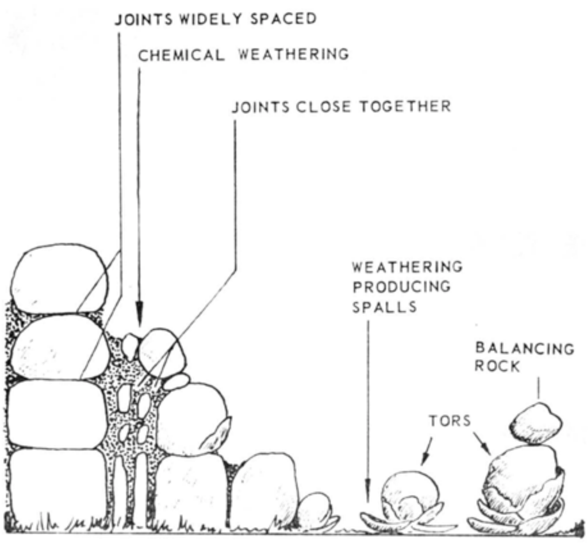
8.2.2 WEATHERING, EROSION AND SEDIMENTATION[M18]

Rocks are broken down in the **process of weathering**. The products of weathering are transported away by wind, water and ice in the process of **erosion**. The processes of weathering and erosion together with the uplifting of the rocks of the earth's crust shape the surface of the earth.

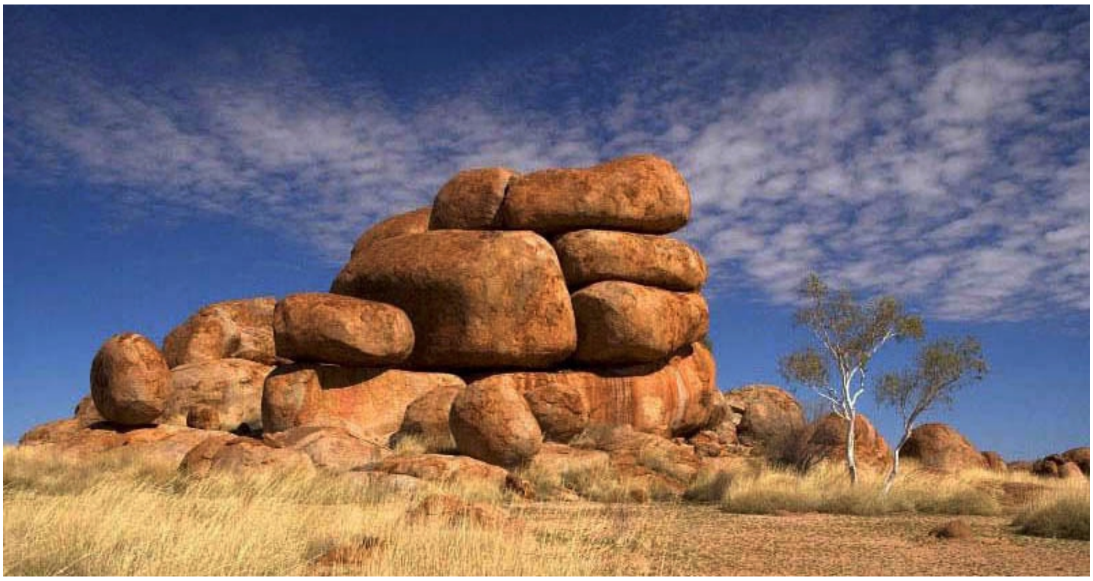
8.2.2.1 Weathering

8.2.2.1.1 Chemical Weathering

Chemical weathering results from the action of oxygen and water containing dissolved substances (such as carbon dioxide) on rocks at the surface of the earth. The iron in ferromagnesian minerals oxidises (rusts), and feldspar breaks down into clay. In igneous rocks, because their grains are closely packed, the effects of chemical weathering are mainly confined to the **surface of the rocks** and to **joints** produced by contraction as the rocks cool during formation.



Clay minerals take up more space than the materials from which they are formed and the resulting increase in volume of the surface layer causes it to crack away from the underlying, unaltered rock as **spalls**, in a process known as **onion skin**, or **spheroidal weathering**. The weathered material may be washed away leaving rounded boulders of unaltered rock. In coarse grained granite these can be quite large and are called **tors**. In basalt the blocks are much smaller.



Granite tors—Devil's Marbles, Northern Territory[1]

[1] http://image63.webshots.com/163/9/77/58/413497758kLnHwG_ph.jpg

8.2.2.1.2 Physical Weathering

Physical weathering includes a number of processes, such as the **expansion and contraction** of rocks as they heat up during the day and then cool at night, or of clay materials as they become wet and then dry out. Both of these examples may also cause thin, external layers or rock to flake off.

In cold climates, water that finds its way into cracks in rocks can freeze. **Water expands when it freezes**, and in doing so can exert a force great enough to widen the crack and ultimately fracture the rock. Plants too, particularly **root growth**, can effect the splitting of rocks.

Most obvious on the beach, **grinding and rubbing** of rocks or particles against one another leads to rock or particle disintegration—this is why beach pebbles and sand become so smooth.

Most sedimentary rocks are not affected by chemical weathering since, as we will see, they are made up of material that was itself produced through the process of weathering. They are not, however, immune to physical weathering. The clay components of sedimentary rocks, for example, expand as they are wet and contract again as they dry out. This cycle of expansion and contraction gradually wedges out harder mineral grains in the rock which, when loose, can be washed or blown away.

8.2.2.2 The Formation of Soil[2]

Soil is primarily the product of the weathering of rock. Soil is, nonetheless, made up of four constituents: mineral material, organic material, air and water. There are, in turn, considered to be three main mineral parts—sand, silt and clay—that give the soil its **mineral texture**. Soils may thus be characterised in terms of the properties they inherit from the underlying rock (the parent material) and the properties resulting from alteration of the original parent material by soil forming (pedogenic) processes.

Five important factors influence the specific soil type that develops:

Parent Material

Few soils weather directly from the underlying rocks. More commonly, soils form from materials that have moved in from elsewhere. Materials may have moved many kilometres or only a few metres. Materials from volcanos, sediment transported by wind, water or glaciers or minerals left behind by drying lakes are examples of parent materials.

Sediments along rivers have different textures, depending on whether the stream moves quickly or slowly. Fast-moving water leaves gravel, rocks, and sand. Slow-moving water and lakes leave fine textured material (clay and silt);

Climate

Variations in temperature, rainfall and ultimately moisture content give rise to different patterns of weathering and leaching, as well as biological activity, rates of chemical reactions, and kinds of vegetation. Wind redistributes sand and other particles, particularly in arid regions;

Living Organisms

Plants, animals, micro-organisms, and humans affect soil formation. As it dies, organic matter incorporates with the weathered parent material and becomes part of the soil. Plant roots open channels in the soil and parent material. Living

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[2] http://soils.usda.gov/education/facts/formation.html
http://www.cjnetworks.com/~sccdistrict/soilpro.htm
http://www.soil-net.com/advanced/index.htm

animals such as moles, earthworms, bacteria, fungi and nematodes are all busy moving through or digesting food found in the soil. All of these actions mix and enrich the soil. Humans can mix the soil so extensively that the soil material can again be considered parent material;

Topography

The slope and aspect of land will influence the temperature, moisture content and erosion of associated soils. In many areas, moist, poorly drained soils are located in low areas, and depressions of the land, while soils in sloping areas are drier and well drained. Both of these soil types may be well developed. Erosion, however, can remove part or all of the topsoil and subsoil in an affected area, leaving weakly developed soil;

Time

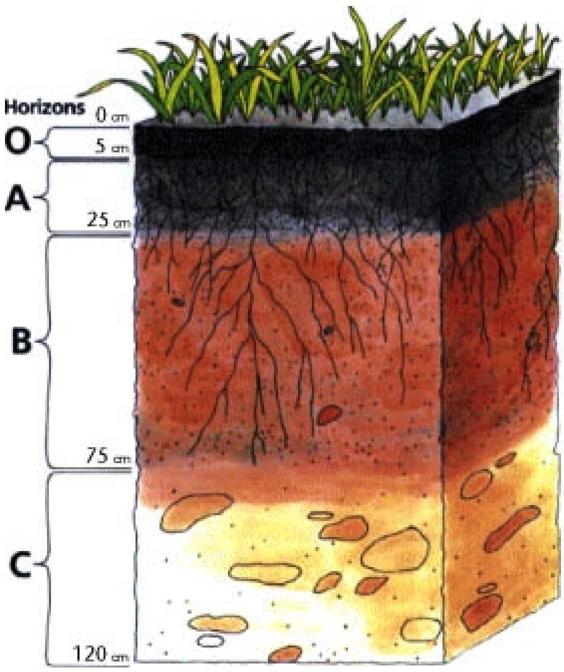
It may take hundreds of years to form one centimetre of soil from parent material. Only the top 10 centimetres or so are productive with respect to being able to sustain plant growth. This is why soil conservation is so important.

Under the influence of these forces, soil develops in layers known as **horizons**. The four uppermost horizons (the top 120 cm), together with the unique characteristics of a given soil sample are used by soil scientists (pedologists) to classify and name the soil, providing what is known as a **soil profile**. Note that actual soil depth varies with location, and under disturbed conditions (*e.g.* heavy agriculture, building sites or severe erosion) not all horizons will be present.

The uppermost horizon is called the organic or **O** horizon. It consists of detritus, leaf litter and other organic material lying on the surface of the soil. This layer is dark because of the decomposition that is occurring. This layer is not present in cultivated fields.

Below this is the **A** horizon, or topsoil. Usually it is darker than lower layers, loose and crumbly with varying amounts of organic matter. In cultivated fields the ploughed layer is topsoil. This is generally the most productive layer of the soil, and the layer upon which soil conservation efforts are focused.

As water moves down through the topsoil, many soluble minerals and nutrients dissolve. The dissolved materials leach downward into lower horizons.



A Soil Profile

The next layer is the **B** horizon, or subsoil. Subsoils are usually lighter in colour, dense and low in organic matter. Most of the materials leached from the **A** horizon stops in this zone.

Still deeper is the **C** horizon. This is a transition area between soil and parent material, where partially disintegrated parent material and mineral particles may be found.

At some point the **C** horizon will give up to the final horizon, bedrock.

On average, by volume, soil comprises 45% minerals, 25% water, 25% air and 5% organic matter (both living and dead organisms), although there are thousands of different types of soil throughout the world.

The formation of soils can be seen as a combination of the products of weathering, of structural development of the soil, of differentiation of that structure into horizons or layers, and lastly of its movement or translocation. In fact there are many ways in which soil may be transported away from the location where it was first formed.

8.2.2.3 Erosion

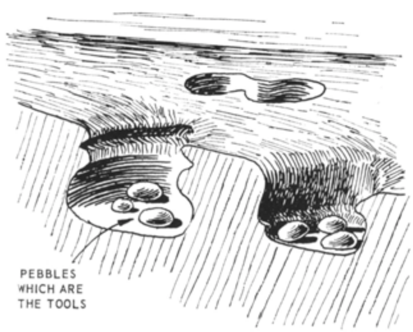
Erosion is the process of physically moving weathered material. Solid and broken rock, for example, can move downhill under the influence gravity, assisted by wetting and drying, freezing and thawing. Soil erosion often occurs where little vegetation grows and water or even wind is able to wash or blow the soil away.

There are, nonetheless, two primary agents of erosion: water, in its various forms (primarily water and ice), and wind. In the following sections, we will examine some of the results of the erosion caused by these agents.

8.2.2.3.1 The Work of Running Water

Rain water has potential energy and can thus do work. Rainfall is important in washing soil off exposed land. Even gentle rain can dislodge and move small soil particles. Where there is a lot of rain, the formation of small gullies can ultimately lead to 'gully erosion'. In tropical countries where there is extremely heavy rain, these gullies can become so deep that you can walk down into them.

Rivers carry water away from the land to the sea. As rivers flow, so they carry soil particles along. When soil is washed into a river, the smallest particles are carried the furthest, as they weigh the least. Heavier particles, such as sand, will be dropped earlier by the river. If pebbles fall in depressions in the river bed, the swirling action of the water on the pebbles in the depression can give rise to potholes.



Formation of potholes[3]

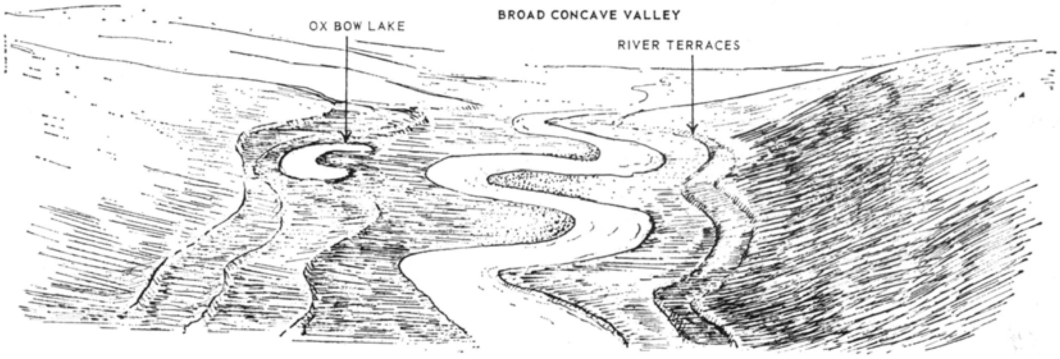
The floor of a river valley is also eroded away and deepened by the action of the sand and pebbles carried by the stream. The sides of a river valley are widened as weathered rock is moved down into the river by soil creep, landslides and the action of water. In deserts and limestone areas little widening of the valley occurs so that canyons are produced as the floor of the valley cuts down into the rock.

3 http://www.eos.ubc.ca/courses/eosc110/fletcher/slideshow/river/river.html

Deepening of the river valley exceeds the lateral erosion

V-shaped valley where lateral erosion keeps pace with valley deepening

Broad valley where lateral erosion exceeds valley deepening



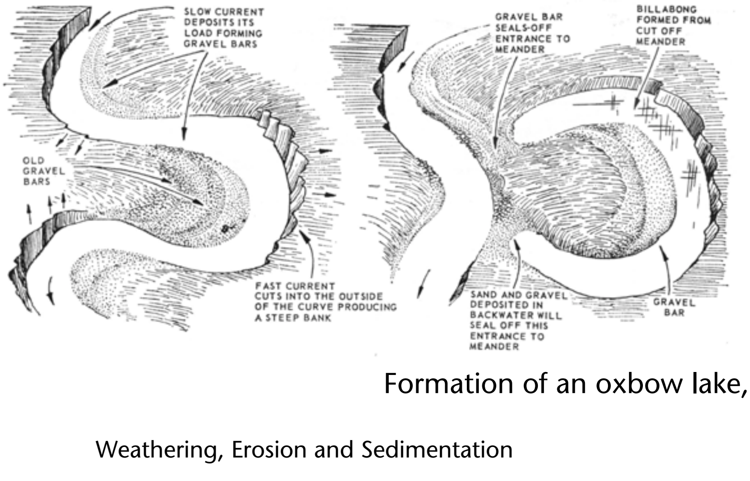
Broad valleys where lateral erosion exceeds valley deepening

Profiles of River Valleys

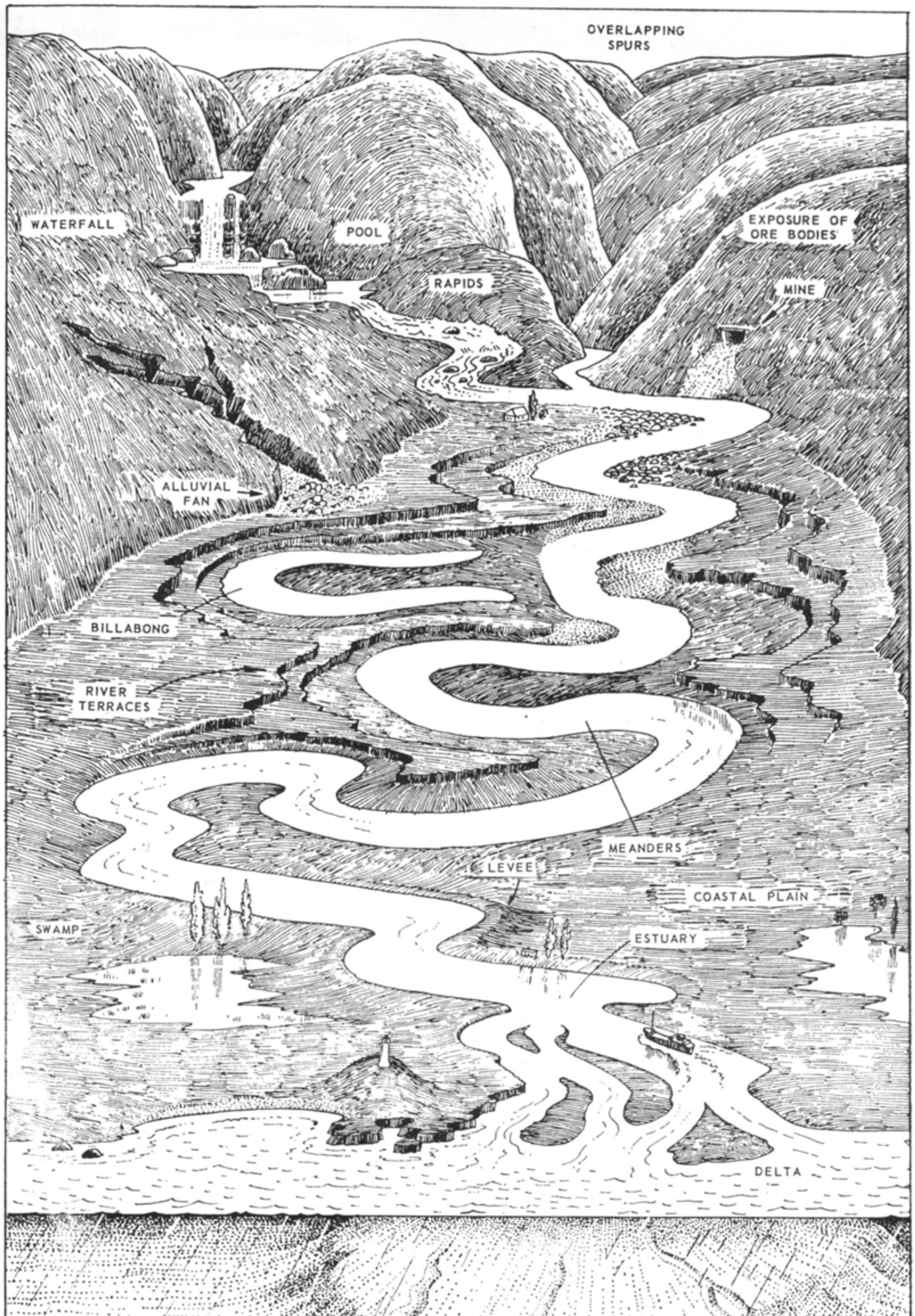
Most of the work of a river (in transforming the landscape) is done in times of flood. In flood, when a river overflows its banks, the deposited material may form an embankment or levee along the side of the river channel.

When a river enters the sea or a large lake, deposition takes place. This can lead to the formation of a delta and coastal flood plain.

Where a river flows over gently sloping ground, meanders may form. The flow is more rapid on the outside of the bends of a meander so that erosion may occur. On the inside of the bends the flow is slower and deposition takes place. The meanders therefore move from side to side across a valley and produce river terraces. The areas between the ends in a meandering stream may eventually be eroded away so that the bends are left as curved lakes known as oxbow lakes or billabongs.



Formation of an oxbow lake, or billabong

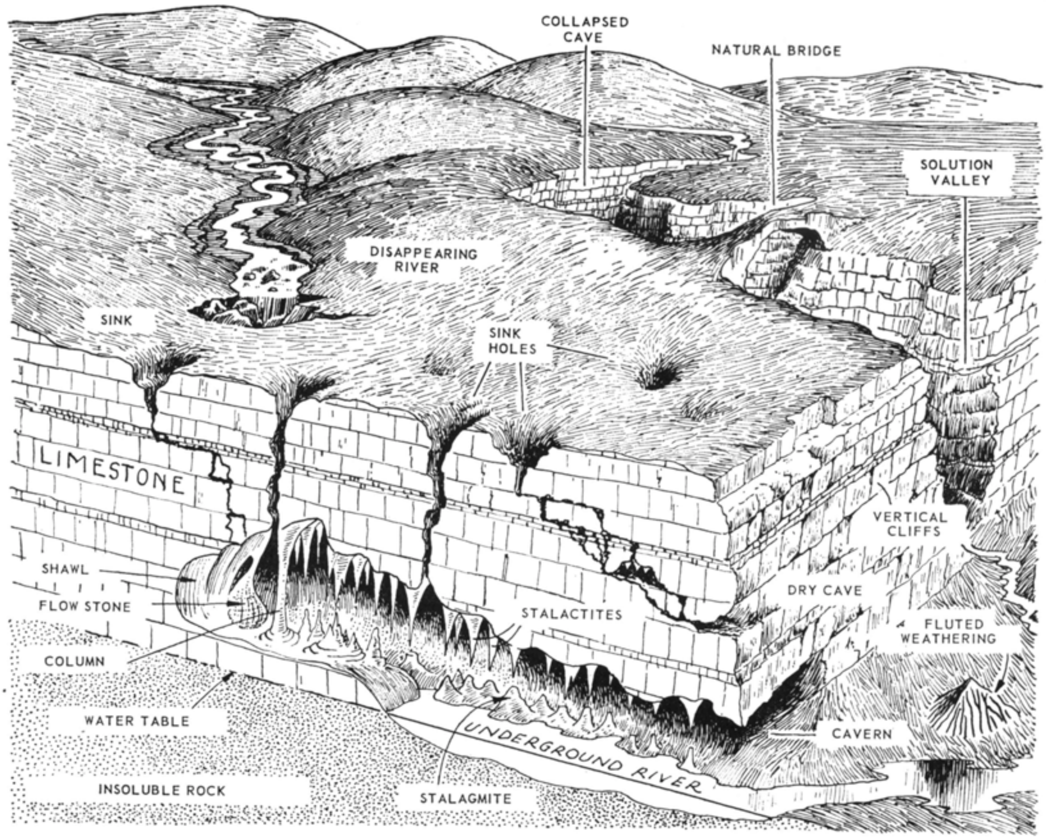


A typical river system

8.2.2.3.2 Limestone Landforms

Limestone is a sedimentary rock composed predominantly of the mineral calcite, which is calcium carbonate. It is formed primarily from the shells of marine organisms, deposited on the ocean floor.

Rainwater contains dissolved carbon dioxide—carbonic acid—that reacts with calcium carbonate to form soluble calcium hydrogen carbonate. As a result, exposed surfaces of limestone become rounded and fluted by the weathering action of rainwater.



Limestone landforms

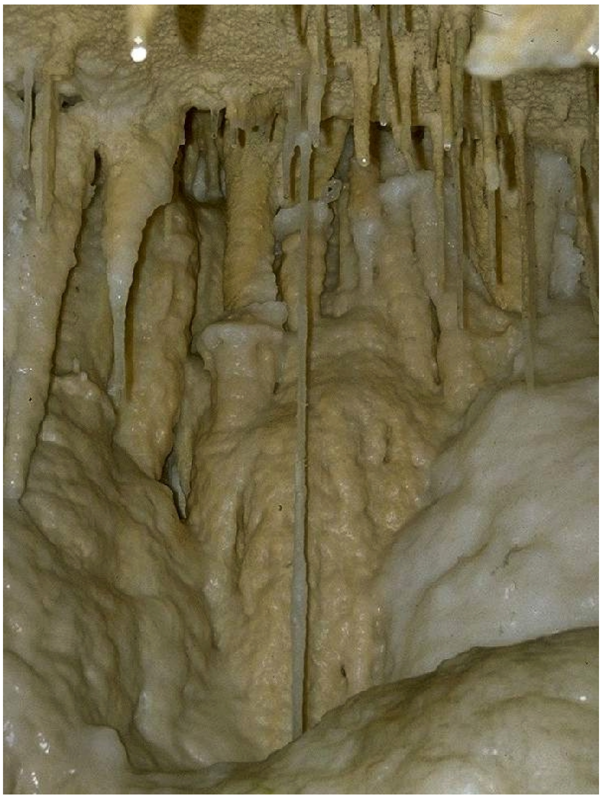
Limestone formations, or karst[4] landforms, are usually overlaid with a pattern of joints, allowing water to easily penetrate the rock. With steady weathering, this process can ultimately lead to the formation of underground caverns or caves. As these caves increase in size (with on-going weathering and erosion), the roof may collapse to form a **sink-hole**.

As water continues to seep down through the rock (dissolving calcite as calcium hydrogen carbonate), it drips from the cave roofs. In this process, the calcium hydrogen carbonate decomposes and is redeposited as calcite in a range of unusual structures:

Stalactites, formed when calcite is deposited from water as it drips from the roof of the cave, hang in long tapering formations;

Soda Straws are formed when a drop of water deposits a circle of calcite. This circle grows to forma thin tube. The straw in the image below is about 4-5mm in diameter and 30cm long;

[4] Named after the Kras region in Solvenia, location of some of the most extensive limestone formations in the world.



Stalactites and a Soda Straw (middle of picture), Aranui Cave, New Zealand[5]

Stalagmites are stumpy pillars that form from calcite deposited by drops of water when they fall to the floor from the stalactites above;

Columns form when stalactites and stalagmites join;

Col. Boles Formation (stalactites, stalagmites) and The Monarch (a column)
Carlsbad Caverns National Park, New Mexico, USA[6]

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5 http://www.showcaves.com/images/Big/070-919.jpg
6 NPS Photo by Peter Jones (http://www.nps.gov/cave/photos_pub_domain.htm)

Shawls grow in sheets as calcite is deposited from fine streams of water running down a wall; and

Shawls in Fern Cave, Alabama, USA[7]

Helectites are small growths of calcite that have an irregular, twisted appearance.

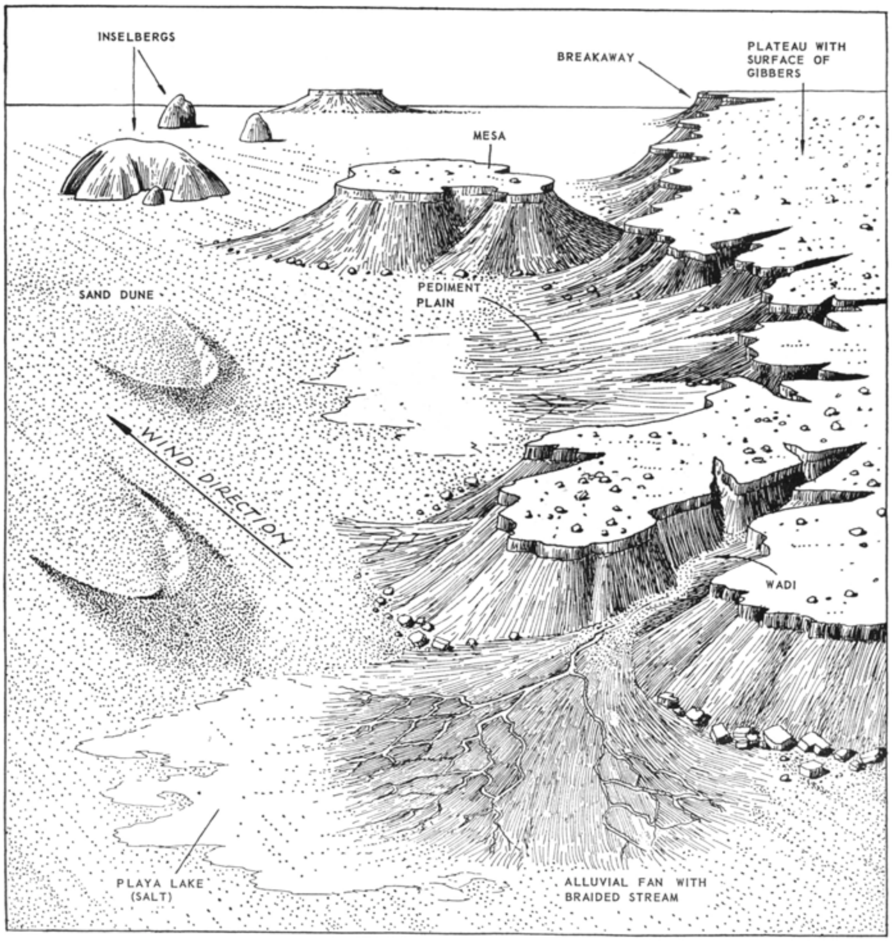
Helectite Heaven, Fern Cave, Alabama, USA[8]

8.2.2.3.3 The Work of Wind and Running Water in Arid Areas

The wind is also able to move surprisingly large quantities of soil. On occasions fine soil deposits can be seen in many parts of the South of England that have been blown all the way from North African deserts. Nonetheless, wind can move only sand and clay and leaves behind the coarse material to form stony or gibber deserts. The stream of air carrying sand near the ground also causes erosion by sand blasting, producing caves, the undercutting of rocks, and the polishing of rock surfaces.

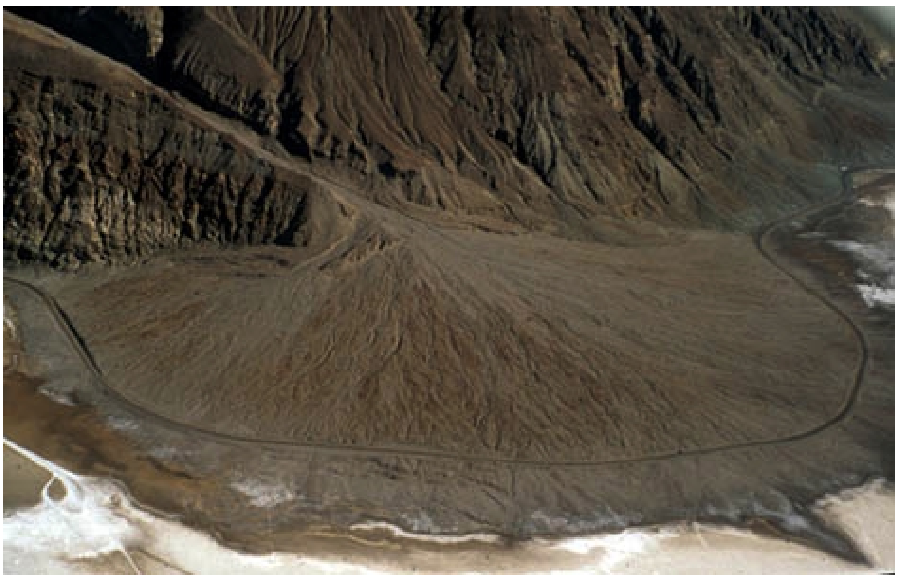
When sand is deposited by wind it forms sand dunes, which may be crescent shaped, transverse—at right angles to the direction of the wind—or longitudinal—parallel to the wind direction.

[7] http://www.spelunkologists.com/Helectiteheaven/pages/-%20(09).htm
[8] http://www.spelunkologists.com/Helectiteheaven/pages/-%20(15).htm



Desert landforms

Although rain is not frequent in arid areas, when it does occur it is usually very heavy. There is little vegetation and weathered material is easily removed from slopes. Large amounts of sediment are washed down through erosion gullies, or canyons, and deposited in flatter areas as alluvial fans.

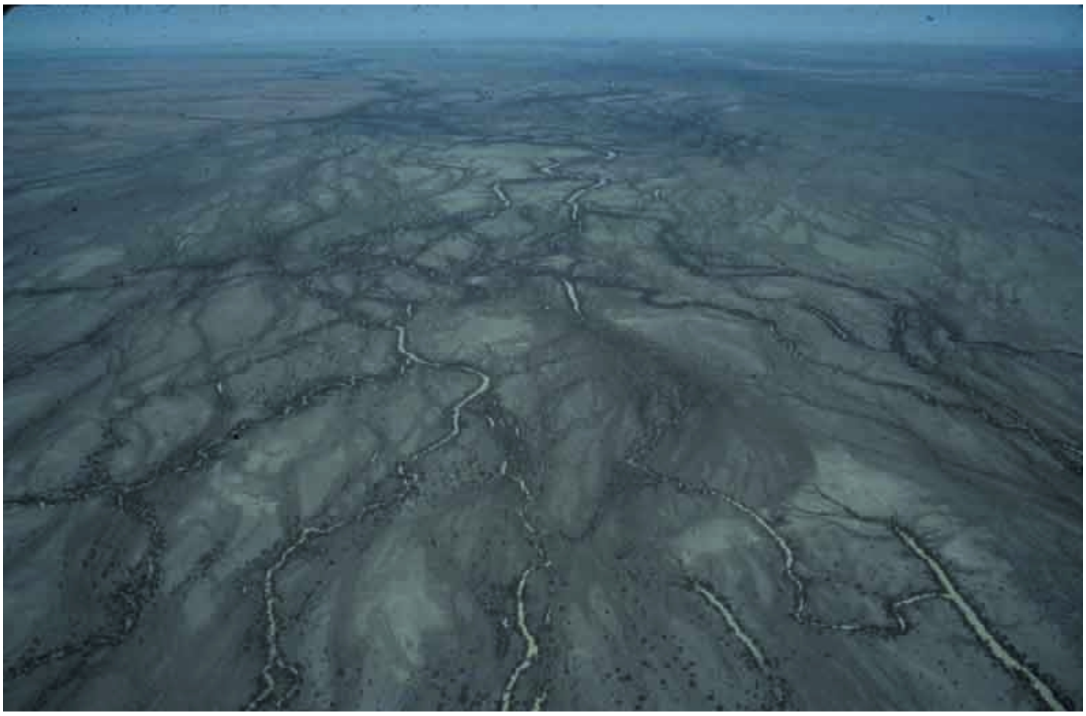


Badwater Fan (Badwater playa in foreground), Death Valley, California[9]

[9] http://geology.wr.usgs.gov/parks/deva/Badwater_fan08.jpg

Where sediment is washed out though several adjacent canyons, overlapping alluvial fans give rise to a **bajada**.

In flat areas the courses of rivers are poorly developed and many channels occur to produce braided streams.



Braided streams near Cooper Creek, in the Channel Country, Queensland

As the valleys erode into hills and plateaus, inselbergs (rounded hills), mesas and buttes (flat topped hills) are formed. Inselbergs are hard, rocky , usually isolated hills that rise abruptly out of the surrounding gently sloping or virtually level plain. Mt Olga and Ayer's Rock are examples of inselbergs.

Australia's most famous inselberg—Ayer's Rock, NT[10]

[10] http://www.terragalleria.com/pacific/australia/ayers-rock/picture.aust2508.html

Mesas are flat-topped hills—the flat top being due to a capping of hard rock—with steep, even sheer sides. The resistant capping layers protect the rock beneath them from eroding. Mesa is the Spanish word for table, and mesas are sometimes called table mountains.

A mesa overlooking the Colorado River in northern Utah[11]

Buttes also are hills with steep sides and a flat top, but are smaller than mesas and plateaus.

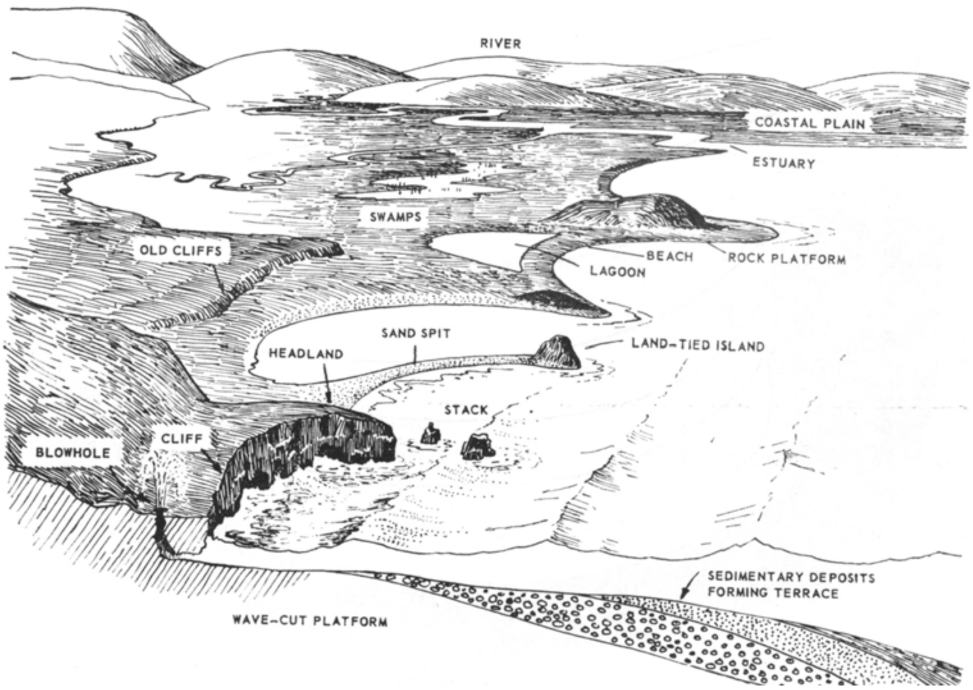
A butte—Chamber's Pillar, NT[12]

[11] http://geology.about.com/library/bl/images/blmesased.htm
[12] http://www.exploroz.com/Places/showImage.asp?id=76179_0

8.2.2.3.4 The Work of the Sea

Waves and **currents** carry sand grains derived from headlands along the coast and from the sediments brought in by rivers. In calm conditions they may deposit this sand on the shore to form a **beach**. Wind may carry the sand inland and produce **sand dunes**. In storms the waves may remove sand from a beach and leave behind the pebbles. Waves may also carry sand along a beach and deposit it in protected places, forming **sand spits**. Where this blocks off a bay a **lagoon** is produced, and where it links an island to the mainland a **tied island** results.

When waves pound a mass of resistant rock, **cliffs** are formed via the undercutting of the base of the rock. A flat area often remains at the base of the cliff as a **rock platform**. Caves and **blowholes** may be produced in weaker areas of cliffs.



Coastal topography

Sea arch, Great Ocean Road, Victoria

London Arch (formerly London Bridge), Great Ocean Road, Victoria

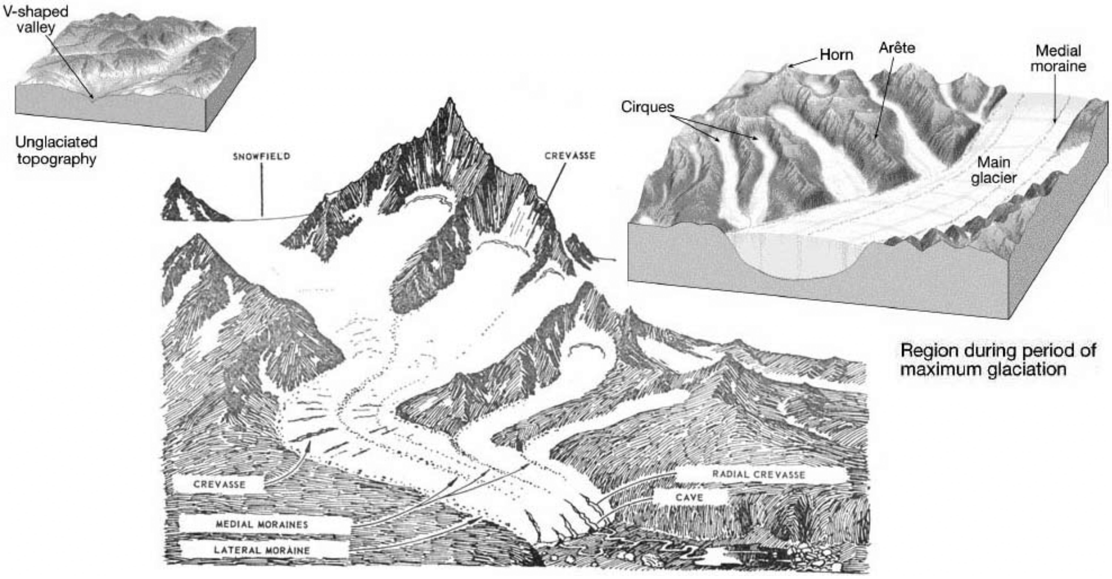
Refraction of waves around a headland causes faster erosion at the sides than the end and produces **stacks**.

(Some of) The Twelve Apostles, Great Ocean Road, Victoria

8.2.2.3.5 The Work of Snow and Ice

Above the **snow line**, where snow never completely melts, ice is produced by compaction of deep layers of snow to form **continental ice caps**. This ice moves down slopes under the action of gravity and from the edges of the ice cap, **glaciers** run down to the sea. As the ice melts on lower ground it leaves behind it loads of weathered rock in the form of **moraines**. The moraines may block up river channels and form lakes. When the glaciers run directly into the sea the ends may break off and form **icebergs**.

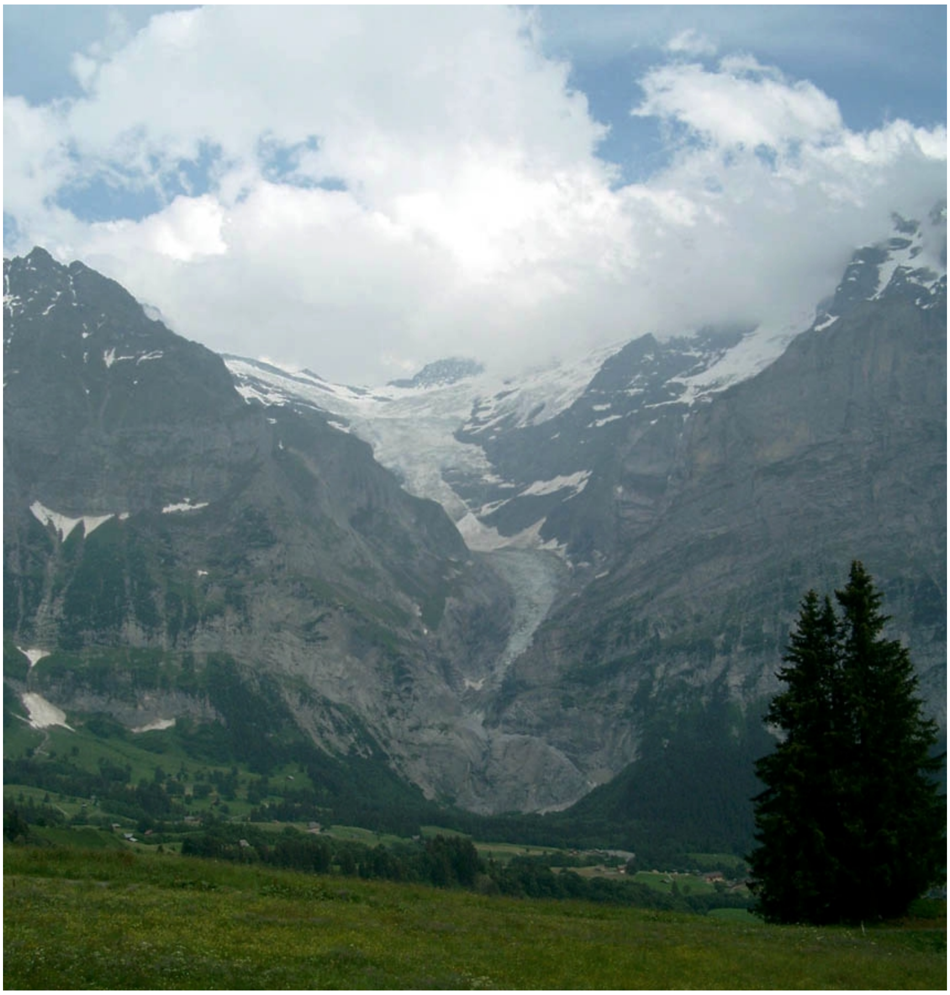
In high mountains, snow collects and is compacted into ice. This, in turn, moves down valleys, under the influence of gravity, as a river of ice known as an **alpine glacier**.



Alpine glacial landscape

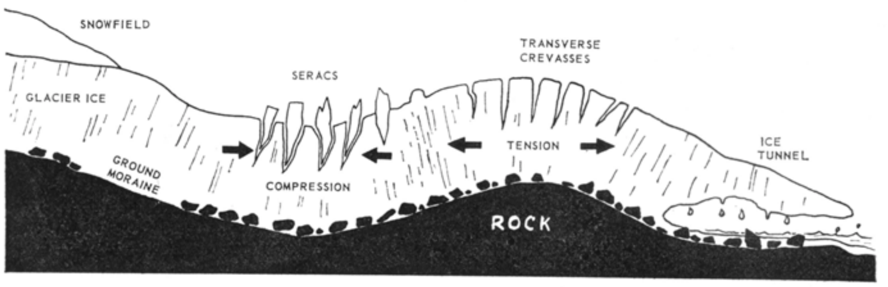
The Alestch Glacier, Switzerland, the longest glacier (23km) in the Alps[13]

[13] http://upload.wikipedia.org/wikipedia/commons/a/a1/Grosser_Alestchgletscher_3196.JPG



Upper Grindelwald Glacier, Switzerland

The speed of a glacier depends on the amount of ice that accumulates each year, and the slope of the valley. The rate is not usually more than a few centimetres a day, but some large glaciers can move as much as 25 metres in a day. As glaciers move over the valley floor, they may dip, compressing the ice and forcing great slivers of ice, known as **seracs**, to rise above the surface of the glacier. If the glacial ice flows over a rise in the valley floor, great **crevasses** can open up across its surface.

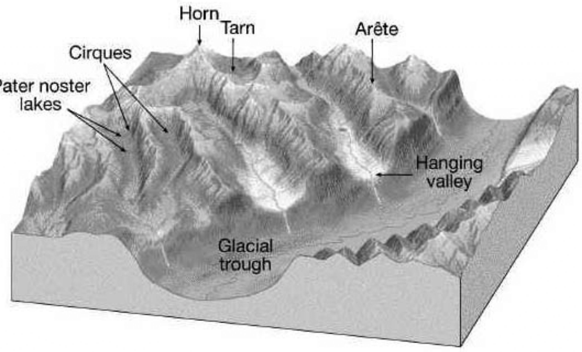


Section along a glacier

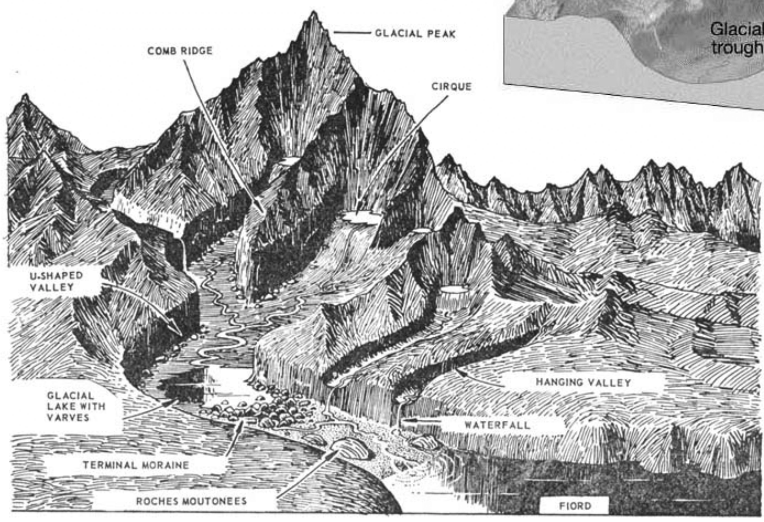
The moving ice gouges rock and soil out the walls and floor of the glacial valleys, generating glacial **till** or **drift**. Till is deposited at the end of a glacier as a **terminal moraine**, which is exposed when the glacier melts and retreats, or along the surface of the glacier as **medial** or **lateral moraines**, which often appear as dark streaks on the surface of the ice. Terminal moraines may also dam up streams to form lakes as a glacier retreats.

Seracs in Eliot Glacier, Mt Hood, Oregon, USA[14]

The head of a glacier forms an armchair shaped area or **cirque**, many of which contain a lake, known as a **tarn**. The formation of successive terminal moraines in a glacial valley, as a glacier advances and retreats, can also lead to the formation of a sting of lakes, known as **paternoster lakes**. As several glaciers eat back into a mountain, sharp peaks, **horns**, are produced and the ridges between valleys, known as **comb ridges** or **arêtes**, are cut into an almost knife-like jagged edge.



Glaciated topography



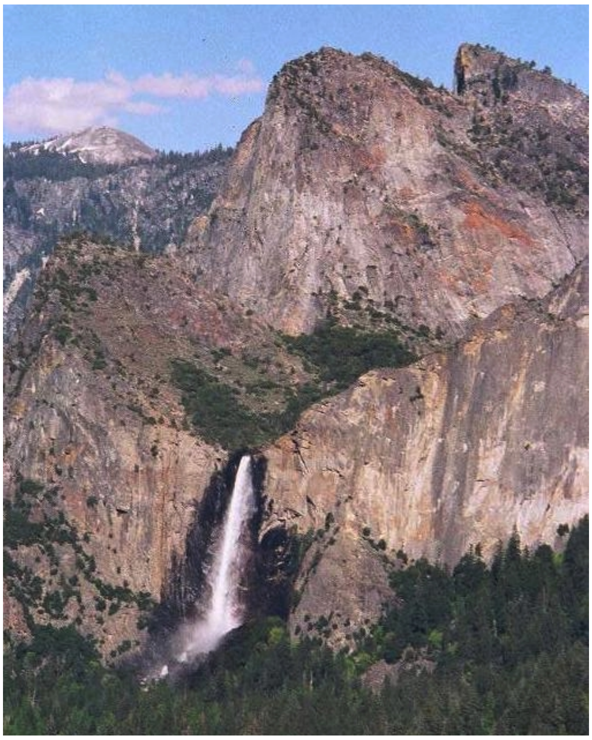
Alpine glacial landforms

[14] http://www.turns-all-year.com/goldhome4/hp187/inimage/snowdomemounthood06.jpg

Because glaciers occupy the whole width of a valley the valley tends to become U–shaped, with straight or gently curving walls.

U-Shaped Glacial Valley—Lauterbrunnen valley Switzerland

The main glaciers, being thicker, erode more quickly than tributaries so that when the ice melts the tributary streams enter the main valley high up on its sides by a **waterfall**. These tributary valleys are then called **hanging valleys**.



A Hanging Valley—Bridalveil Fall, Yosemite National Park, USA[15]

[15] http://en.wikipedia.org/wiki/Valley—Image by Daniel Mayer, May 2002

8.2.2.4 Changing Loose Sediments into Rocks

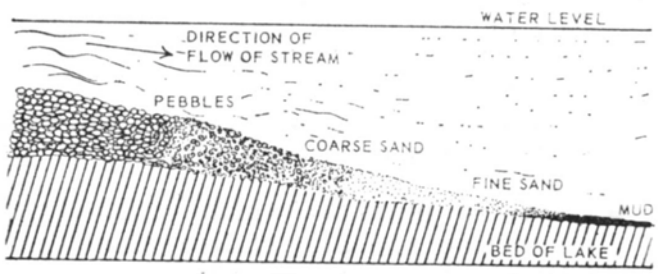
8.2.2.4.1 The Transport and Deposition of Sediments

Loose sediments are formed by the action of weathering on pre-existing rocks. These products include:

- Fragments of broken rock
- Mineral grains;
- Small particles formed by chemical weathering;
- Soluble substances.

As we have seen, the products of weathering are carried away by the wind, and by glaciers, streams and the ocean.

In water the larger particles, rock fragments and mineral grains are carried along the beds streams. The small particles are carried in suspension in the water, and the soluble substances are carried in solution. Fast moving streams can carry large particles, pebbles and coarse sand, slower ones cannot. When the velocity of a stream of water (or air) is reduced, some of the load of sediment is dropped or deposited. Since the larger particles, *e.g.* pebbles, are dropped first, they are separated from the smaller particles, sand and mud. Thus sediments are often well sorted, with pebbles, then sand and finally mud being deposited as the velocity of a stream is progressively reduced. These sediments accumulate in layers on the beds of streams, lakes and the sea.



Variation in the grain size of sediment in a lake due to the retardation of stream inflow as it enters deeper water

As more and more sediment is laid down, usually on the beds of lakes, seas and the coastal waters of the oceans, water contained in the lower layers of sediment is squeezed out. This process of **compaction** causes the layers of sediment to harden. Soluble material may also crystallise out of the water within the sediment, filling spaces like a **cement** for the fragments. Rocks formed in this way are **fragmental**, or **clastic**, consisting of grains, or *clasts*, cemented together.

Two other forms of deposition ultimately lead to the formation of sedimentary rocks:

- The collection of the remains of living organisms, typically shells on the ocean floor or dead plant material in moist or swampy environments; and
- The precipitation of dissolved salts from water as it evaporates from inland bodies of water.

8.2.2.4.2 The Minerals of Sedimentary Rocks

The main minerals of sedimentary rocks are:

Quartz hard and lacks cleavage;

Clay Minerals a class of minerals defined more by physical characteristics—soft, earthy and sticky when wet—than by chemical composition;

Calcite calcium carbonate—soft, with three directions of cleavage; and

Iron Oxides haematite with a red streak, and limonite with a yellowish-brown streak.

8.2.2.4.3 Types of Sedimentary Rocks[16]

Sedimentary rocks are generally classified as one of three types: **clastic**, **biological** or **chemical**.

Clastic

All of the fragmental sedimentary rocks consist of pieces of broken rock or mineral grains (*clasts*) cemented together. Different types differ only in the size of the grains:

Conglomerate—here many of the grains are large and consist mainly of broken rock fragments or pebbles. Conglomerates are not very well sorted;

Sandstone—the particles are mainly mineral grains usually well sorted according to size;

Shale—the particles are very small (silt) and the bedding is very thin.

Biological

Biological or organic sedimentary rocks are produced by the action of living organisms. The most common examples are:

Shelley and **coral limestone**—mainly **calcium carbonate** (the mineral **calcite**) derived from the shells of animals that live in the sea. These animals extract soluble minerals—mainly calcium salts—from the sea water and use them to make their shells. When the animals die, their shells are deposited on the ocean floor;

Coal—produced by the accumulation of dead plant material in moist environments.

Chemical

Members of the third group of sedimentary rocks are formed via **chemical sedimentation** (*e.g.* **hematite**), which occurs, usually in terrestrial or land locked basins where concentration can be effected, when various salts are precipitated from solution.

8.2.2.4.4 Conditions of Deposition

Since pebbles can be carried only by fast flowing streams, the presence of a bed of conglomerate indicates that fast flowing streams were present at the time of deposition, or that periodic flooding has taken place.

Shales are laid down under conditions of low energy and indicate the presence of slowly moving or still water.

Since corals occur today in shallow tropical seas, applying the Uniformitarian Principle to the observed presence of a coral limestone suggests that similar conditions must have prevailed when it was laid down.

Coal indicates the earlier presence of swampy conditions and a humid sub-tropical climate.

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[16] http:/geology.wr.usgs.gov/parks/rxmin/rock2.html

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- Sea arch, Great Ocean Road, Victoria
- London Arch (formerly London Bridge), Great Ocean Road, Victoria
- (Some of) The Twelve Apostles, Great Ocean Road, Victoria

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- Alestch Glacier, Switzerland
- Upper Grindelwald Glacier, Switzerland
- U-Shaped Glacial Valley—Lauterbrunnen valley Switzerland