place of great beauty which he named "Dream Brook" ("Mengxi") after he visited it for the first time in 1086.[17] Shen Kuo permanently moved to the Dream Brook Estate in 1088, and in that same year he completed his life's written work of the *Dream Pool Essays*, naming the book after his garden-estate property. It was there that Shen Kuo spent the last several years of his life in leisure, isolation, and illness, until his death in 1095.[17]

Scholarly achievements

Shen Kuo wrote extensively on a wide range of different subjects. His written work included two geographical atlases, a treatise on music with mathematical harmonics, governmental administration, mathematical astronomy, astronomical instruments, martial defensive tactics and fortifications, painting, tea, medicine, and much poetry.[32] His scientific writings have been praised by sinologists such as Joseph Needham and Nathan Sivin, and he has been compared by Sivin to polymaths such as his contemporary Su Song, as well as Gottfried Leibniz and Mikhail Lomonosov.[33]

Raised-relief map

If the account of Sima Qian (c. 145–86 BC) in his *Records of the Grand Historian* is proven correct upon the unearthing of Qin Shi Huang's (r. 221–210 BC) tomb, the raised-relief map has existed since the Qin Dynasty (221–206 BC).[35] Robert Temple and Joseph Needham suggest that certain pottery vessels of the Han Dynasty (202 BC – 220 AD) showing artificial mountains as lid decorations may have influenced the raised-relief map.[34] The Han Dynasty general Ma Yuan (14 BC – 49 AD) made a raised-relief map of valleys and mountains in a rice-constructed model of 32 AD.[35] [36] Such rice models were expounded on by the Tang Dynasty (618–907) author Jiang Fang in his *Essay on the Art of Constructing Mountains with Rice* (c. 845 AD).[35] A raised-relief map made of wood representing all the provinces of the empire and put together like a giant 0.93 m^2 (10 ft^2) jigsaw puzzle was invented by Xie Zhuang (421–466 AD) during the Liu Song Dynasty (420–479).[35]

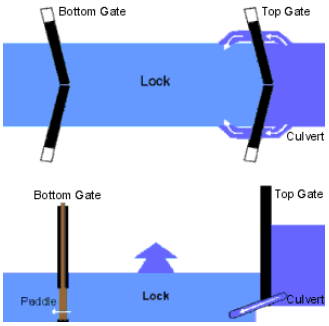
Joseph Needham writes that the raised-relief maps known in China may have been influenced by Han Dynasty (202 BC –220 AD) incense burners and jars such as this, showing artificial mountains as a lid decoration.[34]

Shen's largest atlas included twenty three maps of China and foreign regions that were drawn at a uniform scale of 1:900,000.[5] Shen also created a three dimensional raised-relief map using sawdust, wood, beeswax, and wheat paste.[5] [37] [38] Zhu Xi (1130–1200) was inspired by the raised-relief map of Huang Shang and so made his own portable map made of wood and clay which could be folded up from eight hinged pieces.[38] [39] Later, Ibn Battuta (1304–1377) described a raised-relief map while visiting Gibraltar, while European raised-relief maps started with a Paul Dox who made one to represent Kufstein, Austria, in 1510.[40] [41] The Englishman John Evelyn (1620–1706), in his 1665 paper featured in the *Philosophical Transactions of the Royal Society*, wrote that the raised-relief map was something new from France.[40]

Pharmacology

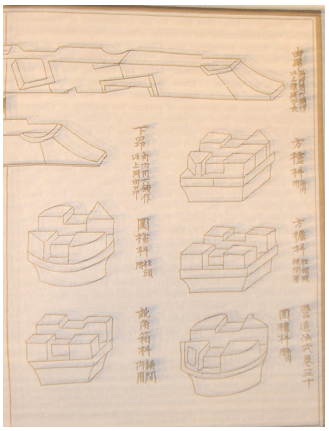
For pharmacology, Shen wrote of the difficulties of adequate diagnosis and therapy, as well as the proper selection, preparation, and administration of drugs.[42] He held great concern for detail and philological accuracy in identification, use and cultivation of different types of medicinal herbs, such as in which months medicinal plants should be gathered, their exact ripening times, which parts should be used for therapy; for domesticated herbs he wrote about planting times, fertilization, and other matters of horticulture.[43] In the realms of botany, zoology, and mineralogy, Shen Kuo documented and systematically described hundreds of different plants, agricultural crops, rare vegetation, animals, and minerals found in China.[44] [45] [46] [47] For example, Shen noted that the mineral orpiment was used to quickly erase writing errors on paper.[48]

Civil engineering



A side view of a pound lock for canals, invented in China in the 10th century and described by Shen.

The writing of Shen Kuo is the only source for the date when the drydock was first used in China.[49] Shen Kuo wrote that during the Xi-Ning reign (1068–1077), the court official Huang Huaixin devised a plan for repairing 60 m (200 ft) long palatial boats that were a century old; essentially, Huang Huaixin devised the first Chinese drydock for suspending boats out of water.[49] These boats were then placed in a roof-covered dock warehouse to protect them from weathering.[49] Shen also wrote about the effectiveness of the new invention (i.e. by the 10th century engineer Qiao Weiyo) of the pound lock to replace the old flash lock design used in canals.[50] He wrote that it saved the work of five hundred annual labors, annual costs of up to 1,250,000 strings of cash, and increased the size limit of boats accommodated from 21 tons/21000 kg to 113 tons/115000 kg.[50]



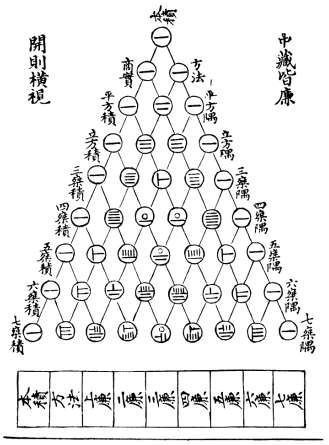
Five bracket arm bases and two cantilever arms, from the *Yingzao Fashi* of 1103.

If it were not for Shen Kuo's analysis and quoting in his *Dream Pool Essays* of the writings of the architect Yu Hao (fl. 970), the latter's work would have been lost to history.[51] d[›] Yu designed a famous wooden pagoda that burned down in 1044 and was replaced in 1049 by a brick pagoda (the 'Iron Pagoda') of similar height, but not of his design. From Shen's quotation—or perhaps Shen's own paraphrasing of Yu Hao's *Timberwork Manual* (木經; *Mujing*)—shows that already in the 10th century there was a graded system of building unit proportions, a system which Shen states had become more precise in his time but stating no one could possibly reproduce such a sound work.[52] [53] However, he did not anticipate the more complex and matured system of unit proportions embodied in the extensive written work by scholar-official Li Jie (1065–1110), the *Treatise on Architectural Methods* (營造法式; *Yingzao Fashi*) of 1103.[53] [54] Klaas Ruitenbeek states that the version of the *Timberwork Manual* quoted by Shen is most likely Shen's summarization of Yu's work or a corrupted passage of the original by Yu Hao, as Shen writes: "According to some, the work was written by Yu Hao."[52]

Anatomy

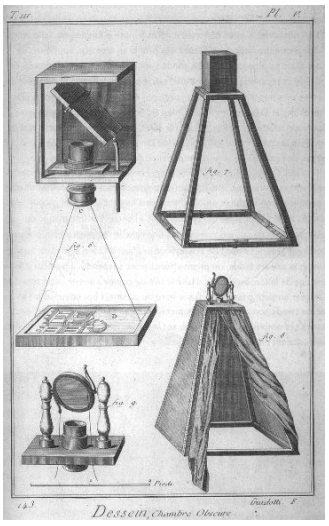
The Chinese had long taken an interest in examining the human body. For example, in 16 AD the Xin Dynasty usurper Wang Mang called for the dissection of an executed man, to examine his arteries and viscera in order to discover cures for illnesses.[55] Shen also took interest in human anatomy, dispelling the long-held Chinese theory that the throat contained three valves, writing, "When liquid and solid are imbibed together, how can it be that in one's mouth they sort themselves into two throat channels?"[43] Shen maintained that the larynx was the beginning of a system that distributed vital *qi* from the air throughout the body, and that the esophagus was a simple tube that dropped food into the stomach.[56] Following Shen's reasoning and correcting the findings of the dissection of executed bandits in 1045, an early 12th century Chinese account of a bodily dissection finally supported Shen's belief in two throat valves, not three.[57] Also, the later Song Dynasty judge and early forensic expert Song Ci (1186–1249) would promote the use of autopsy in order to solve homicide cases, as written in his *Collected Cases of Injustice Rectified*.[58]

Mathematics and optics



Yang Hui triangle (Pascal's triangle) using rod numerals, from a book by mathematician Zhu Shijie, 1303

In the broad field of mathematics, Shen Kuo mastered many practical mathematical problems, including many complex formulas for geometry,[59] 'packing' equations for calculus,[60] and chords and arcs problems employing trigonometry.[61] Shen addressed problems of writing out very large numbers, as large as 10^{43}.[62] Shen's "technique of small increments" laid the foundation in Chinese mathematics for packing problems involving equal difference series.[62] Sal Restivo writes that Shen used summation of higher series to ascertain the number of kegs which could be piled in layers in a space shaped like the frustum of a rectangular pyramid.[63] In his formula "technique of intersecting circles", he created an approximation of the arc of a circle s given the diameter d, sagita v, and length of the chord c subtending the arc, the length of which he approximated as $s = c + 2v^2/d$.[62] Restivo writes that Shen's work in the lengths of arcs of circles provided the basis for spherical trigonometry developed in the 13th century by Guo Shoujing (1231–1316).[63] He also simplified the counting rods technique by outlining short cuts in algorithm procedures used on the counting board, an idea expanded on by the mathematician Yang Hui (1238–1298).[64] Victor J. Katz asserts that Shen's method of "dividing by 9, increase by 1; dividing by 8, increase by 2," was a direct forerunner to the rhyme scheme method of repeated addition "9, 1, bottom add 1; 9, 2, bottom add 2".[65]



An 18th century diagram of camera obscura

Shen wrote extensively about what he had learned while working for the state treasury, including mathematical problems posed by computing land tax, estimating requirements, currency issues, metrology, and so forth.[66] Shen once computed the amount of terrain space required for battle formations in military strategy,[67] and also computed the longest possible military campaign given the limits of human carriers who would bring their own food and food for other soldiers.[68] Shen wrote about the earlier Yi Xing (672–717), a Buddhist monk who applied an early escapement mechanism to a water-powered celestial globe.[69] By using mathematical permutations, Shen described Yi Xing's calculation of possible positions on a *go* board game. Shen calculated the total number for this using up to five rows and twenty five game pieces, which yielded the number 847,288,609,443.[70] [71]

Shen Kuo experimented with the pinhole camera and burning mirror as the ancient Chinese Mohists had done in the 4th century BC. Although the Iraqi Muslim scientist Ibn al-Haytham (965–1039) was the first to experiment with camera obscura, Shen Kuo was the first to attribute geometrical and quantitative properties to the camera obscura, just several decades after Ibn al-Haytham's death.[72] Using a fitting metaphor, Shen compared optical image inversion to an oarlock and waisted drum.[73] He also discussed focal points and noted that the image in a concave mirror is inverted.[74] Shen, who never asserted that he was the first to experiment with camera obscura, hints in his writing that camera obscura was dealt with in the *Miscellaneous Morsels from Youyang* written by Duan Chengshi (d. 863) during the Tang Dynasty (618–907), in regards to the inverted image of a Chinese pagoda by a seashore.[72]

Magnetic needle compass

Since the time of the engineer and inventor Ma Jun (c. 200–265), the Chinese had used the South Pointing Chariot, which did not employ magnetism, as a compass. In 1044 the *Collection of the Most Important Military Techniques* (武經總要; *Wujing Zongyao*) recorded that fish-shaped objects cut from sheet iron, magnetized by thermoremanence (essentially, heating that produced weak magnetic force), and placed in a water-filled bowl enclosed by a box were used for directional pathfinding alongside the South Pointing Chariot.[75] [76]

A Han Dynasty (202 BC–220 AD) ladle-and-basin lodestone south-pointing compass, used by ancient Chinese geomancers, but not for navigation.

However, it was not until the time of Shen Kuo that the earliest magnetic compasses would be used for navigation. In his written work, Shen Kuo made the first known explicit reference to the magnetic compass-needle and the concept of true north.[16] [77] [78] He wrote that steel needles were magnetized once they were rubbed with lodestone, and that they were put in floating position or in mountings; he described the suspended compass as the best form to be used, and noted that the magnetic needle of compasses pointed either south or north.[75] [79] Shen Kuo asserted that the needle will point south but with a deviation,[79] stating "[the magnetic needles] are always displaced slightly east rather than pointing due south."[75]

Shen Kuo wrote that it was preferable to use the twenty-four-point rose instead of the old eight compass cardinal points — and the former was recorded in use for navigation shortly after Shen's death.[5] The preference of use for the twenty-four-point-rose compass may have arisen from Shen's finding of a more accurate astronomical meridian, determined by his measurement between the polestar and true north;[5] however, it could also have been inspired by geomantic beliefs and practices.[5] The book of the author Zhu Yu, the *Pingzhou Table Talks* published in 1119 (written from 1111 to 1117), was the first record of use of a compass for seafaring navigation.[78] [80] However, Zhu Yu's book recounts events back to 1086, when Shen Kuo was writing the *Dream Pool Essays*; this meant that in Shen's time the compass might have already been in navigational use.[80] In any case, Shen Kuo's writing on magnetic compasses has proved invaluable for understanding China's earliest use of the compass for seafaring navigation.

Archaeology

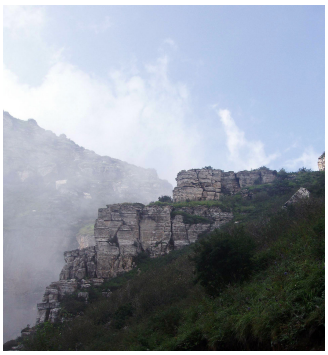
Bronzeware from the Shang Dynasty (1600–1046 BC); Song era antiquarians and archeologists in search of antiques for reviving ancient rituals claimed to have found bronzewares dated as far back as the Shang era, which contained written inscriptions.[81]

Many of Shen Kuo's contemporaries were interested in antiquarian pursuits of collecting old artworks.[82] They were also interested in archaeological pursuits, although for rather different reasons than why Shen Kuo held an interest in archaeology. While Shen's educated Confucian contemporaries were interested in obtaining ancient relics and antiques in order to revive their use in rituals, Shen was more concerned with how items from archeological finds were originally manufactured and what their functionality would have been, based on empirical evidence.[83] Shen Kuo criticized those in his day who reconstructed ancient ritual objects using only their imagination and not the tangible evidence from archeological digs or finds.[83] Shen also disdained the notion of others that these objects were products of the "sages" or the aristocratic class of antiquity, rightfully crediting the items' manufacture and production to the common working people and artisans of previous eras.[83] Fraser and Haber write that Shen Kuo "advocated the use of an interdisciplinary approach to archaeology and practiced such an approach himself through his work in metallurgy, optics, and geometry in the study of ancient measures."[83]

While working in the Bureau of Astronomy, Shen Kuo's interest in archaeology and old relics led him to reconstruct an armillary sphere from existing models as well as from ancient texts that could provide additional information.[83] Shen used ancient mirrors while conducting his optics experiments.[83] He observed ancient weaponry, describing the scaled sight devices on ancient crossbows and the ancients' production of swords with composite blades that had a midrib of wrought iron and low-carbon steel while having two sharp edges of high-carbon steel.[83] Being a knowledgeable musician, Shen also suggested suspending an ancient bell by using a hollow handle.[83] In his assessment of the carved reliefs of the ancient Zhuwei Tomb, Shen stated that the reliefs demonstrate genuine Han Dynasty (202 BC–220 AD) era clothing.[84]

After unearthing an ancient crossbow device from a house's garden in Haichow, Jiangsu, Shen discovered that the cross-wire grid sighting device, marked in graduated measurements on the stock, could be used to calculate the height of a distant mountain in the same way that mathematicians could apply right-angle triangles to measure height.[85] Needham asserts Shen had discovered the survey device known as Jacob's staff, which was not described elsewhere until the Provençal Jewish mathematician Levi ben Gerson (1288–1344) wrote of it in 1321.[86] Shen wrote that while viewing the whole of a mountain, the distance on the instrument was long, but while viewing a small part of the mountainside the distance was short due to the device's cross piece that had to be pushed further away from the observer's eye, with the graduation starting on the further end.[85] He wrote that if one placed an arrow on the device and looked past its end, the degree of the mountain could be measured and thus its height could be calculated.[85]

Geology



View of the Taihang Mountains, where Shen Kuo had his epiphany about geomorphology.

The ancient Greek Aristotle (384 BC–322 BC) wrote in his *Meteorology* of how the earth had the potential for physical change, including the belief that all rivers and seas at one time did not exist where they were, and were dry. The Greek writer Xenophanes (570 BC–480 BC) wrote of how inland marine fossils were evidence that massive periodic flooding had wiped out mankind several times in the past, but never wrote of land formation or shifting seashores.[87] Du Yu (222–285) a Chinese Jin Dynasty officer, believed that the land of hills would eventually be leveled into valleys and valleys would gradually rise to form hills.[88] The Daoist alchemist Ge Hong (284–364) wrote of the legendary immortal Ma Gu; in a written dialogue by Ge, Ma Gu described how what was once the Eastern Sea (i.e. East China Sea) had transformed into solid land where mulberry trees grew, and would one day be filled with mountains and dry, dusty lands.[88] The later Persian Muslim scholar Abū Rayhān al-Bīrūnī (973–1048) hypothesized that India was once covered by the Indian Ocean while observing rock formations at the mouths of rivers.[89]

It was Shen Kuo who formulated a hypothesis about the process of land formation (geomorphology) based upon several observations as evidence. This included his observation of fossil shells in a geological stratum of a mountain hundreds of miles from the ocean. He inferred that the land was reshaped and formed by erosion of the mountains, uplift, and the deposition of silt, after observing strange natural erosions of the Taihang Mountains and the Yandang Mountain near Wenzhou.[90] He hypothesized that, with the inundation of silt, the land of the continent must have been formed over an enormous span of time.[91] While visiting the Taihang Mountains in 1074, Shen Kuo noticed strata of bivalve shells and ovoid rocks in a horizontal-running span through a cliff like a large belt.[91] Shen proposed that the cliff was once the location of an ancient seashore that by his time had shifted hundreds of miles east.[91] Shen wrote that in the Zhiping reign period (1064–1067) a man of Zezhou unearthed an object in his garden that looked like a serpent or dragon, and after examining it, concluded the dead animal had apparently turned to "stone".[92] [93] The magistrate of Jincheng, Zheng Boshun, examined the creature as well, and noted the same scale-like markings that were seen on other marine animals.[92] [93] Shen Kuo likened this to the "stone crabs" found in China.[92] [93]

Bamboo and rocks by Li Kan (1244–1320); using evidence of fossilized bamboo within China's dry northwestern climate zone, Shen Kuo hypothesized that climates naturally shifted geographically over time.

Shen also wrote that since petrified bamboos were found underground in a climatic area where they had never been known to be grown, the climate there must have shifted geographically over time.[94] Around the year 1080, Shen Kuo noted that a landslide on the bank of a large river near Yanzhou (modern Yan'an) had revealed an open space several dozens of feet under the ground once the bank collapsed.[94] This underground space contained hundreds of petrified bamboos still intact with roots and trunks, "all turned to stone" as Shen Kuo wrote.[94] Shen Kuo noted that bamboos do not grow in Yanzhou, located in northern China, and he was puzzled during which previous dynasty the bamboos could have grown.[94] Considering that damp and gloomy low places provide suitable conditions for the growth of bamboo, Shen deduced that the climate of Yanzhou must have fit that description in very ancient times.[94] Although this would have intrigued many of his readers, the study of paleoclimatology in medieval China never developed into an established discipline.

The philosopher Zhu Xi (1130–1200) wrote of this curious natural phenomenon of fossils as well. He was known to have read the works of Shen Kuo.[93] Shen's description of soil erosion and weathering predated that of Georgius Agricola in his book of 1546, *De veteribus et novis metallis*.[95] Furthermore, Shen's theory of sedimentary deposition predated that of James Hutton, who published his groundbreaking work in 1802 (considered the foundation of modern geology).[95] Historian Joseph Needham likened Shen's account to that of the Scottish scientist Roderick Murchison (1792–1871), who was inspired to become a geologist after observing a providential landslide.

Meteorology

Shen accurately hypothesized that rainbows were caused by sunlight passing through rain droplets.

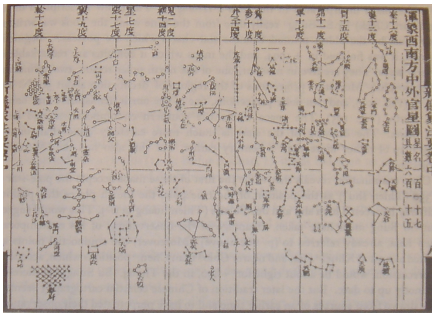
Early speculation and hypothesis pertaining to what is now known as meteorology had a long tradition in China before Shen Kuo.[96]

Shen wrote vivid descriptions of tornadoes—the first known description of them in East Asia.

He also gave reasoning (earlier proposed by Sun Sikong, 1015–1076) that rainbows were formed by the shadow of the sun in rain, occurring when the sun would shine upon it.[97] [98] [99] Paul Dong writes that Shen's explanation of the rainbow as a phenomenon of atmospheric refraction "is basically in accord with modern scientific principles."[100] In Europe, Roger Bacon (1214–1294) was the first to suggest that the colors of the rainbow were caused by the reflection and refraction of sunlight through rain drops.[74]

Shen hypothesized that rays of sunlight refract before reaching the surface of the earth, hence people on earth observing the sun are not viewing it in its exact position, in other words, the altitude of the apparent sun is higher than the actual altitude of the sun.[100] Dong writes that "at the time, this discovery was remarkably original."[100] It should be noted that Ibn al-Haytham, in his *Book of Optics* (1021), also discussed atmospheric refraction (in regards to twilight).[74]

Astronomy and instruments

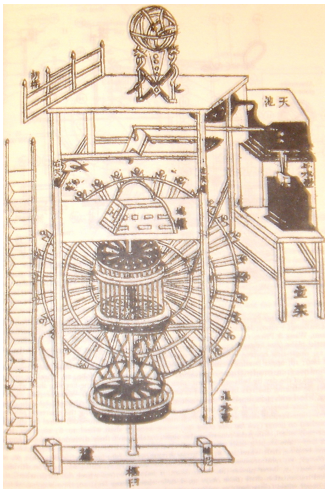


One of the five star maps published in 1092 AD for Su Song's horological and astronomical treatise, featuring Shen Kuo's corrected position of the pole star.

Being the head official for the Bureau of Astronomy, Shen Kuo was an avid scholar of medieval astronomy, and improved the designs of several astronomical instruments. Shen is credited with making improved designs of the gnomon, armillary sphere, and clepsydra clock.[101] For the clepsydra he designed a new overflow-tank type, and argued for a more efficient higher-order interpolation instead of linear interpolation in calibrating the measure of time.[101] Improving the 5th century model of the astronomical sighting tube, Shen Kuo widened its diameter so that the new calibration could observe the polestar indefinitely.[101] This came about due to the position of the polestar shifting in position since the time of Zu Geng in the 5th century, hence Shen Kuo diligently observed the course of the polestar for three months, plotting the data of its course and coming to the conclusion that it had shifted slightly over three degrees.[101] Apparently this astronomical finding had an impact upon the intellectual community in China at the time. Even Shen's political rival and contemporary astronomer Su Song featured Shen's corrected position of the polestar (halfway between Tian shu, at −350 degrees, and the current Polaris) in the fourth star map of his celestial atlas.[102]

The astronomical phenomena of the solar eclipse and lunar eclipse had been observed in the 4th century BC by astronomers Gan De and Shi Shen; the latter gave instructions on predicting the eclipses based on the relative

position of the Moon to the Sun.[103] The philosopher Wang Chong argued against the 'radiating influence' theory of Jing Fang's writing in the 1st century BC and that of Zhang Heng (78–139); the latter two correctly hypothesized that the brightness of the Moon was merely light reflected from the Sun.[104] Jing Fang had written in the 1st century BC of how it was long accepted in China that the Sun and Moon were spherical in shape ('like a crossbow bullet'), not flat.[105] Shen Kuo also wrote of solar and lunar eclipses in this manner, yet expanded upon this to explain why the celestial bodies were spherical, going against the 'flat earth' theory for celestial bodies.[106] However, there is no evidence to suggest that Shen Kuo supported a round earth theory, which was introduced into Chinese science by Matteo Ricci and Xu Guangqi in the 17th century.[107] When the Director of the Astronomical Observatory asked Shen Kuo if the shapes of the Sun and Moon were round like balls or flat like fans, Shen Kuo explained that celestial bodies were spherical because of knowledge of waxing and waning of the Moon.[106] Much like what Zhang Heng had said, Shen Kuo likened the Moon to a ball of silver, which does not produce light, but simply reflects light if provided from another source (the Sun).[106] He explained that when the Sun's light is slanting, the Moon appears full.[106] He then explained if one were to cover any sort of sphere with white powder, and then viewed from the side it would appear to be a crescent, hence he reasoned that celestial bodies were spherical.[100] [106] He also wrote that, although the Sun and Moon were in conjunction and opposition with each other once a month, this did not mean the Sun would be eclipsed every time their paths met, because of the small obliquity of their orbital paths.[106] [108]



The original diagram of Su Song's book of 1092 showing the inner workings of his clocktower; a mechanically rotated armillary sphere crowns the top.

Shen is also known for his cosmological hypotheses in explaining the variations of planetary motions, including retrogradation.[109] His colleague Wei Pu realized that the old calculation technique for the mean Sun was inaccurate compared to the apparent Sun, since the latter was ahead of it in the accelerated phase of motion, and behind it in the retarded phase.[110] Shen's hypotheses were similar to the concept of the epicycle in the Greco-Roman tradition,[109] only Shen compared the side-section of orbital paths of planets and variations of planetary speeds to points in the tips of a willow leaf.[111] [112] In a similar rudimentary physical analogy of celestial motions, as John B. Henderson describes it, Shen likened the relationship of the Moon's path to the ecliptic, the path of the Sun, "to the figure of a rope coiled about a tree."[112]

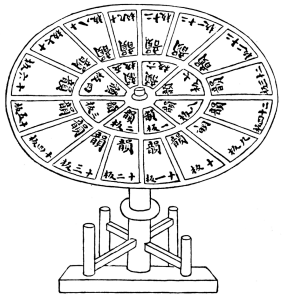
Along with his colleague Wei Pu in the Bureau of Astronomy, Shen Kuo planned to plot out the exact coordinates of planetary and lunar movements by recording their astronomical observations three times a night for a continuum of five years.[8] The Song astronomers of Shen's day still retained the lunar theory and coordinates of the earlier Yi Xing, which after 350 years had devolved into a state of considerable error.[8] Shen criticized earlier Chinese astronomers for failing to describe celestial movement in spacial terms, yet he did not attempt to provide any reasoning for the motive power of the planets or other celestial movements.[112] Shen and Wei began astronomical observations for the Moon and planets by plotting their locations three times a night for what should have been five successive years.[8] The officials and astronomers at court were deeply opposed Wei and Shen's work, offended by their insistence that the coordinates of the renowned Yi Xing were inaccurate.[113] They also slandered Wei Pu, out of resentment that a commoner had expertise exceeding theirs.[114] When Wei and Shen made a public demonstration using the gnomon to prove the doubtful wrong, the other ministers reluctantly agreed to correct the lunar and solar errors.[113] [115] Despite this success, they eventually dismissed Wei and Shen's tables of planetary motions.[22] Therefore, only the worst and most obvious planetary errors were corrected, and many inaccuracies remained.[114]

Movable type printing

The Chinese *Diamond Sutra*, the oldest known printed book in world history (868), using woodblock printing.

Shen Kuo wrote that during the Qingli reign period (1041–1048), under Emperor Renzong of Song (1022–1063), an obscure commoner and artisan known as Bi Sheng (990–1051) invented ceramic movable type printing.[116] [117] Although the use of assembling individual characters to compose a piece of text had its origins in antiquity, Bi Sheng's methodical innovation was something completely revolutionary for his time. Shen Kuo noted that the process was tedious if one only wanted to print a few copies of a book, but if one desired to make hundreds or thousands of copies, the process was incredibly fast and efficient.[116] Beyond Shen Kuo's writing, however, nothing is known of Bi Sheng's life or the influence of movable type in his lifetime.[118] Although the details of Bi Sheng's life were scarcely known, Shen Kuo wrote:

> When Bi Sheng died, his fount of type passed into the possession of my followers (i.e. one of Shen's nephews), among whom it has been kept as a precious possession until now.[2] [119]



A revolving table typecase with individual movable type characters arranged primarily by rhyming scheme, from Wang Zhen's book of agriculture published in 1313.

There are a few surviving examples of books printed in the late Song Dynasty using movable type printing.[120] This includes Zhou Bida's *Notes of The Jade Hall* (玉堂雜記) printed in 1193 using the method of baked-clay movable type characters outlined in the *Dream Pool Essays*.[121] Yao Shu (1201–1278), an advisor to Kublai Khan, once persuaded a disciple Yang Gu to print philological primers and Neo-Confucian texts by using what he termed the "movable type of Shen Kuo".[122] Wang Zhen (fl. 1290–1333), who wrote the valuable agricultural, scientific, and technological treatise of the *Nong Shu*, mentioned an alternative method of baking earthenware type with earthenware frames in order to make whole blocks.[122] Wang Zhen also improved its use by inventing wooden movable type in the years 1297 or 1298, while he was a magistrate of Jingde, Anhui province.[123] The earlier Bi Sheng had experimented with wooden movable type,[124] but Wang's main contribution was improving the speed of typesetting with simple mechanical devices, along with the complex, systematic arrangement of wooden movable type involving the use of revolving tables.[125] Although later metal movable type would be used in China, Wang Zhen experimented with tin metal movable type, but found its use to be inefficient.[126]

By the 15th century, metal movable type printing was developed in Ming Dynasty China (and earlier in Joseon Korea, by the mid 13th century), and was widely applied in China by at least the 16th century.[127] In Jiangsu and Fujian, wealthy Ming era families sponsored the use of metal type printing (mostly using bronze). This included the printing works of Hua Sui (1439–1513), who pioneered the first Chinese bronze-type movable printing in the year 1490.[128] In 1718, during the mid Qing Dynasty (1644–1912), the scholar of Tai'an known as Xu Zhiding developed movable type with enamelware instead of earthenware.[122] There was also Zhai Jinsheng (b. 1784), a teacher of Jingxian, Anhui, who spent thirty years making a font of earthenware movable type, and by 1844 he had over 100,000 Chinese writing characters in five sizes.[122]

Despite these advances, movable type printing never gained the amount of widespread use in East Asia that woodblock printing had achieved since the Chinese Tang Dynasty in the 9th century. With written Chinese, the vast amount of written morpheme characters impeded movable type's acceptance and practical use, and was therefore seen as largely unsatisfactory.[116] Furthermore, the European printing press, first invented by Johannes Gutenberg

(1398–1468), was eventually wholly adopted as the standard in China, yet the tradition of woodblock printing remains popular in East Asian countries still.

Other achievements in science and technology

Shen Kuo described the phenomena of natural predator insects controlling the population of pests, the latter of which had the potential to wreak havoc upon the agricultural base of China.[129]

While visiting the iron producing district at Cizhou in 1075, Shen described the "partial decarburization" method of reforging cast iron under a cold blast, which Hartwell, Needham, and Wertime state is the predecessor of the Bessemer process.[130] Shen was worried about deforestation[g][›] due to the needs of the iron industry and ink makers using pine soot in the production process, so he suggested for the latter an alternative of petroleum, which he believed was "produced inexhaustibly within the earth".[97] [131] Shen used the soot from the smoke of burned petroleum fuel (石油 *Shíyóu*, "rock oil" as Shen called it) to invent a new, more durable type of writing ink; the Ming Dynasty pharmacologist Li Shizhen (1518–1593) wrote that Shen's ink was "lustrous like lacquer, and superior to that made from pinewood lamp-black," or the soot from pinewood.[132] [133]

Beliefs and philosophy

Ideas of the philosopher Mencius deeply influenced Shen.

Shen Kuo was much in favor of philosophical Daoist notions which challenged the authority of empirical science in his day. Although much could be discerned through empirical observation and recorded study, Daoism asserted that the secrets of the universe were boundless, something that scientific investigation could merely express in fragments and partial understandings.[134] Shen Kuo referred to the ancient Daoist *I Ching* in explaining the spiritual processes and attainment of foreknowledge that cannot be attained through "crude traces", which he likens to mathematical astronomy.[134] Nathan Sivin proposes that Shen was the first in history to "make a clear distinction between our unconnected experiences and the unitary causal world we postulate to explain them," which Biderman and Scharfstein state is arguably inherent in the works of Heraclitus, Plato, and Democritus as well.[135] Shen was a firm believer in destiny and prognostication, and made rational explanations for the relations between them.[136] Shen held a special interest in fate, mystical divination, bizarre phenomena, yet warned against the tendency to believe that all matters in life were preordained.[137] When describing an event where lightning had struck a house and all the wooden walls did not burn (but simply turned black) and lacquerwares inside were fine, yet metal objects had melted into liquid, Shen Kuo wrote:

> Most people can only judge of things by the experiences of ordinary life, but phenomena outside the scope of this are really quite numerous. How insecure it is to investigate natural principles using only the light of common knowledge, and subjective ideas.[138]

In his commentary on the ancient Confucian philosopher Mencius (372–289 BC), Shen wrote of the importance of choosing to follow what one knew to be a true path, yet the heart and mind could not attain full knowledge of truth through mere sensory experience.[73] In his own unique way but using terms influenced by the ideas of Mencius, Shen wrote of an autonomous inner authority that formed the basis for one's inclination towards moral choices, a concept linked to Shen's life experiences of surviving and obtaining success through self-reliance.[73] Along with his commentary on the Chinese classic texts, Shen Kuo also wrote extensively on the topics of supernatural divination and Buddhist meditation.[139]

Art criticism

As an art critic, Shen criticized the paintings of Li Cheng (919–967) for failing to observe the principle of "*seeing the small from the viewpoint of the large*" in portraying buildings and the like.[140] He praised the works of Dong Yuan (c. 934–c. 962); he noted that although a close-up view of Dong's work would create the impression that his brush techniques were cursory, seen from afar his landscape paintings would give the impression of grand, resplendent, and realistic scenery.[141] [142] [143] In addition, Shen's writing on Dong's artworks represents the earliest known reference to the Jiangnan style of painting.[144] In his "Song on Painting" and in his *Dream Pool Essays*, Shen praised the creative artworks of the Tang painter Wang Wei (701–761); Shen noted that Wang was unique in that he "penetrated into the mysterious reason and depth of creative activity," but was criticized by others for not conforming his paintings to reality, such as his painting with a banana tree growing in a snowy, wintry landscape.[145] [146] [147]

A painting by Dong Yuan, who Shen praised for his ability to portray landscapes and natural scenery in a grand but realistic style.

Written works

Much of Shen Kuo's written work was probably purged under the leadership of minister Cai Jing (1046–1126), who revived the New Policies of Wang Anshi, although he set out on a campaign of attrition to destroy or radically alter the written work of his predecessors and especially Conservative enemies.[148] For example, only six of Shen's books remain, and four of these have been significantly altered since the time they were penned by the author.[149]

In modern times, the best attempt at a complete list and summary of Shen's writing was an appendix written by Hu Daojing in his standard edition of *Brush Talks*, written in 1956.[150]

Dream Pool Essays

Shen Kuo's *Dream Pool Essays* consists of some 507 separate essays exploring a wide range of subjects.[151] It was Shen's ultimate attempt to comprehend and describe a multitude of various aspects of nature, science, and reality, and all the practical and profound curiosities found in the world. The literal translation of the title, *Dream Brook Brush Talks*, refers to his Dream Brook estate, where he spent the last years of his life. About the title, he is quoted as saying: "Because I had only my writing brush and ink slab to converse with, I call it Brush Talks."[c][›]

The book was originally 30 chapters long, yet an unknown Chinese author's edition of 1166 edited and reorganized the work into 26 chapters.[152]

A passage called "Strange Happenings" contains a peculiar account of an unidentified flying object.

Other written works

A Song era portrait of the poet and statesman Su Shi, whose pharmaceutical work was combined with Shen Kuo's in 1126.

Although the *Dream Pool Essays* is certainly his most extensive and important work, Shen Kuo wrote other books as well. In 1075, Shen Kuo wrote the *Xining Fengyuan Li* (熙寧奉元曆; *The Oblatory Epoch astronomical system of the Splendid Peace reign period*), which was lost, but listed in a 7th chapter of a Song Dynasty bibliography.[153] This was the official report of Shen Kuo on his reforms of the Chinese calendar, which were only partially adopted by the Song court's official calendar system.[153] Shen Kuo wrote a pharmaceutical treatise known as the *Liang Fang* (良方; *Good medicinal formulas*), compiled sometime during his years of retirement from governmental service.[154] Around the year 1126 it was combined into a written work of the famous Su Shi (1037–1101), who was ironically a political opponent to Shen Kuo's faction of Reformers and New Policies supporters at court,[154] yet it was known that Shen Kuo and Su Shi were nonetheless friends and associates.[155] Shen wrote the *Mengqi Wanghuai Lu* (夢溪忘懷錄; *Record of longings forgotten at Dream Brook*), which was also compiled during Shen's retirement. This book was a treatise in the working since his youth on rural life and ethnographic accounts of living conditions in the isolated mountain regions of China.[156] Only quotations of it survive in the *Shuo Fu* (説郛) collection, which mostly describe the agricultural implements and tools used by rural people in high mountain regions. Shen Kuo also wrote the *Changxing Ji* (長興集; *Collected Literary Works of [the Viscount of] Changxing*). However, this book was without much doubt a posthumous collection, including various poems, prose, and administrative documents written by Shen.[156] By the 15th century (during the Ming Dynasty), this book was reprinted, yet only the 19th chapter remained.[156] This chapter was reprinted in 1718, yet poorly edited.[156] Finally, in the 1950s the author Hu Daojing supplemented this small yet valuable work with additions of other scattered poems written by Shen, in the former's *Collection of Shen Kua's Extant Poetry* (Shanghai: Shang-hai Shu-tian, 1958).[156] In the tradition of the popular Song era literary category of 'travel record literature' ('youji wenxue'),[157] Shen Kuo also wrote the *Register of What Not to Forget*, a traveler's guide to what type of carriage is suitable for a journey, the proper foods one should bring, the special clothing one should bring, and many other items.[158]

In his *Sequel to Numerous Things Revealed*, the Song author Cheng Dachang (1123–1195) noted that stanzas prepared by Shen Kuo for military victory celebrations were later written down and published by Shen.[159] This includes a short poem "Song of Triumph" by Shen Kuo, who uses the musical instrument *mawei huqin* ('horse-tail barbarian stringed instrument' or 'horse-tail fiddle'[160]) of the northwestern Inner Asian nomads as a metaphor for prisoners-of-war led by Song troops:

> The *mawei huqin* followed the Han chariot,
> Its music sounding of complaint to the Khan.
> Do not bend the bow to shoot the goose within the clouds,
> The returning goose bears no letter.
>
> Shen Kuo[159]

Historian Jonathan Stock notes that the bent bow described in the poem above represents the arched bow used to play the *huqin*, while the sound of the instrument itself represented the discontent expressed by the prisoners-of-war with their defeated khan.[159]

Legacy

Praise, critique, and criticism

In the *Routledge Curzon Encyclopedia of Confucianism*, Xinzhong Yao states that Shen Kuo's legacy was tainted by his eager involvement in Wang Anshi's New Policies reforms, his actions criticized in the later traditional histories.[1] However, Shen's reputation as a polymath has been well regarded. The British sinologist, historian, and biochemist Joseph Needham (1900–1995) stated that Shen Kuo was "one of the greatest scientific minds in Chinese history."[161] The French sinologist Jacques Gernet is of the opinion that Shen possessed an "amazingly modern mind."[162] Yao states of Shen's thorough recording of natural sciences in his *Dream Pool Essays*:

> We must regard Shen Kuo's collection as an indispensable primary source attesting to the unmatched level of attainment achieved by Chinese science prior to the twelfth century.[163]

However, Toby E. Huff writes that Shen Kuo's "scattered set" of writings lacks clear-cut organization and "theoretical acuteness," that is, scientific theory.[164] Nathan Sivin wrote that Shen's originality stands "cheek by jowl with trivial didacticism, court anecdotes, and ephemeral curiosities" that provide little insight.[164] Donald Holzman writes that Shen "has nowhere organized his observations into anything like a general theory."[164] Huff writes that this was a systemic problem of early Chinese science, which lacked systematic treatment that could be found in European works such as the *Concordance and Discordant Canons* by the lawyer Gratian of Bologna (fl. 12th century).[164] In regards to an overarching concept of science which could branch together all the various sciences studied by the Chinese, Sivin asserts that the writings of Shen Kuo "do not indicate that he achieved, or even sought, an integrated framework for his diverse knowledge; the one common thread is the varied responsibilities of his career as a high civil servant."[165]

Burial and posthumous honors

Upon his death, Shen Kuo was interred in a tomb in Yuhang District of Hangzhou, at the foot of the Taiping Hill.[166] His tomb was eventually destroyed, yet Ming Dynasty records indicated its location, which was found in 1983 and protected by the government in 1986.[166] The remnants of the tomb's brick structure remained, along with Song Dynasty glasswares and coins.[166] The Hangzhou Municipal Committee completed a restoration of Shen's tomb in September 2001.

In addition to his tomb, Shen Kuo's *Mengxi* garden estate, his former two acre (8,000 m²) property in Zhenjiang, was restored by the government in 1985.[167] However, the renovated Mengxi Garden is only part of the original of Shen Kuo's time.[168] A Qing Dynasty era hall built on the site is now used as the main admissions gate.[167] In the Memorial Hall of the gardens, there is a large painting depicting the original garden of Shen Kuo's time, including wells, green bamboo groves, stone-paved paths, and decorated walls of the original halls.[168] In this exhibition hall there stands a 1.4 m (4.6 ft) tall statue of Shen Kuo sitting on a platform, along with centuries-old published copies of his *Dream Pool Essays* in glass cabinets, one of which is from Japan.[168] At the garden estate there are also displayed marble banners, statues of Shen Kuo, and a model of an armillary sphere; a small museum gallery depicts Shen's various achievements.[167]

The Chinese Mount Zijinshan Observatory discovered a new planetoid in 1964; in 1979, the Chinese Academy of Sciences decided to honor Shen by listing "Shen Kuo" as one of its names.

Notes

^ a: See the article Society of the Song Dynasty.

^ b: Refer to the *Partisans and factions, reformers and conservatives* section of the article History of the Song Dynasty.

^ c: From his biography in the *Dictionary of Scientific Biography* (New York 1970–1990)

^ d: For more, see Architecture of the Song Dynasty.

^ g: For deforestation due to the Song Dynasty iron industry and efforts to curb it, refer to Economy of the Song Dynasty

^ h: Zhang's biography on Shen is of great importance as it contains—according to the historian Nathan Sivin — the fullest and most accurate account of Shen Kuo's life.[169]

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External links

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- Shen Kuo at Chinaculture.org (http://www.chinaculture.org/gb/en_madeinchina/2003-09/24/content_72415.htm)
- Shen Kuo at MacTutor (http://www-history.mcs.st-and.ac.uk/Printonly/Shen_Kua.html)
- Shen Kuo's "Bamboo Shoots" (http://rosettastone.wordpress.com/2006/04/30/shen-kuos-bamboo-shoots/)

Shutter ridge

A **shutter ridge** is a ridge which has moved along a fault line, blocking or diverting drainage. Typically, a shutter ridge creates a valley corresponding to the alignment of the fault that produces it.

Slide (geography)

A **Slide** in physical geography is a term for the fixed or settled residue of a landslide that has stabilized, sometimes in the form of an alluvial fan. It has become a mostly permanent fixture to the landscape.

Slump (geology)

A **Slump** is a form of mass wasting that occurs when a coherent mass of loosely consolidated materials or rock layers moves a short distance down a slope.[1] Movement is characterized by sliding along a concave-upward or planar surface. Causes of slumping include earthquake shocks, thorough wetting, freezing and thawing, undercutting, and loading of a slope.

The slump that destroyed Thistle, Utah, by creating an earthen dam that flooded the area

Translational slumps occur when a detached landmass moves along a planar surface.[2] Common planar surfaces of failure include joints or bedding planes, especially where a permeable layer overrides an impermeable surface. Block slumps are a type of translational slump in which one or more related block units move downslope as a relatively coherent mass.

Rotational slumps occur when a slump block, composed of sediment or rock, slides along a concave-upward slip surface with rotation about an axis parallel to the slope.[3] Rotational movement causes the original surface of the block to become less steep, and the top of the slump is rotated backward. This results in internal deformation of the moving mass consisting chiefly of overturned folds called sheath folds.

Slumps have several characteristic features. The cut which forms as the landmass breaks away from the slope is called the scarp and is often cliff-like and concave. In rotational slumps, the main slump block often breaks into a series of secondary slumps and associated scarps to form stair-step pattern of displaced blocks.[4] The upper surface of the blocks are rotated backwards, forming depressions which may accumulate water to create ponds or swampy areas. The surface of the detached mass often remains relatively undisturbed, especially at the top. However,

hummocky ridges may form near the toe of the slump. Addition of water and loss of sediment cohesion at the toe may transform slumping material into an earthflow. Transverse cracks at the head scarp drain water, possibly killing vegetation. Transverse ridges, transverse cracks and radial cracks form in displaced material on the foot of the slump.

Slumps frequently form due to removal of a slope base, either from natural or manmade processes. Stream or wave erosion, as well as road construction are common instigators for slumping. It is the removal of the slope's physical support which provokes this mass wasting event. Thorough wetting is a common cause, which explains why slumping is often associated with heavy rainfall, storm events and earthflows. Rain provides lubrication for the material to slide, and increases the self-mass of the material. Both factors increase the rate of slumping. Earthquakes also trigger massive slumps, such as the fatal slumps of Turnagain Heights Subdivision in Anchorage, Alaska. This particular slump was initiated by a magnitude 8.4 earthquake that resulted in liquefaction of the soil. Around 75 houses were destroyed by the Turnagain Slump. Power lines, fences, roads, houses, and other manmade structures may be damaged if in the path of a slump.

The speed of slump varies widely, ranging from meters per second, to meters per year. Sudden slumps usually occur after earthquakes or heavy continuing rains, and can stabilize within a few hours. Most slumps develop over comparatively longer periods, taking months or years to reach stability. An example of a slow-moving slump is the Swift Creek Landslide, a deep-seated rotational slump located on Sumas Mountain, Washington.

Slumps may also occur underwater along the margins of continents and islands, resulting from tidal action or a large seismic event. These submarine slumps can generate disastrous tsunamis. The underwater terrain which encompasses the Hawaiian Islands gains its unusual hummocky topography from the many slumps that have taken place for millions of years.

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Slumped chalk slopes at Mupe Bay, Dorset

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Spill containment

Spill containment is where spills of chemicals, oils, sewage etc are contained within a barrier or drainage system rather than being absorbed at the surface. One method is to use an inflatable stopper or pneumatic bladder which is inserted into the outflow of a drainage system to create a containment vessel. In the event of a spill the stopper bladder is inflated to block the drain/s and to prevent the spilled agent from entering the ground water, stream or river.

The National Response Center (NRC)[1] reports over 10,000 annual spills in the US from facilities. All of these can employ the spill containment measures mentioned above.

Advantages

Spill containment is considered by some to be a more eco-friendly solution than using absorbent spill kits that have very small capacity, require disposal after use and do not permit re-cycling of the spilled agent. Chemical handling and oil transfer companies in the UK are now deploying spill containment bladders and valves that can be retro-fitted to existing drainage systems in just a few hours.

Technology

Remote control of the inflation process is also available eliminating risk to operatives in the event of hazardous chemical spills. Normally controls are pneumatic eliminating the need to run electrical cables down into the drainage system.

The latest technology in wireless spill containment eliminates any infrastructure changes using a wireless network (ZigBee) which inflates bladders that employ disposable gas cylinders. The wireless plugs[2] enable spill containment in virtually any location. Using the ZigBee network enables the user to connect any type of component to the wireless system such as sensors, fire alarms, panic buttons, remote controls etc.

Drains of all sizes can be fitted with systems available with extension brackets that cater for drain depths from 500 mm to over 2.5m deep. There are also pneumatically controllable flap valves or pneumatically controlled non-return valves which can be fitted to existing soil waste systems. Again containment is controlled by application of pneumatic pressure in the event of a spill.

References

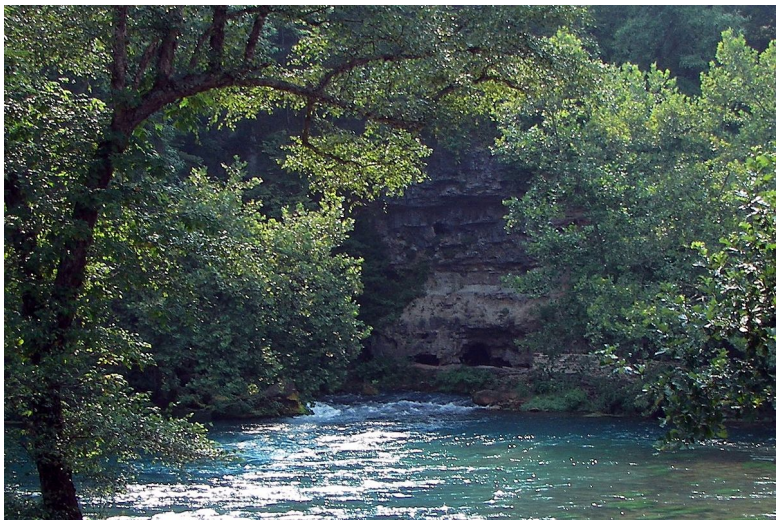
[1] (http://www.nrc.uscg.mil/incident_type_2000up.html), National Response Center.
[2] (http://www.chemigreen.com), Chemigreen.

External links

- Preparing for chemical spill containment in the 21st century (p. 41) (http://ese.dgtlpub.com/2009/2009-08-31/home.php)
- Environment Canada, spill reporting Databases (http://www.ec.gc.ca/inrp-npri/default.asp?lang=en&n=0EC58C98-)
- Wireless Spill Containment (http://www.chemigreen.com)

Spring (hydrosphere)

A **spring**—also known as a **rising** or **resurgence**—is a component of the hydrosphere. Specifically, it is any natural situation where water flows to the surface of the earth from underground. Thus, a spring is a site where the aquifer surface meets the ground surface.



On an average day nearly 300 million gallons of water issue from Big Spring in Missouri at a rate of 465 cfs.

Formation

A spring may be the result of karst topography where surface water has infiltrated the Earth's surface (recharge area), becoming part of the area groundwater. The groundwater then travels through a network of cracks and fissures—openings ranging from intergranular spaces to large caves. The water eventually emerges from below the surface, in the form of a spring.

Sunrise at Middle Spring, Fish Springs National Wildlife Refuge

The forcing of the spring to the surface can be the result of a confined aquifer in which the recharge area of the spring water table rests at a higher elevation than that of the outlet. Spring water forced to the surface by elevated sources are artesian wells. This is possible even if the outlet is in the form of a 300-foot-deep (91 m) cave. In this case the cave is used like a hose by the higher elevated recharge area of groundwater to exit through the lower elevation opening.

Non-artesian springs may simply flow from a higher elevation through the earth to a lower elevation and exit in the form of a spring, using the ground like a drainage pipe.

Still other springs are the result of pressure from an underground source in the earth, in the form of volcanic activity. The result can be water at elevated temperature such as a hot spring.

The action of the groundwater continually dissolves permeable bedrock such as limestone and dolomite creating vast cave systems.[1]

Types of spring outlets

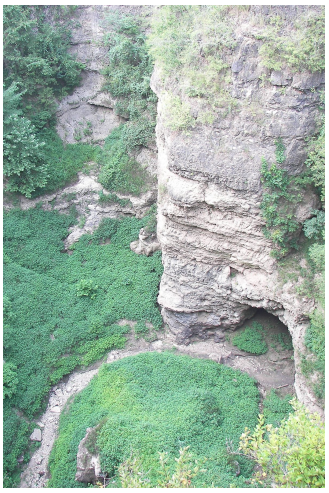
- Seepage or filtration spring. The term seep refers to springs with small flow rates in which the source water has filtered into permeable earth.
- Fracture springs, discharge from faults, joints, or fissures in the earth, in which springs have followed a natural course of voids or weaknesses in the bedrock.

A natural spring on Mackinac Island in Michigan.

- Tubular springs are essentially water dissolved and created underground channels, basically cave systems.

Flow

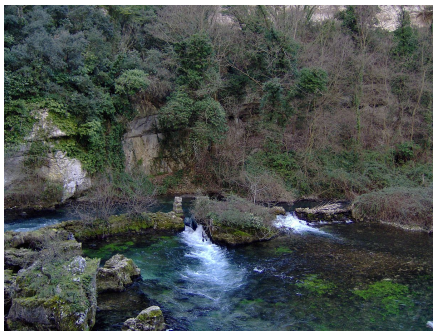
Spring discharge, or resurgence, is determined by the spring's recharge basin. Factors that affect the recharge include the size of the area in which groundwater is captured, the amount of precipitation, the size of capture points, and the size of the spring outlet. Water may leak into the underground system from many sources including permeable earth, sinkholes, and losing streams. In some cases entire creeks seemingly disappear as the water sinks into the ground via the stream bed. Grand Gulf State Park in Missouri is an example of an entire creek vanishing into the groundwater system. The water emerges nine miles away, forming some of the discharge of Mammoth Spring in Arkansas. Human activity may also affect a spring's discharge-withdraw of groundwater reduces the water pressure in an aquifer, decreasing the volume of flow.



The stream flowing into this cave at the bottom of Grand Gulf, a huge sinkhole in Missouri, resurfaces at Mammoth Spring in Arkansas.

Classification

Springs are often classified by the volume of the water they discharge. The largest springs are called "first-magnitude," defined as springs that discharge water at a rate of at least 2800 liters or 100 cubic feet (2.8 m^3) of water per second. Some locations contain many first-magnitude springs, such as Central Florida where there are 33[2] known to be that size, the southern Missouri Ozarks (11 known of first-magnitude), and 11[3] more in the Thousand Springs area along the Snake River in Idaho. The scale for spring flow is as follows:



Fontaine de Vaucluse or Spring of Vaucluse in France discharges about 470 million gallons (1.8 billion liters) of water per day at a rate of 727 cubic feet (21 m^3) per second.

Magnitude	Flow (ft³/s, gal/min, pint/min)	Flow (L/s)
1st magnitude	> 100 ft³/s	2800 L/s
2nd magnitude	10 to 100 ft³/s	280 to 2800 L/s
3rd magnitude	1 to 10 ft³/s	28 to 280 L/s
4th magnitude	100 US gal/min to 1 ft³/s (448 US gal/min)	6.3 to 28 L/s
5th magnitude	10 to 100 gal/min	0.63 to 6.3 L/s
6th magnitude	1 to 10 gal/min	63 to 630 mL/s
7th magnitude	1 pint to 1 gal/min	8 to 63 mL/s
8th magnitude	Less than 1 pint/min	8 mL/s
0 magnitude	no flow (sites of past/historic flow)	

Water content

Pruess Lake is entirely spring-fed in the arid Snake Valley (Great Basin)

Minerals become dissolved in the water as it moves through the underground rocks. This may give the water flavor and even carbon dioxide bubbles, depending on the nature of the geology through which it passes. This is why spring water is often bottled and sold as mineral water, although the term is often the subject of deceptive advertising. Springs that contain significant amounts of minerals are sometimes called 'mineral springs'. Springs that contain large amounts of dissolved sodium salts, mostly sodium carbonate, are called 'soda springs'. Many resorts have developed around mineral springs and are known as spa towns.

Water from springs are usually clear. However some springs may be colored by the minerals that are dissolved in the water. Iron and tannins often give spring water an orange color.[1]

A stream carrying the outflow of a spring to a nearby primary stream is called a spring branch or run. Groundwater tends to maintain a relatively long-term average temperature of its aquifer; so flow from a spring may be cooler than a summer day, but remain unfrozen in the winter. The cool water of a spring and its branch may harbor species such as certain trout that are otherwise ill-suited to a warmer local climate.

Historic uses

Springs have been used for a variety of human needs including drinking water, powering of mills, and navigation, and more recently some have been used for electricity generation.

Sacred springs

Main article: Holy well.

Trout fishing on Maramec Spring in Missouri.

A sacred spring, or holy well, is a small body of water emerging from underground and revered either in a pagan or a Christian context, often both. The lore and mythology of ancient Greece was replete with sacred and storied springs—notably, the Corycian, Pierian and Castalian. In medieval Europe, holy wells were frequently pagan sacred sites that later became Christianized. The term "holy well" is commonly employed to refer to any water source of limited size (i.e. not a lake or river, but including pools and natural springs and seeps), which has some significance in the folklore of the local area. This can take the form of a particular name, an associated legend, the attribution of healing qualities to the water through the numinous presence of its guardian spirit or Christian saint, or a ceremony or ritual centred on the well site. In Christian legend, the spring water is often said to have been made to flow by the action of a saint, a familiar theme especially in the hagiography of Celtic saints.

Modern uses

Present-day uses include recreational activities, such as trout-fishing, swimming, and floating. The water is also used for livestock and fish hatcheries.

Notable springs

Europe:

- Castalian Spring, Delphi, Greece
- Fontaine de Vaucluse, France
- Pierian Spring, Pieria, Greece
- Spring of Juturna, Roman Forum, Rome, Italy

Asia:

- Baotu Spring, Jinan, Shandong, China ("City of Springs")

Western Asia:

- Gihon Spring, Jerusalem, Israel

North America:

- Berkeley Springs, West Virginia
- Big Spring, Missouri
- Blue Spring, Florida
- Giant Springs, Montana
- Greer Spring, Missouri
- Mammoth Spring, Arkansas
- Maramec Spring, Missouri
- Poland Spring, Maine
- Kitch-iti-kipi, Michigan

- Rainbow Springs, Florida
- Saratoga Springs, New York
- Wakulla Springs, Florida
- Warm Springs, Georgia
- Wekiwa Springs, Florida

South America:

- São Lourenço, Minas Gerais, Brazil

Oceania:

- Te Waikoropupu Springs, New Zealand

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- "What Is A Spring?" (http://www.srwmd.state.fl.us/index.aspx?NID=56)
- List of First-Magnitude springs in Florida (http://www.tfn.net/springs/Springbook/FirstMagnitude.htm)
- Technical and educational material on mineral springs and mineral water in Victoria (http://www.mineralwater.vic.gov.au)
- "Database of Historically Documented Springs and Springflow Measurements in Texas" (http://pubs.er.usgs.gov/pubs/ofr/ofr03315)
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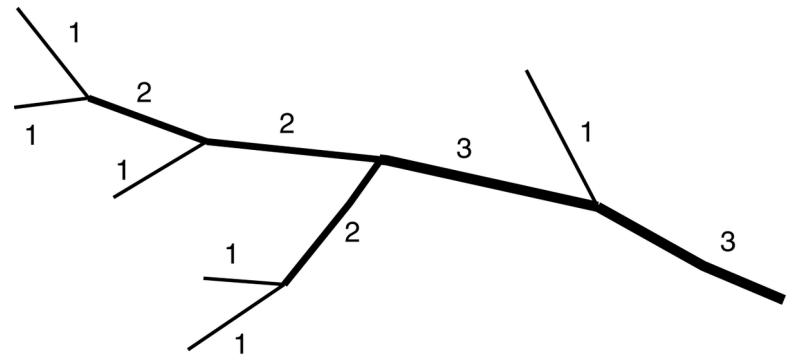
- The Water Cycle: Springs USGS (http://ga.water.usgs.gov/edu/watercyclesprings.html)
- Find a spring (http://www.findaspring.com/)

Strahler number

In mathematics, the **Strahler number** or **Horton–Strahler number** of a mathematical tree is a numerical measure of its branching complexity.



U.S. Corps of Engineer diagram showing the Strahler stream order

These numbers were first developed in hydrology by Robert E. Horton (1945) and Arthur Newell Strahler (1952, 1957); in this application, they are referred to as the **Strahler stream order** and are used to define stream size based on a hierarchy of tributaries. They also arise in the analysis of hierarchical biological structures such as (biological) trees and animal respiratory and circulatory systems, in register allocation for compilation of high level programming languages and in the analysis of social networks.

Abstract trees

All trees in this context are directed graphs, oriented from the root towards the leaves; in other words, they are arborescences. The degree of a node in a tree is just its number of children. One may assign a Strahler number to all nodes of a tree, in bottom-up order, as follows:

- If the node is a leaf (has no children), its Strahler number is one.
- If the node has one child with Strahler number i, and all other children have Strahler numbers less than i, then the Strahler number of the node is i again.
- If the node has two or more children with Strahler number i, and no children with greater number, then the Strahler number of the node is $i + 1$.

The Strahler number of a tree is the number of its root node.

Algorithmically, these numbers may be assigned by performing a depth-first search and assigning each node's number in postorder. The same numbers may also be generated via a pruning process in which the tree is simplified in a sequence of stages, where in each stage one removes all leaf nodes and all of the paths of degree-one nodes leading to leaves: the Strahler number of a node is the stage at which it would be removed by this process, and the Strahler number of a tree is the number of stages required to remove all of its nodes. Another equivalent definition of the Strahler number of a tree is that it is the height of the largest complete binary tree that can be homeomorphically embedded into the given tree; the Strahler number of a node in a tree is similarly the height of the largest complete binary tree that can be embedded below that node.

Any node with Strahler number i must have at least two descendants with Strahler number $i - 1$, at least four descendants with Strahler number $i - 2$, etc., and at least 2^{i-1} leaf descendants. Therefore, in a tree with n nodes, the largest possible Strahler number is $\log_2 n$. However, unless the tree forms a complete binary tree its Strahler number will be less than this bound. In an n-node binary tree, chosen uniformly at random among all possible binary trees, the expected index of the root is with high probability very close to $\log_4 n$.[1]

Bifurcation ratio

Associated with the Strahler numbers of a tree are *bifurcation ratios*, numbers describing how close to balanced a tree is. For each order i in a hierarchy, the ith bifurcation ratio is

$$\frac{n_i}{n_{i+1}}$$

where n_i denotes the number of nodes with order i.

The bifurcation ratio of an overall hierarchy may be taken by averaging the bifurcation ratios at different orders. In a complete binary tree, the bifurcation ratio will be 2, while other trees will have smaller bifurcation ratios.

River networks

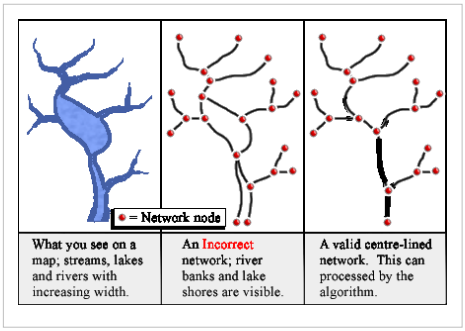
In the application of the Strahler stream order to hydrology, each segment of a stream or river within a river network is treated as a node in a tree, with the next segment downstream as its parent. When two **first-order** streams come together, they form a **second-order** stream. When two second-order streams come together, they form a **third-order** stream. Streams of lower order joining a higher order stream do not change the order of the higher stream. Thus, if a first-order stream joins a second-order stream, it remains a second-order stream. It is not until a second-order stream combines with another second-order stream that it becomes a third-order stream. As with mathematical trees, a segment with index i must be fed by at least 2^{i-1} different tributaries of index 1.

To qualify as a stream a hydrological feature must be either recurring or perennial. Recurring streams have water in the channel for at least part of the year. The index of a stream or river may range from 1 (a stream with no tributaries) to 12 (the most powerful river, the Amazon, at its mouth). The Ohio River is of order eight and the Mississippi River is of order 10. 80% of the streams and rivers on the planet are first or second order.

If the bifurcation ratio of a river network is low, there is a higher chance of flooding, as the water will be concentrated in one channel rather than spread out, as a higher bifurcation ratio would indicate. The bifurcation ratio can also show which parts of a drainage basin is more likely to flood, comparatively, by looking at the separate ratios. Most British rivers have a bifurcation ratio of between 3 and 5. [2]

GIS algorithms

Gleyzer et al. (2004) developed a recursive algorithm which would process vector river networks for Strahler stream order values in a GIS application. This algorithm is implemented by RivEX [3], an ESRI ArcGIS 9.1 tool. The algorithm requires the vector network to be topologically correct to successfully process. The network must be a centre-lined network where each arc (sometimes referred to as an edge) must be joined at their node (sometime referred to as a junction). No left and right banks or lake side shores should be present. The image below demonstrates a map representation of a river network, an invalid network where lake and river bank sides have been digitally captured and a valid, topologically correct, centre-lined river network which the algorithm can process.



If the network is "broken" (arcs not connecting) then the output will be incorrect. The algorithm would treat the disconnected catchment as a separate river system, so it is important to check the connectivity of one's river network

before attempting to compute Strahler order values.

Other applications

The Strahler numbering may be applied in the statistical analysis of any hierarchical system, not just to rivers. Arenas et al. (2004) describe an application of the Horton–Strahler index in the analysis of social networks. It has also been applied to biological hierarchies such as the branching structures of trees[4] and of animal respiratory and circulatory systems.[5]

When translating a high-level programming language to assembly language the minimum number of registers required to evaluate an expression tree is exactly its Strahler number.[6]

Notes

[1] Devroye & Kruszewski (1995).
[2] Waugh (2002).
[3] http://www.rivex.co.uk
[4] Borchert & Slade (1981)
[5] Horsfield (1976).
[6] Flajolet, Raoult & Vuillemin (1979).

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Stream

"Rivulet" redirects here. This is also the name of some moths in genus Perizoma*, namely* P. affinitata.

A **stream** is a body of water with a current, confined within a bed and stream banks. Depending on its locale or certain characteristics, a stream may be referred to as a *branch*, *brook*, *beck*, *burn*, *creek*, "crick", *gill* (occasionally *ghyll*), *kill*, *lick*, *rill*, *river*, *syke*, *bayou*, *rivulet*, *streamage*, *wash*, *run* or *runnel*.

Butchers Creek, Omeo, Victoria, Australia.

Streams are important as conduits in the water cycle, instruments in groundwater recharge, and corridors for fish and wildlife migration. The biological habitat in the immediate vicinity of a stream is called a riparian zone. Given the status of the ongoing Holocene extinction, streams play an important corridor role in connecting fragmented habitats and thus in conserving biodiversity. The study of streams and waterways in general is known as *surface hydrology* and is a core element of environmental geography.[1]

Types

River

> A large natural stream, which may be a waterway.

CreekIn North America, Australia and New Zealand, a small to medium sized natural stream. Sometimes navigable by motor craft and may be intermittent. In parts of New England,Spruce Creek Association. Kittery, ME. "About the Spruce Creek Watershed." Accessed 2010-10-02. the UK and India, a tidal inlet, typically in a salt marsh or Mangrovemangrove swamp, or between enclosed and drained former salt marshes or swamps (e.g. Port Creek separating Portsea Island from the mainland). In these cases, the stream is the tidal stream, the course of the seawater through the creek (tidal)creek channel at low and high tide.

The Perkiomen Creek in Perkiomenville, Pennsylvania, United States

Tributary

> A contributory stream, or a stream which does not reach the sea but joins another river (a parent river). Sometimes also called a branch or fork.

Brook

> A stream smaller than a creek, especially one that is fed by a spring or seep. It is usually small and easily forded. A brook is characterized by its shallowness and its bed being composed primarily of rocks.

A rocky stream in Hawaii, United States

Other names

In the United Kingdom, there are several regional names for a stream:

- *Beck* is used in Yorkshire, Lancashire , Dumfriesshire and Cumbria.
- *Bourne* is used in the chalk downland of southern England (although strictly a bourne is wet in summer and dry in winter).
- *Brook* is used in the Midlands, Lancashire and Cheshire.
- *Burn* is used in Scotland and North East England.
- *Nant* is used in Wales.
- *Stream* is used in Southern England.
- *Syke* is used in lowland Scotland and Cumbria.
- *Allt* is used in Highland Scotland.

In North America:

- *Kill* in southern New York, Pennsylvania, Delaware, and New Jersey comes from a Dutch language word meaning "riverbed" or "water channel", and can also be used for the UK meaning of 'creek'.
- *Run* in Ohio, Pennsylvania, Maryland, or Virginia can be the name of a stream.
- *Branch*, *fork*, or *prong* can refer to tributaries or distributaries that share the same name as the main stream, generally with the addition of a cardinal direction.
- *Branch* is also used to name streams in Maryland and Virginia.
- *Falls* is also used to name streams in Maryland. Little Gunpowder Falls and The Jones Falls are actually rivers named in this manner, unique to Maryland.
- *Stream* and *brook* are used in Midwestern states, Mid-Atlantic states and New England.
- *Crick* is used in some parts of the United States.

River in Arkhangelsk Oblast, Russia.

A creek in Australia.

Wyming Brook in Sheffield, UK

Parts of a stream

Bar

> A shoal that develops at the mouth of a river as sediment carried by the river is deposited as the current slows or is impedded by wave action. The Temperance River on Lake Superior's north shore is so named because it is one of the few rivers flowing into the lake that does not have a bar at its mouth.

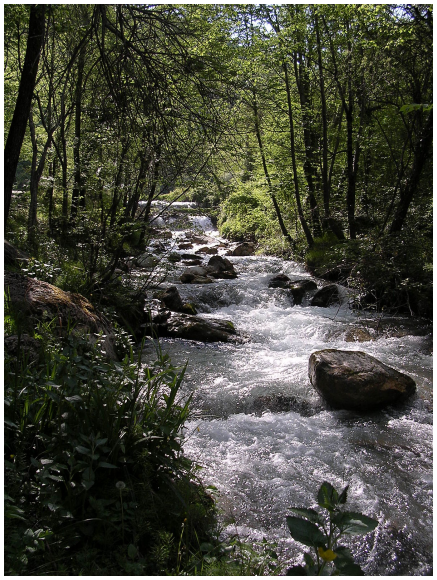
Spring

> The point at which a stream emerges from an underground course through unconsolidated sediments or through caves. A stream can, especially with caves, flow aboveground for part of its course, and underground for part of its course.

Source

A brook in the Bay of Fundy, Nova Scotia, Canada

The spring from which the stream originates, or other point of origin of a stream.



Ambro torrent, Italy.

Headwaters

The part of a stream or river proximate to its source. The word is most commonly used in the plural where there is no single point source.

Confluence

The point at which the two streams merge. If the two tributaries are of approximately equal size, the confluence may be called a fork.

Run

A somewhat smoothly flowing segment of the stream.

Pool

A segment where the water is deeper and slower moving.

Riffle

A segment where the flow is shallower and more turbulent.

Channel

A depression created by constant erosion that carries the stream's flow.

Floodplain

Lands adjacent to the stream that are subject to flooding when a stream overflows its banks.

Stream bed

The bottom of a stream.

Gauging station

A point of demarkation along the route of a stream or river, used for reference marking or water monitoring.

Thalweg

The river's longitudinal section, or the line joining the deepest point in the channel at each stage from source to mouth.

Wetted perimeter

The line on which the stream's surface meets the channel walls.

Knickpoint

The point on a stream's profile where a sudden change in stream gradient occurs.

Waterfall or cascade

The fall of water where the stream goes over a sudden drop called a nickpoint; some nickpoints are formed by erosion when water flows over an especially resistant stratum, followed by one less so. The stream expends kinetic energy in "trying" to eliminate the nickpoint.

Mouth

The point at which the stream discharges, possibly via an estuary or delta, into a static body of water such as a lake or ocean.

Sources

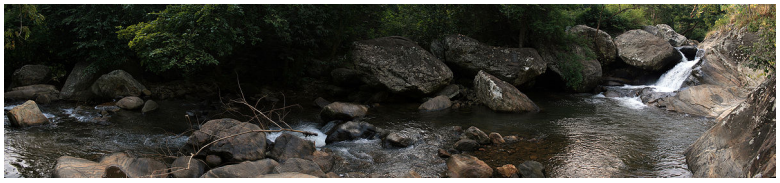
Streams typically derive most of their water from precipitation in the form of rain and snow. Most of this water re-enters the atmosphere by evaporation from soil and water bodies, or by the evapotranspiration of plants. Some of the water proceeds to sink into the earth by infiltration and becomes groundwater, much of which eventually enters streams. Some precipitated water is temporarily locked up in snow fields and glaciers, to be released later by evaporation or melting. The rest of the water flows off the land as runoff, the proportion of which varies according to many factors, such as wind, humidity, vegetation, rock types, and relief. This runoff starts as a thin film called sheet wash, combined with a network of tiny rills, together constituting sheet runoff; when this water is concentrated in a channel, a stream has its birth.

Characteristics

Ranking

To qualify as a stream it must be either recurring or perennial. Recurring streams have water in the channel for at least part of the year. A stream of the first order is a stream which does not have any other stream feeding into it. When two first-order streams come together, they form a second-order stream. When two second-order streams come together, they form a third-order stream. Streams of lower order joining a higher order stream do not change the order of the higher stream. Thus, if a first-order stream joins a second-order stream, it remains a second-order stream. It is not until a second-order stream combines with another second-order stream that it becomes a third-order stream.

Gradient



A tributary on the Uluguru Mountains which joins to the river Ruvu

The *gradient* of a stream is a critical factor in determining its character and is entirely determined by its base level of erosion. The base level of erosion is the point at which the stream either enters the ocean, a lake or pond, or enters a stretch in which it has a much lower gradient, and may be specifically applied to any particular stretch of a stream.

In geologic terms, the stream will erode down through its bed to achieve the base level of erosion throughout its course. If this base level is low, then the stream will rapidly cut through underlying strata and have a steep gradient, and if the base level is relatively high, then the stream will form a flood plain and meander.

Meander

Meanders are looping changes of direction of a stream caused by the erosion and deposition of bank materials. These are typically serpentine in form. Typically, over time the meanders gradually migrate downstream.

If some resistant material slows or stops the downstream movement of a meander, a stream may erode through the neck between two legs of a meander to become temporarily straighter, leaving behind an arc-shaped body of water termed an *oxbow lake* or *bayou*. A flood may also cause a meander to be cut through in this way.

Profile

Typically, streams are said to have a particular *profile*, beginning with steep gradients, no flood plain, and little shifting of channels, eventually evolving into streams with low gradients, wide flood plains, and extensive meanders. The initial stage is sometimes termed a "young" or "immature" stream, and the later state a "mature" or "old" stream. However, a stream may meander for some distance before falling into a "young" stream condition.

Intermittent and ephemeral streams

A *perennial* stream is one which flows continuously all year.[3] :57

In the United States, an *intermittent* or seasonal stream is one that only flows for part of the year and is marked on topographic maps with a line of blue dashes and dots.[3] :57-58 A *wash* or *desert wash* is normally a dry streambed in the deserts of the American Southwest which flows only after significant rainfall. Washes can fill up quickly during rains, and there may be a sudden torrent of water after a thunderstorm begins upstream, such as during monsoonal conditions. These flash floods often catch travelers by surprise. An intermittent stream can also be called an arroyo in Latin America, a winterbourne in Britain, or a wadi in the Arabic-speaking world.

An Australian creek, low in the dry season, carrying little water. The energetic flow of the stream had, in flood, moved finer sediment further downstream. There is a pool to lower right and a riffle to upper left of the photograph.

In Italy an intermittent stream is termed a **torrent** (Italian *torrente*). In full flood the stream may or may not be "torrential" in the dramatic sense of the word, but there will be one or more seasons in which the flow is reduced to a trickle or less. Typically torrents have Apennine rather than Alpine sources, and in the summer they are fed by little precipitation and no melting snow. In this case the maximum discharge will be during the spring and autumn. However there are also glacial torrents with a different seasonal regime.

A *blue-line* stream is one which flows for most or all of the year and is marked on topographic maps with a solid blue line. In Australia, an intermittent stream is usually called a creek and marked on topographic maps with a solid blue line.

Generally, streams that flow only during and immediately after precipitation are termed *ephemeral*. There is no clear demarcation between surface runoff and an ephemeral stream.[3] :58

Drainage basins

The extent of land basin drained by a stream is termed its **drainage basin** (also known in North America as the **watershed** and, in British English, as a **catchment**).[4] A basin may also be composed of smaller basins. For instance, the Continental Divide in North America divides the mainly easterly-draining Atlantic Ocean and Arctic Ocean basins from the largely westerly-flowing Pacific Ocean basin. The Atlantic Ocean basin, however, may be further subdivided into the Atlantic Ocean and Gulf of Mexico drainages. (This delineation is termed the Eastern Continental Divide.) Similarly, the Gulf of Mexico basin may be divided into the Mississippi River basin and several smaller basins, such as the Tombigbee River basin. Continuing in this vein, a component of the Mississippi River basin is the Ohio River basin, which in turn includes the Kentucky River basin, and so forth.

Gallery

A creek in Perisher Blue, New South Wales, Australia

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[2] Spruce Creek Association. Kittery, ME. "About the Spruce Creek Watershed." (http://www.sprucecreekassociation.org/sprucecreek.html) Accessed 2010-10-02.

[3] Meinzer, Oscar E. (1923). *Outline of ground-water hydrology, with definitions* (http://pubs.er.usgs.gov/publication/wsp494). Washington, DC: USGS. . Water Supply Paper 494.

[4] Langbein, W.B.; Iseri, Kathleen T. (1995). "Hydrologic Definitions: Watershed" (http://water.usgs.gov/wsc/glossary.html#Watershed). *Manual of Hydrology: Part 1. General Surface-Water Techniques* (Water Supply Paper 1541-A). Reston, VA: USGS. .

Stream bed

The bed of this stream is armored with rocks, some very rounded (having had a longer life in the stream) and some not.

A **stream bed** is the channel bottom of a stream, river or creek; the physical confine of the normal water flow. The lateral confines or channel margins, during all but flood stage, are known as the **stream banks** or **river banks**. In fact, a flood occurs when a stream overflows its banks and flows onto its flood plain. As a general rule, the bed is that part of the channel, just at the "normal" water line and the banks are that part above the water line. However, because water flow varies, this differentiation is subject to local interpretation. Usually, the bed is kept clear of terrestrial vegetation, whereas the banks are subjected to water flow only during unusual or perhaps infrequent high water stages and therefore, might support vegetation some or much of the time.

The descriptive terms "right bank" and "left bank" are relative to an observer looking downstream, in which the right bank is to the observer's right, and vice versa. A famous example of this is the naming of the two sides of the river Seine in Paris.

The nature of any stream bed is always a function of the flow dynamics and the local geologic materials, influenced by that flow. With small streams in mesophytic regions, the nature of the stream bed is strongly responsive to conditions of precipitation runoff. Where natural conditions of either grassland or forest ameliorate peak flows, stream beds are stable, possibly rich, with organic matter and exhibit minimal scour. These streams support a rich biota. Where conditions produce unnatural levels of runoff, such as occurs below roads, the stream beds will exhibit a greater amount of scour, often down to bedrock and banks may be undercut. This process greatly increases watershed erosion and results in thinner soils, upslope from the stream bed, as the channel adjusts to the increase in flow.

Beds are usually what would be left once a stream is no longer in existence; the beds are usually well preserved even if they get buried, because the walls and canyons made by the stream usually have hard walls, usually soft sand and debris fill the bed. Dry stream beds are also subject to becoming underground water pockets (buried stream beds only) and flooding by heavy rains and water rising from the ground and may sometimes be part of the rejuvenation of the stream.

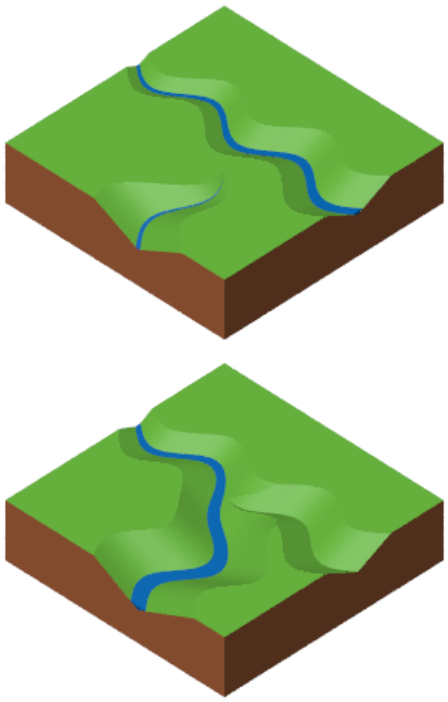
Stream capture

Stream capture, **river capture**, or **stream piracy** is a geomorphological phenomenon occurring when a stream or river drainage system or watershed is diverted from its own bed, and flows instead down the bed of a neighbouring stream. This can happen for several reasons, including:

- Tectonic earth movements, where the slope of the land changes, and the stream is tipped out of its former course.
- Natural damming, such as by a landslide or ice sheet.
- Erosion, either
  - Headward erosion of one stream valley upwards into another, or
  - Lateral erosion of a meander through the higher ground dividing the adjacent streams.
  - Within an area of karst topography, where streams may *sink*, or flow underground (a sinking or losing stream) and then reappear in a nearby stream valley.

The additional water flowing down the capturing stream may accelerate erosion and encourage the development of a canyon (gorge).

The now-dry valley of the original stream is known as a wind gap.



Stream capture by headward erosion, leaving a wind gap.

Capture mechanisms

Tectonic uplift

- Barmah Choke

  About 25,000 years BP, an uplift of the plains near Moama first dammed the Murray River and then forced it to take a new course. The new course dug its way through the so called Barmah Choke and captured the lower course of the Goulburn River for 500km.

- Barrier Range

  The original course of the Murray River was to a mouth near Port Pirie where a large delta is still visible protruding into the calm waters of Spencer Gulf. An uplift of the land blocked the river near the southern end of the Flinders Ranges, and the river eventually found its way to a new mouth near Lake Alexandrina.

Glacial damming

- The River Thames in southern England originally entered the North Sea near Ipswich. About 450,000 years BP, an ice sheet expanding from the north pushed the course of the river southwards, forcing the Thames to cut a new mouth where the mouth of the River Blackwater, Essex now is, north of London. It later moved southwards again to its current position as a result of cutting through the Chiltern Hills at Goring-on-Thames, an event which created the Goring Gap.

The River Thames as it passes through the Goring Gap

Headward erosion

- The Teays River, captured by the Ohio River.
- The Rio Grande which before capture flowed into a closed basin, Lake Cabeza de Vaca, but after capture flowed into the Gulf of Mexico.
- The River Stour, Kent, largely captured by the River Beult (pronounced /ˈbɛlt/ "belt"), River Teise (/ˈtiːz/ "tease") and others.
- The River Wey, in southern England, the western arm of which is the former upper waters of the River Blackwater (River Loddon).
- The River Rheidol in Wales which has captured the headwaters of other streams and now runs for part of its length in a deep gorge.
- The River Lyd in Devon, England.
- Vlara Moravia; Czech Republic

Karst

- The *Donauversickerung* (Danube Sink), currently developing in Germany, where a large portion of the upper parts of the Danube river sinks into the limestone bedrock, and resurfaces in the Aachtopf spring, a tributary of the River Rhine.

Effect on freshwater life

River capture is a shaping force in the biogeography or distribution of many freshwater fish species.

Australian freshwater fish

Australia provides a particularly fascinating series of examples of freshwater fish species and distributions resulting from river capture events. The formerly massive Great Dividing Range runs the length of the eastern coastline of Australia and has isolated native freshwater fish populations east and west of the range for millions of years. In the last two million years erosion has reduced the Great Dividing Range to a critical point where west-to-east river capture events have been possible. A number of native fish species that originated in the Murray-Darling river system to the west are (or were) found naturally occurring in a number of coastal systems spanning almost the entire length of the range.

None of the river capture events that allowed native fish of the Murray-Darling system to cross into and colonise these East Coast river systems seem to have formed permanent linkages. The colonising Murray-Darling fish in these East Coast river systems have therefore become isolated from their parent species, and due to isolation, the founder effect, genetic drift and natural selection, have become separate species (see allopatric speciation).

Examples include:

- Golden perch (Dawson-Fitzroy river system, central Queensland).
- Eel-tailed catfish (several rivers, northern New South Wales) (However, note recent genetic research which now indicates eel-tailed catfish colonised east coast drainages in multiple colonisation events relatively recently (by evolutionary standards) and may subsequently have colonised the Murray-Darling system via an east-to-west river capture event, contrary to usual west-to-east capture events listed here.)
- Macquarie perch (Hawkesbury-Nepean rivers, Shoalhaven River, southern New South Wales).
- River blackfish (multiple rivers, Victoria).
- Murray cod, whose eastern species/subspecies are:
  - Eastern freshwater cod (Clarence River system, northern New South Wales. It was also found in the Richmond River system in New South Wales but that population is now extinct.)
  - Brisbane River cod (Brisbane River system, southern Queensland. That population is now extinct, and its exact taxonomic status is not known.)
  - The Mary River cod (Mary River, southern/central Queensland.)
- The mountain galaxias species complex (multiple rivers, southern Queensland, New South Wales, Victoria).

Olive perchlet (*Ambassis agassizii*), western carp gudgeon (*Hypseleotris klungzingeri*), pygmy perch (*Nannoperca australis*) and Australian smelt (*Retropinna semoni*) also appear to have made crossings into coastal systems, the last two species seemingly many times as they are found in most or all coastal streams in south eastern Australia as well as the Murray-Darling system.

Unfortunately, with the exception of eastern freshwater cod and Mary River cod, it has not been widely recognised that these coastal populations of Murray-Darling native fish are separate species and their classifications have not been updated to reflect this. Many are threatened and two, the Richmond River cod and the Brisbane River cod, have become extinct.

Stream channel

Stream channel is the physical confine of a stream (river) consisting of a bed and stream banks. Stream channels exist in a variety of geometries. The stream channel development is controlled by both water and sediment movement. There is a difference between low gradient streams (less than a couple of percent in gradient) and high gradient streams. Wide variety of stream channel types can be distinguished (e.g. Braided rivers, Wandering rivers, Single Thread Sinuous rivers etc.). During floods may water exceed the capacity of the channel and floodwaters spill out of the channel and across the valley bottom or floodplain.

Stream gradient

Stream gradient is the grade (slope) measured by the ratio of drop in a stream per unit distance, usually expressed as feet per mile or meters per kilometer.

Hydrology and geology

A high gradient indicates a steep slope and rapid flow of water (i.e. more ability to erode); whereas a low gradient indicates a more nearly level stream bed and sluggishly moving water, that may be able to carry only small amounts of very fine sediment. High gradient streams tend to have steep, narrow V-shaped valleys, and are referred to as young streams. Low gradient streams have wider and less rugged valleys, with a tendency for the stream to meander.

Fluvial Erosion

A stream that flows upon a uniformly erodible substrate will tend to have a steep gradient near its source, and a low gradient nearing zero as it reaches its base level. Of course, a uniform substrate would be rare in nature; hard layers of rock along the way may establish a temporary base level, followed by a high gradient, or even a waterfall, as softer materials are encountered below the hard layer.

Human dams, glaciation, changes in sea level, and many other factors can also change the "normal" or *natural* gradient pattern.

Topographic mapping

On topographic maps, stream gradient can be easily approximated if the scale of the map and the contour intervals are known. Contour lines form a V-shape on the map, pointing upstream. By counting the number of lines that cross a certain segment of a stream, multiplying this by the contour interval, and dividing that quantity by the length of the stream segment you can determine the stream gradient.

Because stream gradient is customarily given in feet per 1000 feet, one should then measure the amount a stream segment rises and the length of the stream segment in feet, then multiply feet per foot gradient by 1000. For example, if one measures a scale mile along the stream length, and counts three contour lines crossed on a map with ten-foot contours, the gradient is approximately 5.7 feet per 1000 feet, a fairly steep gradient.

Stream power

Stream power is the rate of energy dissipation against the bed and banks of a river or stream per unit downstream length. It is given by the equation:

$$\Omega = \rho g Q S$$

where Ω is the stream power, ϱ is the density of water (1000 kg/m^3), g is acceleration due to gravity (9.8 m/s^2), Q is discharge (m^3/s), and S is the channel slope.

It can be derived by the fact that if the water is not accelerating and the river cross-section stays constant (generally good assumptions for an averaged reach of a stream over a modest distance), all of the potential energy lost as the water flows downstream must be used up in friction or work against the bed: none can be added to kinetic energy. Therefore, the potential energy drop is equal to the work done to the bed and banks, which is the stream power.

We know that change in potential energy over change in time is given by the equation:

$$\frac{\Delta PE}{\Delta t} = mg\frac{\Delta z}{\Delta t}$$

where water mass and gravitational acceleration are constant. We can use the channel slope and the stream velocity as a stand-in for $\Delta z/\Delta t$: the water will lose elevation at a rate given by the downward component of velocity u_z . For an channel slope (as measured from the horizontal) of α :

$$\frac{\Delta z}{\Delta t} = u_z = u\sin(\alpha) \approx uS$$

where u is the downstream flow velocity. It is noted that for small angles, $\sin(\alpha) \approx \tan(\alpha) = S$. Rewriting the first equation, we now have:

$$\frac{\Delta PE}{\Delta t} = mguS$$

Remembering that power is energy per time and using the equivalence between work against the bed and loss in potential energy, we can write:

$$\Omega = \frac{\Delta PE}{\Delta t}$$

Finally, we know that mass is equal to density times volume. From this, we can rewrite the mass on the right hand side

$$m = \rho L b h$$

where L is the channel length, b is the channel width (**b**readth), and h is the channel depth (**h**eight). We use the definition of discharge

$$Q = ubh$$

where A is the cross-sectional area, which can often be reasonably approximated as a rectangle with the characteristic width and depth. This absorbs velocity, width, and depth. We define stream power per unit channel length, so that term goes to 1, and the derivation is complete.

$$\Omega = \rho g Q \cancel{L}^{1} S$$

Unit stream power is stream power per unit channel width, and is given by the equation:

$$\omega = \frac{\rho g Q S}{b}$$

where ω is the unit stream power, and b is the width of the channel.

Stream power is used extensively in models of landscape evolution and river incision. Unit stream power is often used for this, because simple models use and evolve a 1-dimensional downstream profile of the river channel. It is

also used with relation to river channel migration, and in some cases is applied to sediment transport.[1]

References

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Stream power law

The term **stream power law** describes a semi-empirical family of equations used to predict the rate of erosion of a river into its bed. These combine equations describing conservation of water mass and momentum in streams with relations for channel hydraulic geometry (width-discharge scaling) and basin hydrology (discharge-area scaling) and an assumed dependency of erosion rate on either unit stream power or shear stress on the bed to produce a simplified description of erosion rate as a function of power laws of upstream drainage area, A, and channel slope, S:

$$E = KA^m S^n$$

where E is erosion rate and K, m and n are positive.[1] The value of these parameters depends on the assumptions made, but all forms of the law can be expressed in this basic form.

The parameters K, m and n are not necessarily constant, but rather may vary as functions of the assumed scaling laws, erosion process, bedrock erodibility, climate, sediment flux, and/or erosion threshold. However, observations of the hydraulic scaling of real rivers believed to be in erosional steady state indicate that the ratio m/n should be around 0.5, which provides a basic test of the applicability of each formulation.[2]

Although consisting of the product of two power laws, note that the term *stream power law* refers to the derivation of the early forms of the equation from assumptions of erosion dependency on stream power, rather than to the presence of power laws in the equation. Note also that this relation is not a true scientific law, but rather a heuristic description of erosion processes based on previously observed scaling relations which may or may not be applicable in any given natural setting.

References

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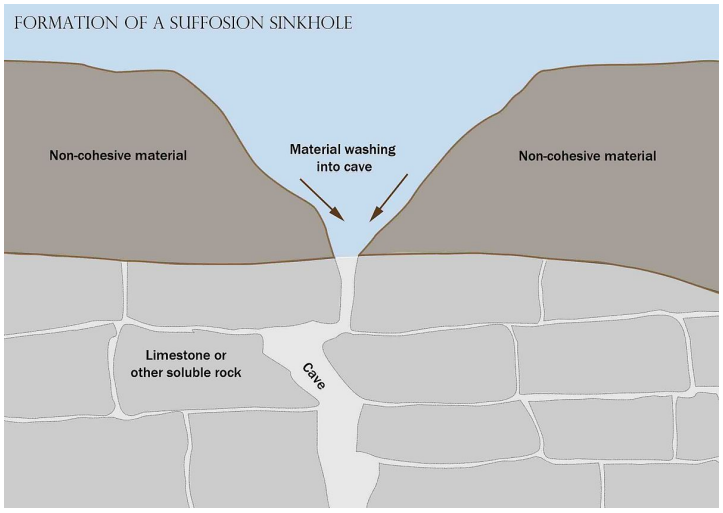
[2] Whipple, K.X., 2004, Bedrock Rivers and the Geomorphology of Active Orogens, Annu. Rev. Earth Planet. Sci., v.32, p.151-85.

Suffosion

Suffosion is one of the two geological processes by which subsidence sinkholes or dolines are formed, the other being "dropout" ,[1] with most sinkholes formed by the suffosion process.[2] Suffosion sinkholes are normally associated with karst topography although they may form in other types of rock including chalk, gypsum and basalt. In the karst of the UK's Yorkshire Dales, numerous surface depressions known locally as "shakeholes", are the result of glacial till washing into fissures in the underlying limestone.[3]

Process

Suffosion occurs when loose soil, loess or other non-cohesive material lies on top of a limestone substratum containing fissures and joints. Rain and surface water gradually wash this material through these fissures and into caves beneath.[2] Overtime, this creates a depression on the landscape of varying depth.



Formation of a suffosion sinkhole

Examples

The following sites are examples of sinkholes formed by suffosion:

- Whitepit, south of Priddy, Somerset, UK;

References

[1] Waltham, T.; Bell, T.; Culshaw, M. (2005). *Sinkholes and Subsidence*. Berlin: Springer.

[2] "Dolines and sinkholes" (http://www.bgs.ac.uk/mendips/caveskarst/karst_3.htm). British Geological Survey. . Retrieved February 21, 2011.

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Surface exposure dating

Surface exposure dating is a collection of geochronological techniques for estimating the length of time that a rock has been exposed at or near the earth's surface. Surface exposure dating is used to date glacial advances and retreats, erosion history, lava flows, meteorite impacts, rock slides, fault scarps, and other geological events. It is most useful for rocks which have been exposed for between 10 and 30,000,000 years.

The Earth is constantly bombarded with primary cosmic rays, high energy charged particles comprised mostly mostly protons and alpha particles. These particles interact with atoms in atmospheric gases, producing a cascade of secondary particles that may in turn interact and reduce their energies in many reactions as they pass through the atmosphere. By the time the cosmic ray cascade reaches the surface of the earth it is primarily composed of neutrons.[1] When one of these particles strikes an atom it can dislodge one or more protons and/or neutrons from that atom, producing a different element or a different isotope of the original element. In rock and other materials of similar density, most of the cosmic ray flux is absorbed within the first meter of exposed material in reactions that produce new isotopes called cosmogenic nuclides. At the earth's surface most of these nuclides are produced by neutron spallation. By measuring the concentration of these cosmogenic nuclides in a rock sample, and accounting for the flux of the cosmic rays and the half-life of the nuclide, it is possible to estimate how long the sample has been exposed to the cosmic rays.

The cumulative flux of cosmic rays at a particular location can be affected by several factors, including elevation, latitude, the varying intensity of the Earth's magnetic field, solar winds, and atmospheric shielding due to air pressure variations.

Rates of nuclide production must be estimated in order to date a rock sample. These rates are usually estimated empirically by comparing the concentration of nuclides produced in samples whose ages have been dated by other means, such as radiocarbon dating, thermoluminescence, or optically stimulated luminescence.

The two most frequently measured cosmogenic nuclides are beryllium-10 and aluminum-26. These nuclides are particularly useful to geologists because they are produced when cosmic rays strike oxygen-16 and silicon-28, respectively. The parent isotopes are the most abundant of these elements, and are common in crustal material, whereas the radioactive daughter nuclei are not commonly produced by other processes. As oxygen-16 is also common in the atmosphere, the contribution to the beryllium-10 concentration from material deposited rather than created *in situ* must be taken into account.

Chlorine-36 nuclides are also measured to date surface rocks. This isotope may be produced by cosmic ray spallation of calcium or potassium.

The excess relative to natural abundance of cosmogenic nuclides in a rock sample is usually measured by means of accelerator mass spectroscopy.

Notes

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- Terrestrial in situ cosmogenic nuclides: theory and application. Gosse, J.C. and Phillips, F.M. Quaternary Science Reviews, 20, 1475-1560, 2001.

External links

- Online system for exposure age calculations (http://hess.ess.washington.edu)
- Cosmogenic Isotope Laboratory, University of Washington (http://depts.washington.edu/cosmolab)
- Surface exposure dating (http://www.nd.gov/ndgs/newsletter/nl02s/PDF/insitu.pdf)
- Cosmogenic exposure dating (http://www.fettes.com/cairngorms/cosmo.htm)
- Cosmogenic dating of the foothills erratics train (http://www3.telus.net/lejgeology/etrain/htmls/36cl.htm)
- Dating rockslides (http://www.uibk.ac.at/geologie/cra/Dating.html#Surface_exposure_dating)
- Cosmogenic isotope laboratory (http://www.gns.cri.nz/nic/cosmogenicisotopes/sed.html)
- New techniques for surface exposure dating (http://www.gps.caltech.edu/people/farley/research/surface_exposure)

Talik

A **talik** (from the Russian Language *talik*, derived from the verb *tait*, to melt) is a layer of year-round unfrozen ground that lies in permafrost areas. In regions of continuous permafrost, taliks often occur underneath shallow thermokarst lakes and rivers, where the deep water does not freeze in winter, and thus the soil underneath will not freeze either. Sometimes open, closed and through talik are distinguished. These terms refer to whether the talik is completely surrounded by permafrost, is open to the top or open to both top and unfrozen layers beneath the permafrost, respectively.

Supra-permafrost taliks

Due to climate fluctuation or change, some permafrost regions may develop an unfrozen layer between the seasonally thawing/freezing active layer and the permafrost. The layer is called supra-permafrost (above the permafrost) talik; it is different from traditional taliks, which are usually associated with water bodies, in that supra-permafrost talik occurs because the ground that thawed in the summer does not completely refreeze in the winter. Calculations show that climate warming would induce supra-permafrost taliks in intermediately cold regions (in very cold regions, warming simply induces a deeper summer thaw without forming the talik layer; while in warm, shallow permafrost regions, permafrost quickly disappears). This type of taliks has recently been observed in Russia. With time and continued increase in air temperature or snow depth, this talik layer will become thicker and thicker and the deep permafrost layer would eventually disappear.

Tectonic uplift

Tectonic uplift is a geological process most often caused by plate tectonics which increases elevation. The opposite of uplift is subsidence, which results in a decrease in elevation. Uplift may be orogenic or isostatic.

Kupe's Sail New Zealand

Orogenic uplift

Orogenic uplift is the result of tectonic-plate collisions and results in mountain ranges or a more modest uplift over a large region. The Himalayas were (and are still being) formed by the collision of two continental plates, the Indian and Eurasian Plates. This ongoing collision produced the Tibetan Plateau as well as the Himalayas and associated ranges. Ozark Plateau is a broad uplifted area which resulted from the Ouachita Orogeny to the south during the Permian Period. Another related uplift is the Llano Uplift in Texas, a geographical location named after its uplift features. The Colorado Plateau with its spectacular scenic canyons, the Grand Canyon, is also the result of broad tectonic uplift followed by river erosion.

Isostatic uplift

Isostatic uplift includes the gradual uplift following rapid erosional removal of material from a mountain range. The land rises as a result of the removal of the weight. Another example of isostatic uplift is post-glacial rebound following the melting of continental glaciers and ice sheets. The Hudson Bay region of Canada and the Great Lakes of Canada and the United States are currently undergoing gradual rebound as a result of the melting of the ice sheets 10,000 years ago.

Coral islands

In a few cases, tectonic uplift can be seen in the cases of coral islands. This is evidenced by the presence of various oceanic islands composed entirely of coral, which otherwise appear to be high islands (*i.e.*, islands of volcanic origin). Examples of such islands are found in the Pacific, notably the three phosphate islets, Nauru, Makatea, and Banaba as well as Maré and Lifou in New-Caledonia, Fatu Huku in the Marquesas Islands and Henderson Island in the Pitcairn Islands. The uplift of these islands is the result of the movement of oceanic tectonic plates. Sunken islands or guyots with their coral reefs are the result of crustal subsidence as the oceanic plate carries the islands to deeper or lower oceanic crust areas.

External links

- An explanation of tectonic forces [1]

References

[1] http://www.tectonic-forces.org

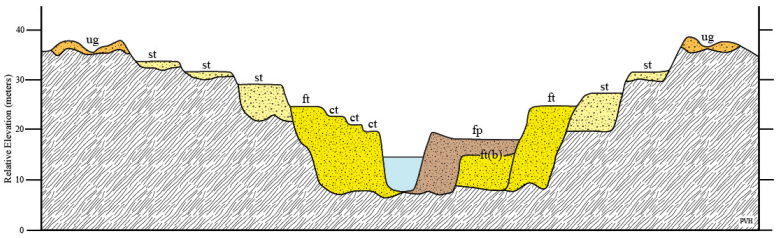
Terrace (geology)

A **terrace** is a geological term for a step-like landform. A terrace consists of a flat or gently sloping geomorphic surface, called a tread, that is typically bounded one side by a steeper ascending slope, which called a "riser" or "scarp." The term terrace is typically applied to both the tread and the steeper descending slope (riser or scarp). Terraces can also consist of a tread bounded on all sides by a descending riser or scarp. This term is commonly but incorrectly applied to the sediments underlying the tread and riser of a terrace. This is a practice that leads to much unneeded confusion. A narrow terrace is often called a bench.[1] [2]

Sediments underlying fluvial terrace exposed in cutbanks along the Manu River, Peru

Fluvial terraces are remnants of the former floodplain of a stream of river. They are formed by the downcutting of a river or stream channel into and the abandonment and lateral erosion of its former floodplain. The downcutting, abandonment, and lateral erosion of a former floodplain can be the result of either changes in sea level, local or regional tectonic uplift; changes in local or regional climate; changes the amount of sediment being carried by the river or stream; change in discharge of the river; or a complex mixture of these and other factors. The most common sources of the variations in rivers and streams that create fluvial terraces are vegetative, geomorphic, and hydrologic responses to climate. More recently, the direct modification of rivers and streams and their watersheds by cultural processes have result in the development of terraces along many rivers and streams.[1] [3]

A **marine terrace** represents the former shoreline of a sea or ocean. It can be formed by marine abrasion or erosion of materials comprising the shoreline (marine-cut terraces or wave-cut platforms); the accumulations of sediments in the shallow-water to slightly emerged coastal environments (marine-built terraces or raised beach); or the bioconstruction by coral reefs and accumulation of reef materials (reef flats) in intertropical regions.[4]



Hypothetical valley cross-section illustrating a complex sequence of aggradational (fill) and degradational (cut and strath) terraces and deposits (upland gravels). Note ct = cut terraces, ft = fill terraces, ft(b) = buried fill terrace, fp = active floodplain, st = strath terrace, and ug = upland gravels.

A **lake (lacustrine) terrace** represents the former shoreline of either a nonglacial, glacial, or proglacial lake. As in case of marine terraces, a lake terrace can be formed by either the abrasion or erosion of materials comprising the shoreline; the accumulations of sediments in the shallow-water to slightly emerged environments. or some combination of these. Given the smaller size of lakes relative to the size of typical marine water bodies, lake terraces are overall significantly narrower and less well developed than marine terraces.[5] [6] However not all lake terraces are relict shorelines. In case of the lake terraces of ancient ice-walled lakes, some proglacial lakes, and alluvium-dammed (slackwater) lakes, they often represent the relict bottom of these lakes.[7] [8] [9] Finally, glaciolacustrine kame terraces are either the relict deltas or bottoms of ancient ice marginal lakes.[10]

A **structural terrace** is a terrace created by the differential erosion of flat-lying or nearly flat-lying layered strata. The terrace results from preferential stripping by erosion of a layer of softer strata from an underling layer of harder strata. The preferential removal of softer material exposes the flat surface of the underlying harder layer creating the tread of a structural terrace. Structural terraces are commonly paired and not always associated with river valleys.[1]

References

[1] Howard, A.D., R.W. Fairbridge, J.H. Quinn, 1968, *Terraces, fluvial—Introduction.* in R.W. Fairbridge, ed., The Encyclopedia of Geomorphology: Encyclopedia of Earth Science Series, vol. 3. Reinhold. Book Corporation. New York, New York..

[2] Jackson, J.A., 1997, *Glossary of Geology.* American Geological Institute. Alexandria, Virginia.

[3] Blum, M., and T.E. Tonqvist, 2000, *Fluvial responses to climate and sea-level change, a review and look forward.* Sedimentology. v. 47 suppl. 1, pp. 2-48.

[4] Pirazzoli, P. A., 2005, *Marine Terraces.* in M. L. Scheartz, ed., pp. 632-633. Encyclopedia of Coastal Science. Springer, New York, New York.

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[7] Shaw. E.D., 1915, *Newly discovered beds of extinct lakes in southern and western Illinois and adjacent states.* Bulletin no. 20, Illinois State Geological Survey, Champaign, Illinois, p. 139-157.

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[9] Grimley, D.A., D. Larsen, S.W. Kaplan, C.H. Yansa, B.B. Curry, and E.A. Oches, 2009, *A multi-proxy palaeoecological and palaeoclimatic record within full glacial lacustrine deposits, western Tennessee, USA* Journal of Quaternary Science. v. 24, no. 8, p. 960 - 981.

[10] Bitinas, A. D. Karmaziene, and A. Jusiene, 2004, *Glaciolacustrine kame terraces as an indicator of conditions of deglaciation in Lithuania during the Last Glaciation.* Sedimentary Geology. v. 165, no. 3-4, p. 285–294.

External links

- Here is a good example of a river terrace: http://www.geographie.uni-erlangen.de/mrichter/gallery/photos/asia/images/river_terraces_near_kasbeki.jpg

Terrace Crossing

A **terrace crossing** is a geographical zone between the sedimentation (downstream) part and the erosion (upstream) part of the river. This zone develops on the location where the transition of erosion to sedimentation takes place. Upstream of the crossing, terraces will exist. The highest terraces will be the oldest. Downstream of the crossing, older sediments will be buried beneath younger deposits.

Thalweg

Thalweg (/ˈtɑːlvɛg/;[1] **"valley way"**) in geography and fluvial geomorphology signifies the deepest continuous inline within a valley or watercourse system.[2]

Hydrology

In hydrological and fluvial landforms, the thalweg is a line drawn to join the lowest points along the entire length of a stream bed or valley in its downward slope, defining its deepest channel. The thalweg thus marks the natural direction (the profile) of a watercourse. The thalweg is almost always the line of fastest flow in any river.

The term is also sometimes used to refer to a subterranean stream that percolates under the surface and in the same general direction as the surface stream.

Real world application

Slowing stream bed erosion by taking advantage of a thalweg helps stabilize running water sources. Placing boulders along the thalweg in a running water source helps to protect the channels sedimentary erosion and deposit balance. In concurrence with the placement of boulders along a thalweg, the placement of boulders along an instream to form man-made sills also helps to slow the sedimentary erosion and deposit of running water sources. While in-turn keeping the esteem (Fishing, Local Wildlife, and Recreation) and natural resources [3] of the running water source intact. The placement of boulders along a thalweg and the creation of instream sills help to aid the flow of water during late summer months when the flow rate drops, and helps to slow sedimentary erosion and deposit in the spring and fall months when the flow rates are high. This process of utilizing a thalweg to slow stream bed erosion was used in Meacham Creek, Umatilla, Oregon (1990).[4]

Thalweg principle

The *thalweg principle* is the principle in which the boundary between two political states separated by a watercourse is denoted as the thalweg of that watercourse, if those two states have agreed to use the thalweg definition. Various states have also defined their watercourse international boundaries by a median line, left bank, right bank, etc.

The precise drawing of river boundaries has been important on countless occasions; notable examples include the Shatt al-Arab (known as Arvand Rud in Iran) between Iraq and Iran, the Danube in central Europe, the Kasikili/Sedudu Island dispute between Namibia and Botswana, settled by the International Court of Justice in 1999 [5], and the 2004 dispute settlement under the UN Law of the Sea concerning the offshore boundary between Guyana and Suriname, in which the thalweg of the Courantyne River played a role in the ruling.

Etymology

Thalweg is an English loan word from German. The German word *Thalweg* (nowadays spelt *Talweg*) is a compound noun that is built from the German elements *Thal* (since Duden's orthography reform of 1901 written *Tal*) meaning *valley*, and *Weg*, meaning *way.*

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[4] Umatilla River Basin Anadromous Fish Habitat Enhancement Project 1990 Annual Report Carl A. Sheeler, Fish Habitat Biologist Slatick, January 1991
[5] http://www.icj-cij.org/docket/index.php?case=98&p1=3&p2=1&p3=6&pr=318&search=%22botswana%22

External links

- USGS: Stream Modeling website (http://smig.usgs.gov/SMIG/features_0300/otis_fs.html)

Till plain

A **till plain** is an extensive flat plain of glacial till that forms when a sheet of ice becomes detached from the main body of a glacier and melts in place depositing the sediments it carried. A till plain with irregular topography is referred to as a ground moraine.

Tinaja

Tinaja is a term used in the American Southwest for water pockets formed in bedrock depressions that occur below waterfalls or are carved out by spring flow or seepage [1] . Tinajas are important sources of surface water storage in these arid environments [2] . These relatively rare landforms are important ecologically because they support unique plant communities and provide important services to terrestrial wildlife [3] .

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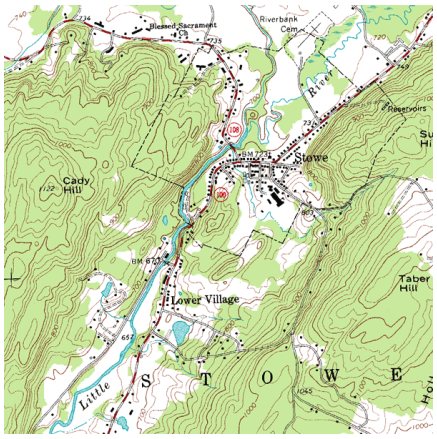
Topography

Topography (from Greek *τόπος topos*, "place", and *γράφω graphō*, "write") is the study of Earth's surface shape and features or those of planets, moons, and asteroids. It is also the description of such surface shapes and features (especially their depiction in maps).

The topography of an area can also mean the surface shape and features themselves.

In a broader sense, topography is concerned with local detail in general, including not only relief but also vegetative and human-made features, and even local history and culture. This meaning is less common in America, where topographic maps with elevation contours have made "topography" synonymous with relief. The older sense of topography as the study of place still has currency in Europe.



A topographic map with contour intervals

For the purposes of this article, topography specifically involves the recording of relief or terrain, the three-dimensional quality of the surface, and the identification of specific landforms. This is also known as geomorphometry. In modern usage, this involves generation of elevation data in electronic form. It is often considered to include the graphic representation of the landform on a map by a variety of techniques, including contour lines, Hypsometric tints, and relief shading.[1] [2] [3]

Etymology

The term topography originated in ancient Greece and continued in ancient Rome, as the detailed description of a place. The word comes from the Greek words τόπος (*topos*, place) and γραφία (*graphia*, writing).[4] In classical literature this refers to writing about a place or places, what is now largely called 'local history'. In Britain and in Europe in general, the word topography is still sometimes used in its original sense.[5]

Detailed military surveys in Britain (beginning in the late eighteenth century) were called Ordnance Surveys, and this term was used into the 20th century as generic for topographic surveys and maps.[6] The earliest scientific surveys in France were called the Cassini maps after the family who produced them over four generations. The term "topographic surveys" appears to be American in origin. The earliest detailed surveys in the United States were made by the “Topographical Bureau of the Army,” formed during the War of 1812.[7] After the work of national mapping was assumed by the U.S. Geological Survey in 1878, the term topographical remained as a general term for detailed surveys and mapping programs, and has been adopted by most other nations as standard.

In the 20th century, the term topography started to be used to describe surface description in other fields where mapping in a broader sense is used, particularly in medical fields such as neurology.

Objectives

An objective of topography is to determine the position of any feature or more generally any point in terms of both a horizontal Coordinate system such as latitude, longitude, and altitude. Identifying (naming) features and recognizing typical landform patterns are also part of the field.

A topographic study may be made for a variety of reasons: military planning and geological exploration have been primary motivators to start survey programs, but detailed information about terrain and surface features is essential for the planning and construction of any major civil engineering, public works, or reclamation projects.

Techniques of topography

There are a variety of approaches to studying topograpy. Which method(s) to use depend on the scale and size of the area under study, its accessibility, and the quality of existing surveys.

Direct survey

Surveying helps determine accurately the terrestrial or three-dimensional space position of points and the distances and angles between them using leveling instruments such as theodolites, dumpy levels and clinometers.

A surveying point in Germany

Even though remote sensing has greatly speeded up the process of gathering information, and has allowed greater accuracy control over long distances, the direct survey still provides the basic control points and framework for all topographic work, whether manual or GIS-based.

In areas where there has been an extensive direct survey and mapping program (most of Europe and the Continental US, for example), the compiled data forms the basis of basic digital elevation datasets such as USGS DEM data. This data must often be "cleaned" to eliminate discrepancies between surveys, but it still forms a valuable set of information for large-scale analysis.

The original American topographic surveys (or the British "Ordnance" surveys) involved not only recording of relief, but identification of landmark features and vegetative land cover.

Remote sensing

Remote sensing is a general term for geodata collection at a distance from the subject area.

Aerial and satellite imagery

Besides their role in photogrammetry, aerial and satellite imagery can be used to identify and delineate terrain features and more general land-cover features. Certainly they have become more and more a part of geovisualization, whether maps or GIS systems. False-color and non-visible spectra imaging can also help determine the lie of the land by delineating vegetation and other land-use information more clearly. Images can be in visible colours and in other spectrum

Photogrammetry

Photogrammetry is a measurement technique for which the co-ordinates of the points in 3D of an object are determined by the measurements made in two photographic images (or more) taken starting from different positions, usually from different passes of an aerial photography flight. In this technique, the common points are identified on each image. A line of sight (or ray) can be built from the camera location to the point on the object. It is the intersection of its rays (triangulation) which determines the relative three-dimensional position of the point. Known control points can be used to give these relative positions absolute values. More sophisticated algorithms can exploit other information on the scene known a priori (for example, symmetries in certain cases allowing the rebuilding of three-dimensional co-ordinates starting from one only position of the camera).

Radar and sonar

Satellite radar mapping is one of the major techniques of generating Digital Elevation Models (see below). Similar techniques are applied in bathymetric surveys using sonar to determine the terrain of the ocean floor. In recent years, LIDAR (**Li**ght **D**etection **a**nd **R**anging), a remote sensing technique using a laser instead of radio waves, has increasingly been employed for complex mapping needs such as charting canopies and monitoring glaciers.

Forms of topographic data

Terrain is commonly modelled either using vector (triangulated irregular network or TIN) or gridded (Raster image) mathematical models. In the most applications in environmental sciences, land surface is represented and modelled using gridded models. In civil engineering and entertainment businesses, the most representations of land surface employ some variant of TIN models. In geostatistics, land surface is commonly modelled as a combination of the two signals - the smooth (spatially correlated) and the rough (noise) signal.

In practice, surveyors first sample heights in an area, then use these to produce a Digital Land Surface Model (also known as a digital elevation model). The DLSM can then be used to visualize terrain, drape remote sensing images, quantify ecological properties of a surface or extract land surface objects. Note that the contour data or any other sampled elevation datasets are not a DLSM. A DLSM implies that elevation is available continuously at each location in the study area, i.e. that the map represents a complete surface. Digital Land Surface Models should not be confused with Digital Surface Models, which can be surfaces of the canopy, buildings and similar objects. For example, in the case of surface models produces using the LIDAR technology, one can have several surfaces - starting from the top of the canopy to the actual solid earth. The difference between the two surface models can then be used to derive volumetric measures (height of trees etc.).

Raw survey data

Topographic survey information is historically based upon the notes of surveyors. They may derive naming and cultural information from other local sources (for example, boundary delineation may be derived from local cadastral mapping. While of historical interest, these field notes inherently include errors and contradictions that later stages in map production resolve.

Remote sensing data

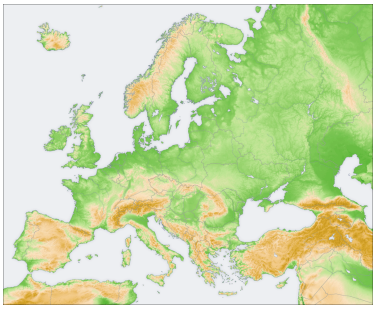
As with field notes, remote sensing data (aerial and satellite photography, for example), is raw and uninterpreted. It may contain holes (due to cloud cover for example) or inconsistencies (due to the timing of specific image captures). Most modern topographic mapping includes a large component of remotely sensed data in its compilation process.

Topographic mapping

In its contemporary definition, topographic mapping shows relief. In the United States, USGS topographic maps show relief using contour lines. The USGS calls maps based on topographic surveys, but without contours, "planimetric maps."

These maps show not only the contours, but also any significant streams or other bodies of water, forest cover, built-up areas or individual buildings (depending on scale), and other features and points of interest.

While not officially "topographic" maps, the national surveys of other nations share many of the same features, and so they are often generally called "topographic maps."



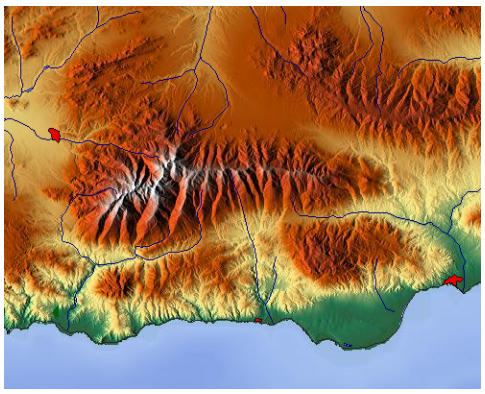
A map of Europe using **elevation modeling**

Existing topographic survey maps, because of their comprehensive and encyclopedic coverage, form the basis for much derived topographic work. Digital Elevation Models, for example, have often been created not from new remote sensing data but from existing paper topographic maps. Many government and private publishers use the artwork (especially the contour lines) from existing topographic map sheets as the basis for their own specialized or updated topographic maps[8]

Topographic mapping should not be confused with Geologic mapping. The latter is concerned with underlying structures and processes to the surface, rather than with identifiable surface features.

Digital elevation modeling

The digital elevation model (DEM) is a raster-based digital dataset of the topography (hypsometry and/or bathymetry) of all or part of the Earth (or a telluric planet). The pixels of the dataset are each assigned an elevation value, and a header portion of the dataset defines the area of coverage, the units each pixel covers, and the units of elevation (and the zero-point). DEMs may be derived from existing paper maps and survey data, or they may be generated from new satellite or other remotely-sensed radar or sonar data.

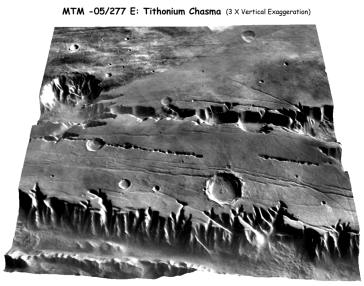


Relief map: Sierra Nevada Mountains, Spain

Topological modeling

A geographic information system (GIS) can recognize and analyze the spatial relationships that exist within digitally stored spatial data. These topological relationships allow complex spatial modelling and analysis to be performed. Topological relationships between geometric entities traditionally include adjacency (what adjoins what), containment (what encloses what), and proximity (how close something is to something else).

- reconstitute a sight in synthesized images of the ground,
- determine a trajectory of overflight of the ground,
- calculate surfaces or volumes,
- trace topographic profiles,



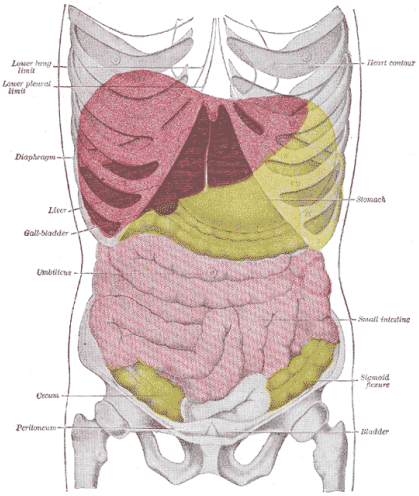
3D rendering of a DEM used for the topography of Mars

Topography in other fields

Topography has been applied to different science fields. In neuroscience, the neuroimaging discipline uses techniques such as EEG topography for brain mapping. In ophthalmology, corneal topography is used as a technique for mapping the surface curvature of the cornea.

In human anatomy, topography is superficial human anatomy.

In mathematics the concept of topography is used to indicate the patterns or general organization of features on a map or as a term referring to the pattern in which variables (or their values) are distributed in a space.



Topography of thoracic and abdominal viscera.

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[3] Definition from Federal Citizen Information Center - pueblo.gsa.gov
[4] Online Etymology Dictionary (http://www.etymonline.com/index.php?term=topography) - etymonline.com
[5] For example, see the website of the London Topographical Society (http://www.topsoc.org)
[6] Oxford English Dictionary "Ordnance Survey"
[7] Topographical Engineers - History and Personnel (http://www.topogs.org/History.htm)
[8] see for example the publications of National Geographic Trails Illustrated Maps (http://www.ngmapstore.com/jump.jsp?itemType=CATEGORY&itemID=54) and DeLorme products

Toreva block

A **Toreva block** landslide is a distinctive landslide type which may occur when a stronger material such as sandstone or limestone overlies a weaker material such as shale and an eroding agent undercuts the weaker lower layer. The type was first recognized by *Parry Reiche* in 1937, and takes its name from Toreva, Arizona. Toreva blocks exhibit a characteristic backward rotation toward the parent cliff.

The existence of Toreva blocks may be used to infer a warmer or wetter earlier climate, e.g. toreva blocks in the Transantarctic Mountains.

A trail cuts across a large Toreva block bench several hundred feet below the level of the parent cliff in White Rock Canyon. The weaker base is the Tesuque Formation, the stronger overburden is the Cerros del Rio basalt, and the eroding agent is the Rio Grande river.

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Reiche, Parry. "The Toreva block, a distinctive landslide type". *Journal of Geology* **45** (5): 538–548. doi:10.1086/624563.

External links

- Toreva, AZ Landsliding [1]
- TOREVA BLOCKS IN THE TRANSANTARCTIC MOUNTAINS: IMPLICATIONS FOR CENOZOIC PALEOCLIMATE [2]

References

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Trough (geology)

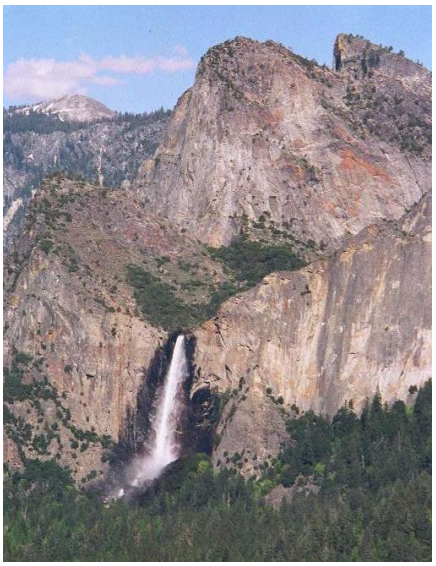
In geology, a **trough** generally refers to a linear structural depression that extends laterally over a distance, while being less steep than a trench.

A trough can be a narrow basin or a geologic rift.

There are various **oceanic troughs**, troughs found under oceans; examples include the rift along the mid-oceanic ridge and the Cayman Trough.

Truncated spur

A **truncated spur** is a geologic formation created under specific conditions which result in a ridge of land with its end cut off. It occurs when ridge spurs, which were formed in a mountainous area by river action, have been (or are still being) truncated by the action of ice or active faulting.



Bridal Veil Falls in Yosemite National Park. Either side of the waterfall are the flat vertical faces of the truncated spurs

Formation

Glaciation

Before glaciation, relatively immature rivers display a pattern of interlocking spurs. A valley glacier cannot avoid the interlocking spurs as a river can. As the valley glacier moves, abrasion and plucking erode the protruding tips of the spurs, leaving steep cliff-like truncated spurs. Hanging valleys are found in between truncated spurs as the they join the main glacial valley from the side. It is common for waterfalls to form from them, where they fall into the main valley.

Truncated spurs can be found in mountainous regions. The Mer de Glace, in the European Alps, is a valley through which a glacier currently flows. This is a geologically active process where the glacier continues to gradually erode the valley sides.

Faulted southeastern side of Svyatoy Nos peninsula, Lake Baikal - active faulting shown by truncated spurs forming triangular facets

Active faulting

Truncated spurs are also formed by active faulting, especially normal faulting, producing characteristic triangular facets, sometimes known as a 'flat irons', at the mountain front. These landforms provide evidence for recent fault movement and are used in seismotectonic analysis.[1]

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U-shaped valley

A **U-shaped valley** is one formed by the process of glaciation. It has a characteristic U-shape, with steep, straight sides, and a flat bottom. Glaciated valleys are formed when a glacier travels across and down a slope, carving the valley by the action of scouring. When the ice recedes or thaws, the valley remains, often littered with small boulders that were transported within the ice.

A glaciated valley in the Mount Hood Wilderness showing the characteristic U-shape.

Examples of U-valleys are found in mountainous region like the Alps or Rocky mountains but also in Scotland, Scandinavia or Canada. A classic glacial trough was formed by the St. Mary River in Glacier National Park in Montana, USA.

Formation

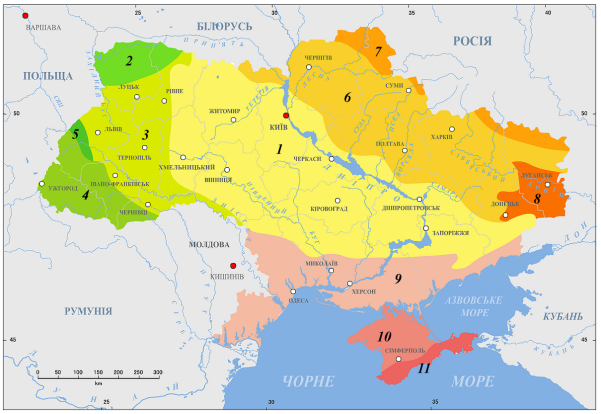
As a Glacier moves downhill through a valley, the shape of the valley is transformed. A V-shaped valley is transformed into a U-shaped valley through the glacial erosion processes of (glaciation) and abrasion, this results in large rocky material (glacial till) being carried in the glacier. A material called boulder clay is deposited on the floor of the valley. As the ice melts and retreats, the valley is left with very steep sides and a wide, flat floor. A river or stream may flow through the valley due to melt-water from the glacier.

This replaces the original stream or river and is known as a misfit stream. If the material which pushed in front of the glacier is left, this material is called a terminal moraine. The valley dammed by the moraine may then flood creating a lake which may twist and turn, which is termed a ribbon lake.

U-shaped valley in Glacier National Park in Montana, United States.

Ukrainian Shield

The **Ukrainian Shield** is the southwest shield of the East European craton. The Ukrainian Shield and the Voronezh Massif consist of 3.2-3.8 Ga Archaean crust in the southwest and east, and 2.3-2.1 Ga Early Proterozoic orogenic belts.



1. Ukrainian Shield

Unaweep Canyon

Unaweep Divide	
Unaweep Canyon west of the Unaweep Divide	
Elevation	7008 ft (2136 m) [1]
Traversed by	SH 141
Location	
Location	Unaweep Canyon, Mesa County, Colorado
Coordinates	38°47′26″N 108°39′18″W
Topo map	USGS Snyder Flats

Unaweep Canyon is a geologically unique canyon that cuts across the Uncompahgre Plateau in western Colorado. It is unique because two creeks, East Creek and West Creek, flow out of opposite ends of the canyon, separated by the almost imperceptible **Unaweep Divide**.[2]

Hypotheses of origin

There are multiple explanations for the origin of Unaweep Canyon. In the late 19th century, members of the Hayden Survey recognized the oddity of a canyon with two outlets, and suggested it was carved by the ancestral Colorado or Gunnison river.[3] [4] Many others have also suggested it was carved by either the Gunnison or Colorado Rivers, but evidence for gravel deposits characteristic of these rivers was elusive, and the existence of the divide remains difficult to explain. Several have suggested that Plio-Pleistocene uplift caused diversion of the (Colorado and/or Gunnison) river(s) and abandonment of the canyon.[5] [6] But rates of river incision typically exceed those of tectonic uplift, making this unlikely. The many apparent glacial-like features of the canyon's inner gorge have led some to suggest a Pleistocene glacial origin for the canyon[7] , but the low elevation of the canyon, and lack of Pleistocene glacial deposits, make this problematic. More recently, documentation of gravels characteristic of the Gunnison River and located at the western mouth of Unaweep Canyon provide evidence for occupation of the canyon by an ancestral Gunnison River[8] Hence, the ancestral Gunnison River may have carved the canyon. However, another hypothesis holds that the ancestral Gunnison River did not carve the canyon, but exhumed a pre-existing (paleo) canyon. This hypothesis of an ancient age for the inner gorge of Unaweep Canyon comes from dating of sediments recovered in a core through the canyon fill[9] . This core proved the existence of a thick (>300 m) sediment fill in the canyon, an idea first proposed in the 1970s on the basis of a geophysical study.[10] Related to the proposed ancient age for the canyon is the hypothesis that the canyon was glaciated during the Late Paleozoic, roughly 300 million years ago. [11] . The hypotheses of a Paleozoic age and glacial origin for the canyon, remain debated[12] [13] , like many other hypotheses for the origin of this scenic canyon.

Access

State Highway 141 runs inside Unaweep Canyon between Whitewater and Gateway, one segment of the Colorado designated Unaweep Tabeguache Scenic Byway.[14] The Unaweep Divide, elevation 7008 ft (2136 m), is near mile marker 135 on SH 141.[2]

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External links

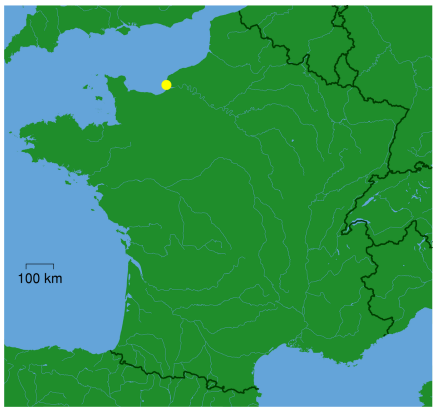
- Unaweep Canyon cuts across the Uncompahgre Plateau (http://www.durangobill.com/UnaweepCanyon.html)

Valleuse

In the Pays de Caux, Normandy, France a **valleuse** is a depression in the land surface of the plateau which permits access to the sea. On the rest of this coast, that access is prevented by the height of the chalk cliffs.

There are three sorts:

- living valleuses: natural depressions as at Fécamp, Yport and Étretat.
- dead valleuses: to obtain the final access to the beach it is necessary to set up a stairway.
- perched valleuses: simple depressions in the plateau surface which do not descend far enough to permit access to the beach. Elsewhere, it might be called a hanging valley though it is formed, not by a glacier but by maritime erosion.

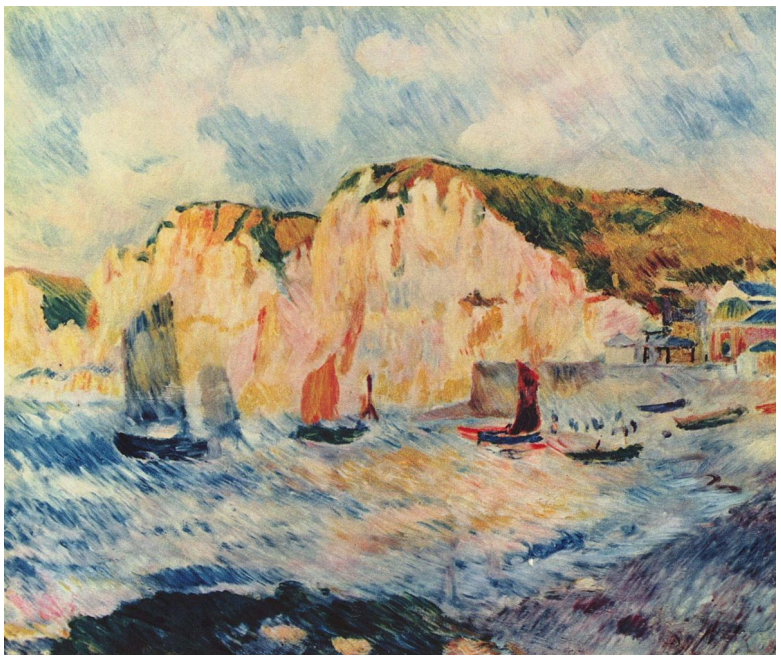


Location within France

Origins

The word is peculiar to the Pays de Caux but the feature is not, though it shows itself particularly well here. The valleys developed while the water table was much higher in the chalk than it now is so that a stream flowed in each of these truncated valleys. It is likely that most of the formation of the valleys in the plateau occurred during cold periods. This region was never covered by an ice cap but it has been only about 230 kilometres from one. In those circumstances, the conditions will have been tundra, sometimes verging on periglacial. When the frozen ground thawed in the spring, the surface soil was very wet because the melted snow and ground water could not sink into the permafrost. Any appreciable slope on the surface will have induced slumping and erosion but we have a plateau so the slopes were not originally great.

During the glacial periods, the sea level was low enough to have emptied the English Channel to the north of the Pays de Caux. The truncated valleys in the chalk, represent the headwaters of streams flowing down to what is now the bottom of the sea. During the interglacials the sea eroded the coast and steepened the slope down which they flowed but they will have required ever wetter conditions to keep the water table in the chalk sufficiently high to make the streams flow. In the end, the sea cut the cliff back quicker than the streams cut the valleys downward.



Pierre-Auguste Renoir, Mer et bateaux, 1883, Metropolitan Museum of Art, New York. Note the one living and two perched Valleuses.

Vegetation and slope stability

Vegetation and slope stability are interrelated by the ability of the plant life growing on slopes to both promote and hinder the stability of the slope. The relationship is a complex combination of the type of soil, the rainfall regime, the plant species present, the slope aspect, and the steepness of the slope. Knowledge of the underlying slope stability as a function of the soil type, its age, horizon development, compaction, and other impacts is a major underlying aspect of understanding how vegetation can alter the stability of the slope. (Mattia et al. 2005).

There are four major ways in which vegetation influences slope stability: wind throwing, the removal of water, mass of vegetation (surcharge), and mechanical reinforcement of roots.

Wind throwing

Wind throw is the toppling of a tree due to the force of the wind, this exposes the root plate and adjacent soil beneath the tree and influences slope stability. Wind throw is factor when considering one tree on a slope, however it is of lesser importance when considering general slope stability for a body of trees as the wind forces involved represent a smaller percentage of the potential disturbing forces and the trees which are in the centre of the group will be sheltered by those on the outside (Greenwood et al. 2004)

Removal of water

Vegetation influences slope stability by removing water through transpiration. Transpiration is the vaporisation of liquid water contained in plant tissue and the vapour removal to the air (Food and Agriculture Organisation of the United Nations 2007). Water is drawn up from the roots and transported through the plant up to the leaves as demonstrated in figure 2.

The major effect of transpiration is the reduction of soil pore water pressures which counteracts the loss of strength which occurs through wetting, this is most readily seen as a loss of moisture around trees. However it is not easy to rely on tree and shrub roots to remove water from slopes and consequently help ensure slope stability. The ability to transpire in wet conditions is severely reduced and therefore any increase in soil strength previously gained in evaporation and transpiration will be lost or significantly reduced, consequently the effects of transpiration cannot be taken into account at these times. However it can be assumed that the chance of slope failure following saturation by storm event or periods of extended rainfall will be lessened as a result of transpiration. Moreover, although changes in moisture content will affect the undrained shear strength, the effective shear stress parameters as commonly used in routine slope stability analysis are not directly influenced by changing moisture content, although the water pressures (suctions) used in the analysis will change (Food and Agriculture Organisation of the United Nations 2007; Greenwood et al. 2004) .

It is important to note that desiccation cracks can potentially be extended by vegetation in dry weather promoting the deeper penetration of water to a potential slip plane and increased water pressure into the soil during the wet periods. Nevertheless these cracks will be filled by roots growing deeper into the soil as they follow the path of least resistance (Greenwood et al. 2004).

Studies in Malaysia by Osman & Barakbah (2006) have shown that there is a significant relationship between root length density, soil water content and ultimately slope stability. Slopes that had high root density (due to dense vegetation on the surface) were less likely to undergo slope failure. This is because a high root length density results in low soil water content which in turn results in an increase in shear strength and a decrease in soil permeability. It is suggested that root length density and soil water level could be used as indicators of slope stability and possibly could be used to predict future slope failure (Osman & Barakbah 2006).

Transpiration is accentuated when the vegetation has an extensive root system and rapid transpiration continues throughout winter (Perry et al. 2003).

The removal of water is also affected by the shading provided by vegetation. Shading helps prevent the desiccation of the soils which results in shrinkage and cracking allowing the deep penetration of rain water. Plants need to have a high leaf to root ratio and have the ability to persist through hot summer months in order to provide effective shading of the soils (Perry et al. 2003).

The mass of vegetation

The mass of vegetation is only likely to have an influence on slope stability when larger trees are growing on the slope. A tree of 30 -50m height is likely to have a loading of approximately 100 -150kN/m2. The larger trees should be planted at the toe of the slope with a potential rotational failure as this could increase the factor of safety by 10%. However if the tree is planted at the top of the slope this could reduce the factor of safety by 10%. A suggested design vegetation envelope which shows which type of plant should be grown at each level of the slope is shown in figure 3 (Greenwood et al. 2004; Perry et al. 2003).

Each slope stability situation should be considered independently for the vegetation involved. It is important to remember that transpiration will reduce the weight of the slope as moisture is lost. This can be significant on slopes of marginal stability (Greenwood et al. 2004).

If larger trees are removed from the toe area of a slope there will be both a reduction in soil strength due to the loss of evapotranspiration effects and a reduction in applied loading which may result in temporary suctions in clay soils

which could lead to softening as the available water is drawn in to compensate for the suction forces. This is similar to the recognised softening of overconsolidated clays due to the relaxation of overburden pressures when placed in the top layers of an embankment from deep cutting (Greenwood et al. 2004).

Mechanical reinforcement of roots

Roots reinforce the soil through growing across failure planes, root columns acting as piles, and through limiting surface erosion (Cammeraat et al., 2005; Morgan 2007; Perry et al. 2003).

Root growth across failure planes

When roots grow across the plane of potential failure there is an increase in shear strength by binding particles. The roots anchor the unstable surficial soil into the deeper stable layers or bedrock (Mattia et al., 2005). This most readily occurs when there is rapid deep growth (1.5m deep) of roots which last for more than two years. However it is important to note that the strength exerted by roots generally only extends down to 1m while most failures occur between 1.2 – 1.5m soil depth (Perry et al. 2003).

Root reinforcement model

The root reinforced earth root model is the result of the root elongation across a potential slip plane which produces a tensile root force which is transferred to the soil by cohesive and frictional contacts between the root and the soil, as shown in figure 4 (van Beek et al. 2005).

Tensile root strength contribution and pull out resistance

The pull out resistance of a root is the measured resistance of root structure to be pulled out of the ground and is likely to be only a little less than the measured tensile strength of the root which is the roots resistance to breaking as measured in the laboratory, shown in figure 5. In the cases where there is no pull out data available the tensile strength data maybe used as a rough guide to the maximum pull out resistance available (Greenwood et al. 2004).

The tensile root strength of a range of diameters over a range of species has been tested in the laboratory and has been found to be approximately 5 – 60MN/m2. In order for the root to actually enhance slope stability the root must have sufficient embedment and adhesion with the soil. The way that roots interact with the soil is intricate but for engineering purposes the available force contributions may be measured with in situ pull out tests (Greenwood et al. 2004).

Root morphology and modes of failure

The root length and the type of root branching effects the way that root failure occurs (Greenwood et al. 2004; Norris 2005). Three different modes of failure have been identified in hawthorn roots which relate to the root soil relationship which is shown in the shape of the roots and the shape of the failure curve. Roots which have no branches tend to fail in tension and pull straight out of the ground with minimal resistance. Roots which have multiple branches generally fail in stages as each branch breaks inside the soil. These roots can then separated into two different groups; 1) those that initially reach their maximum peak force and then maintain a high force that progressively decreases as the root branches fail after significant strain and 2) those that break with increasingly applied force. In a number of tests considerable adhesion between a segment of the root and the soil can be measured prior to the root eventually slipping out of the soil mass (Greenwood et al. 2004).

Type A failure

Roots that do not have branches generally fail in tension and pull straight out of the ground with only minimal resistance, as shown in figure 6. The root reaches its maximum pullout resistance then rapidly fails at a weak point. The root easily slips out of the soil due to the gradual tapering (progressive decrease in root diameter along its length) which means that as the root is pulled out it is moving through a space that is larger than its diameter which consequently has no further bonds or interaction with the surrounding soil (Norris 2005).

Type B failure

Figure 7: Pull out resistance vs displacement graph and associated root morphology for roots with branches (d is diameter of root and ιT is root length) (Source: Norris 2005).

Type B failure occurs when branched roots initially reach their maximum peak resistance then sustain a high resistance which slowly reduces as the branches of the roots fail after significant strain, as shown in figure 7. In some tests considerable adhesion between a section of the root and the soil mass can be measured before the root eventually slips out. Forked roots require a greater force to be pulled out as the cavity above the fork is thinner than the root which is trying to move through the cavity, this can then result in deformation of the soil as the root moves through the soil (Norris 2005).

Type C failure

Figure 8: Pull out resistance vs displacement graph and associated root morphology for multi-branched roots with branches (d is diameter of root and ιT is root length) (Source: Norris 2005).

Roots that have multiple branches or forked branches also can undergo tensile failure but predominantly fail in stages as each branch breaks within the soil. These roots break with increasingly applied force in stages in the form of stepped peaks corresponding to the progressive breaking of roots of greater diameters. The root progressively releases its bonds with the soil until final tensile failure as shown in figure 8 (Norris 2005).

In some cases when the root has a sinusoidal shape with many small rootlets along its length the root reaches its maximum pull out resistance on straightening and then breaks at the weakest point, however at this point the root is not pulled out of the soil as it adheres and interacts with the soil producing a residual strength. If pulling was stopped at this point, the root would give increased strength to the soil. However if the root is completely pulled out of the ground then there is no further interaction with soil and therefore no increase in soil strength is provided (Norris 2005).

Factors which affect root pull out resistance

Studies by Norris (2005) have shown that the pull out resistance of hawthorn and oak roots are affected by intra species differences, inter-species variations and root size (diameter) in a similar as way as root tensile strength varies (as measured in the laboratory). In the pull out test the applied force acting on the root acts across a larger root area, which involves multiple branches, longer lengths) than the short (approximately 150mm) length of root used in tensile strength tests. In pull out test the root is likely to fail at weak points such as branching points, nodes or damaged areas.

Norris (2005) also showed that there is a positive correlation between maximum root pull out resistance and root diameter for hawthorn and oat root. Smaller diameter roots had a lower pull out resistance or breaking force than the larger diameter roots.

Root columns acting as piles

Trees and root columns can prevent shallow mass movement through acting as piles when there is buttressing and soil arching through a woody deep root system which has multiple sinker roots with embedded stems and laterals (Perry et al. 2003).

Limitation of surface erosion

Vegetation can also be used to control water erosion by limiting surface processes such as sheet wash and overland flow (Cammeraat et al., 2005; Morgan 2007). Vegetation can provide a considerable contribution to the stability of slope through enhancing soil cohesion. This cohesion is dependent upon the morphological characteristics of root systems and the tensile strength of single roots (Mattia et al. 2005).

There is considerable evidence of fine roots resisting surface erosion. The role of fine roots in general slope stability is not fully understood. It is thought that the fine roots help keep the surface soil together and prevent surface erosion. The fine root network may have an apparent enhanced cohesion which is comparable to geosynthetic mesh elements. The limitation of surface erosion processes is particularly apparent in areas of shrub and grass where the fine root distribution is consistent and clearly defined, however cohesion is generally limited to the top 1m of soil (Greenwood et al. 2004).

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Vein (geology)

In geology, a **vein** is a distinct sheetlike body of crystallized minerals within a rock. Veins form when mineral constituents carried by an aqueous solution within the rock mass are deposited through precipitation. The hydraulic flow involved is usually due to hydrothermal circulation.

Veins are classically thought of as being the result of growth of crystals on the walls of planar fractures in rocks, with the crystal growth occurring normal to the walls of the cavity, and the crystal protruding into open space. This certainly is the method for the formation of some veins. However, it is rare in geology for significant open space to remain open in large volumes of rock, especially several kilometers below the surface. Thus, there are two main mechanisms considered likely for the formation of veins: *open-space filling* and *crack-seal growth*.

A quartz vein, prominent from the surrounding weathered rock

Open space filling

Open space filling is the hallmark of epithermal vein systems, such as a stockwork, in greisens or in certain skarn environments. For open space filling to take effect, the confining pressure is generally considered to be below 0.5 GPa, or less than 3-5 kilometres. Veins formed in this way may exhibit a colloform, agate-like habit, of sequential selvedges of minerals which radiate out from nucleation points on the vein walls and appear to fill up the available open space. Often evidence of fluid boiling is present. Vugs, cavities and geodes are all examples of open-space filling phenomenon in hydrothermal systems.

Alternatively, hydraulic fracturing may create a breccia which is filled with vein material. Such breccia vein systems may be quite extensive, and can form the shape of tabular dipping sheets, diatremes or laterally extensive mantos controlled by boundaries such as thrust faults, competent sedimentary layers, or cap rocks.

Crack-seal veins

When the confining pressure is too great, or when brittle-ductile rheological conditions predominate, vein formation occurs via crack-seal mechanisms.

Crack-seal veins are thought to form quite quickly during deformation by precipitation of minerals within incipient fractures. This happens swiftly by geologic standards, because pressures and deformation mean that large open spaces cannot be maintained; generally the space is in the order of millimetres or micrometres. Veins grow in thickness by reopening of the vein fracture and progressive deposition of minerals on the growth surface.

Tectonic implications

Veins generally need either hydraulic pressure in excess of hydrostatic pressure (to form hydraulic fractures or hydrofracture breccias) or they need open spaces or fractures, which requires a plane of extension within the rock mass.

In all cases except brecciation, therefore, a vein measures the plane of extension within the rock mass, give or take a sizeable bit of error. Measurement of enough veins will statistically form a plane of principal extension.

In ductilely deforming compressional regimes, this can in turn give information on the stresses active at the time of vein formation. In extensionally deforming regimes, the veins occur roughly normal to the axis of extension.

Mineralisation and veining

Boudinaged Quartz vein(with strain fringe) showing **sinistral shear sense**. Starlight Pit, Fortnum Gold Mine, Western Australia.

Veins are of prime importance to mineral deposits, because they are the source of mineralisation either in or proximal to the veins. Typical examples include gold lodes, as well as skarn mineralisation. Hydrofracture breccias are classic targets for ore exploration as there is plenty of fluid flow and open space to deposit ore minerals.

Ores related to hydrothermal mineralisation which are associated with vein material may be composed of vein material and/or the rock in which the vein is hosted.

Gold-bearing veins

In many of the gold mines exploited during the gold rushes of the 19th century, vein material alone was typically sought as ore material. In most modern mines, ore material is primarily composed of the veins and some component of the wall rocks which surrounds the veins.

In situ gold-bearing vein (in brown) a the Toi gold mine, Japan.

The difference between 19th century and modern mining techniques and the type of ore sought is based on the grade of material being mined and the methods of mining which are used. Historically, hand-mining of gold ores permitted the miners to pick out the lode quartz or reef quartz, allowing the highest-grade portions of the lodes to be worked, without dilution from the unmineralised wall rocks.

Modern mining using larger machinery and equipment forces the miners to take low-grade waste rock in with the ore material, resulting in dilution of the grade.

However, modern mining and assaying allows the delineation of lower-grade bulk tonnage mineralisation, within which the gold is invisible to the naked eye. In these cases, veining is the subordinate host to mineralisation and may

only be an indicator of the presence of metasomatism of the wall-rocks which contains the low-grade mineralisation.

For this reason, veins within hydrothermal gold deposits are no longer the exclusive target of mining, and in some cases gold mineralization is restricted entirely to the altered wall rocks within which entirely barren quartz veins are hosted.

Gold Bearing Quartz Veins, Blue Ribbon Mine, Alaska

Wash load

Wash load is the portion of sediment that is carried by a fluid flow, usually in a river, such that it always remains near the free surface (near the top of the flow in a river). It consists of the finest particles. Wash load is significant because it is the mode of sediment transport in which there is little to no interaction with the bed or banks and in which particles can be moved without extracting non-negligible momentum from the flow.

Wind erosion equation

A **wind erosion equation** is an equation used to design wind erosion control systems, which considers soil erodibility, soil roughness, climate, the unsheltered distance across a field, and the vegetative cover on the ground.

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Colin D. Woodroffe is a geographer and coastal geomorphologist currently serving as Professorial Fellow at the University of Wollongong. He is the Coordinator of the **GeoQuEST Research Centre**.

His international research focuses on the morphology, stratigraphy and sedimentary dynamics of tropical and subtropical coasts, and the application of Geographical Information Systems (GIS) to the study of processes and change in the coastal zone.

He has researched the following:

- Morphodynamics of estuaries and deltas
- Reef morphology and sedimentation
- Coral paleoclimatology and ocean circulation
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External links

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Yazoo stream

A **yazoo stream** is a hydrologic term for any tributary stream that runs parallel to, and within the floodplain of, a larger river which the stream eventually joins. Where the two meet is known as a belated confluence or deferred junction. This is especially the characteristic when such a stream is forced to flow along the base of the main river's natural levee. The name comes from the Yazoo River, which runs parallel to the Mississippi River for 280 km (175 miles) before converging, constrained from doing so by the river's levees.

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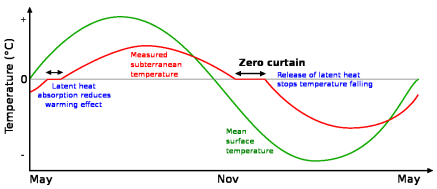
Zero-curtain effect

The **zero-curtain effect** occurs in cold (particularly periglacial) environments where the phase change of water to ice is retarded due to latent heat release. The effect is notably found in arctic and alpine permafrost sediments, and occurs where the air temperature falls below 0°C (the freezing point of water) followed by a rapid drop in soil temperature.[1]



Theoretical illustration of the zero-curtain effect over a 12 month period

Because of this effect, the lowering of temperature in moist, cold ground does not happen at a uniform rate. The loss of heat through conduction is reduced when water freezes, and latent heat is released. This heat of fusion is continually released until all the subsurface water has frozen, at which point temperatures can continue to fall.[2]

Therefore, for as long as water is available to the system (for example, through cryosuction/capillary action) the temperature of the sediment will remain at a constant temperature.

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External links

- Zero Curtain at Intersnow.co.uk (http://www.intersnow.co.uk/glossary/z/zero-curtain.html)

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