

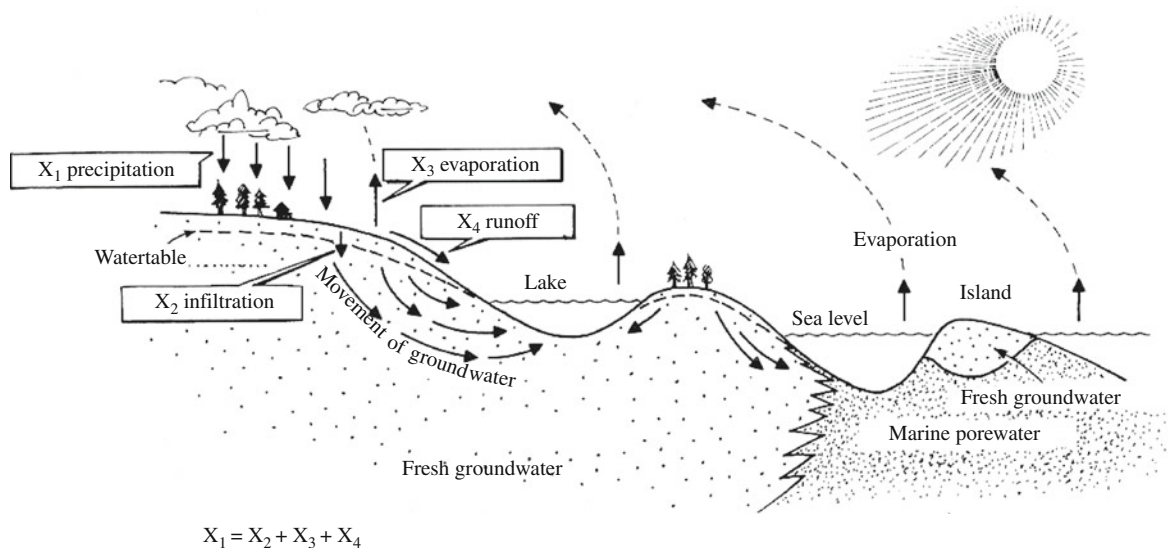


Fig. 2.26 Diagram showing the circulation of groundwater on land and under marine basins

Runoff is the fraction of precipitation which reaches the rivers. The percentage of precipitation which filters down to and recharges the groundwater is of particular importance. Rivers also have groundwater added to them if their surface is below the water table. If their surface is above the water table they will lose water. In consequence, rivers cannot be considered in isolation from groundwater reserves.

Infiltration of surface water into the ground depends on the permeability of the soil cover and on the vegetation. Clayey sediments allow far slower infiltration of surface water than sand or gravel. Where there are soil types with swelling clay (smectite group), which are very common in desert areas, the first rains will cause these minerals to swell, further reducing their permeability. Consequently, infiltration is reduced, and the runoff which creates floods increases. If the earth is dry above groundwater level, water has to overcome the capillary forces which act against water percolating down through dry, fine-grained sediments. We may find a layer with air in the pores between the groundwater table and the water filtering down from above (trapped air).

Alluvial fans are porous and have a relatively good potential as water reservoirs, and we often find springs at the foot of fans. In dry areas the depth to the water table can be most simply charted through seismic recordings.

Because freshwater is lighter than saltwater, it will flow over saline porewater and form pockets of freshwater under islands. Freshwater may also flow from the continents, following permeable beds beneath the continental shelf. Freshwater of high quality (little pollution) is scarce in many regions, and in recent years in particular a large number of geologists have been involved in mapping groundwater reserves.

2.25 Desert

Deserts are areas with little or no vegetation and we can distinguish between different types of desert:

1. Deserts due to low precipitation and high evaporation in hot climates.
2. Deserts due to low precipitation in cold climates.
3. Deserts due to soil erosion.

The first two types of desert are largely governed by meteorological factors. Areas which lie on the lee-side of major mountains will be dry. At about 30°N and 30°S high pressure areas predominate, resulting in low precipitation. Since the prevailing wind at these latitudes will come from the east, we find most of the deserts on the western side of mountain chains. This is true of Asia Minor, the Sahara,

California and Nevada in the northern hemisphere, and Australia, South Africa and Chile in the southern hemisphere. Inland areas surrounded by mountains tend to have a desert climate. During the glacial periods there was less evaporation and therefore less rainfall. North Africa and the Sahara were then very much drier than the present day.

Iceland has good examples of desert regions which are due to a cold climate, and has problems with soil erosion due to lack of vegetation in many areas.

Shortly after the withdrawal of the ice across Scandinavia there was a desert with considerable aeolian deposits, which formed before the vegetation cover developed. Loess deposits are fine-grained sediments which form largely through aeolian erosion and transport from deserts and also from glacial sediments exposed after glacial retreat. Large areas of China, for example west of Beijing, are covered by up to several hundred metres of Quaternary loess.

The lack of vegetation naturally means that aeolian transport and deposition are important in deserts, but only a relatively small part of the desert areas are covered by wind-blown sand.

Large areas consist of bare rocks and mountains with little sediment. In other regions there is only wind erosion (deflation), which leaves the ground covered (*armoured*) by a layer of stones which protect it from further erosion. Even in desert regions like the Sahara many areas are dominated by a fluvial drainage pattern. Although several years may pass between rains in this area, a heavy rainstorm may transport so much sediment that the fluvial drainage pattern survives for many years.

Large expanses of wind-blown sand are called *ergs*. They may be formed by the coalescence of different aeolian bedforms. *Barchans* are crescent-shaped isolated aeolian dunes with a convex erosion side and a concave lee side (Fig. 2.27). Barchans are found

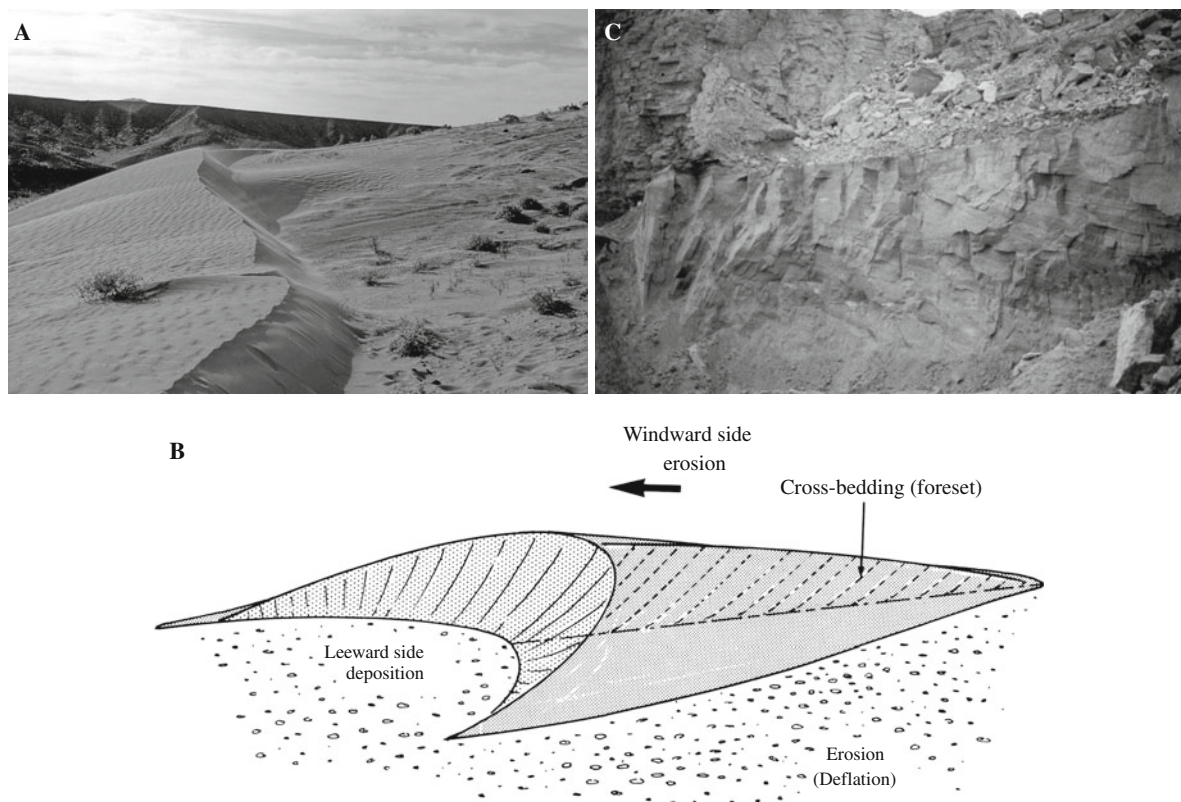


Fig. 2.27 (a) Aeolian dune from the desert in Death Valley, California. (b) Schematic representation of a barchan. (c) Aeolian cross-bedding 4–5 m high in the Permian

“Yellow Sand” of northeast England (Old Quarrington Quarry, Durham). This sand is equivalent to the “Rothliegendes” sandstone of the North Sea

mainly on the edges of the erg area, where there is not enough sand to form a continuous thick cover. Transverse dunes are common within ergs. *Seif dunes* are long, straight sand dunes which may occur within an erg but are also found in areas with incomplete sand cover. In the central zones very large dunes form which may be over 100 m high and 1 km long.

Ancient aeolian deposits are recognised by:

1. Their large-scale cross-bedding, up to 20–30 m and often with wind ripple marks on top of slanting cross-bedded surfaces (foreset beds).
2. High degree of oxidation which gives a red colour.
3. Good sorting – largely medium- to fine-grained sand.
4. Lack of fossils or organic material.

The lack of thin silt or clay beds between the cross-bedded layers, and the general association with overlying and underlying sediments, are also important criteria. One of the best-known examples of an aeolian sandstone is the Navajo Sandstone (Jurassic) in the Rocky Mountains. In Northern Europe there are aeolian sandstones in the Lower Permian (Rotliegendes) and the equivalent Yellow Sand in Eastern England (Fig. 2.27).

In pre-Devonian times all continental environments were deserts in the sense that they lacked vegetation. Also in these rocks, however, we can distinguish between dry and wet climates, largely from the nature of the fluvial or aeolian deposits.

Sand dunes are always moving and may end up in the sea, still partly preserving an aeolian sorting and grain-size distribution.

2.26 Lacustrine Deposits

How Are Lakes Formed?

In principle we have three types of lake:

1. Lakes of glacial origin:
 - (a) lakes formed through glacial erosion,
 - (b) lakes formed through damming by moraines or by the glaciers themselves.
2. Lakes of tectonic origin:
 - (a) lakes formed in areas of rapid tectonic subsidence (rifting) or more uniform subsidence,

- (b) lakes formed as a result of damming by horsts which have been elevated through faulting, or damming by lava etc.

3. Lakes formed by sedimentary processes, e.g. *oxbow lakes* in fluvial environments, and delta top lakes.

Lakes of glacial origin will have a relatively short lifetime by geological standards. In 10,000–100,000 years most of the lakes in Scandinavia and North America will have filled up with sediment, if we do not have another glaciation.

Lakes of tectonic origin, however, will continue to subside. If the rate of subsidence keeps pace with the rate of sedimentation, a lake will continue to exist.

Extensive carbonate beds (freshwater carbonates) and diatom deposits are also common in lacustrine basins. Some of the largest lakes formed by rifting are found in East Africa, where a number of lakes occur in the actual rift valley system. Lake Victoria, which lies between two rift valley systems, was formed by tectonic movements about 100,000 years ago.

In humid climates all lakes will have outlets in the form of rivers or via the groundwater, but in arid climates lakes develop into evaporite basins without outlets. Normal, non-saline lakes differ from ocean basins in several ways:

1. Low salinity leads to slower flocculation of clay particles than in marine basins, producing more distinct lamination.
2. Low wave and tidal energy and weaker currents mean less erosion and resedimentation. Seasonal variation in the influx of sediments may produce annual cycles in lacustrine sediments.
3. Limited water circulation makes it easier for the water to develop layering based on temperature (thermocline) and therefore also density (pycnocline) between dense layers at the bottom and less dense water near the surface. This may restrict oxidation of organic material and promote the development of organic-rich sediments (source rocks) in the deeper parts of the lakes. In warm climates the temperatures of the lake waters are always above 4°C which makes the water stratification rather stable. In colder climates the water column will be inverted when the temperatures falls to 4°C which is the highest density. This results in an oxygen supply to the lake bottom.

4. River water will generally have approximately the same density as lake water, and will therefore mix well and deposit sediments rapidly. Cold (glacial) river water or river water with a lot of suspended material will be heavier than lake water, however, and will form turbidity currents along the bottom.
5. Lake sediments have a distinctly different fauna from marine basins. The geochemistry of lake sediments and the composition of carbonates and evaporites are also different from those of marine sediments.

By comparison with marine deltas, lacustrine deltas are among the most constructive of all (e.g. the Gilbert Delta) because erosion in the basin is so limited. Nevertheless, wind conditions, the size of the lake and the composition of the sediments will be crucial factors. In large lakes we might have relatively high wave energy which could erode sediments from the river mouth and deposit them laterally on beaches.

Wind will also cause water to well up from the bottom, increasing the circulation of oxygen along the bottom.

In dry regions we may get evaporitic lakes and lakes which dry up after each flood (*ephemeral lakes*).

Lake deposits are characterised by:

1. Lack of marine fossils, but diatoms and algae may be important components.
2. Very fine laminations in clay and silt sediments.
3. Bioturbation structures may be found in lacustrine sediments, but they are less common than in marine sediments.
4. Chemical analyses of freshwater sediments will reveal low concentrations of the trace elements which are enriched in seawater (e.g. Cl, Br and B). Minerals formed in freshwater lakes may have characteristic isotopic compositions. Evaporites in lakes consist mainly of carbonate minerals; sulphates and chlorides are normally less common.
5. The content of sulphur-bearing authigenic minerals must be relatively low since there is little sulphate in freshwater. However, organic material in lakes contains a fair amount of sulphur which can be precipitated as sulphides by sulphate-reducing bacteria. Sulphur may also be derived from volcanic sources.
6. Lack of tidal structures and similar marine structures is also an important indicator.

Amongst the most important ancient lacustrine deposits are the Karoo deposits of South and East Africa, from the Carboniferous to the Jurassic periods. These sediments contain important coal deposits. In eastern China there are large areas of Cretaceous and Tertiary lacustrine sediments, which are also important petroleum-bearing sediments.

The Green River Formation (Eocene) of Colorado, Wyoming and Utah, is a lacustrine sediment of great extent which represents one of the most important petroleum source rocks in the world.

Rifting associated with the opening of the Atlantic Ocean in Mesozoic times resulted in a large number of lacustrine basins, and sediments deposited in such basins now underlie the continental shelves. In dry regions these turned into evaporite basins.

2.27 River Deposits

Transport of sediments in rivers depends on the gradient and cross-section of the river, which determine the flow rate, and on the composition and concentration of sediment. In rivers which flow only during and directly after the rains, but are otherwise dry (*ephemeral streams*), equilibrium between flow and sediment load is not achieved, so that even fine-grained sediment is deposited in the channel when it dries up, leaving a mud-cracked surface. Intensive oxidation of sediments, including silt and clay beds, is typical of such fluvial deposits. There is little organic production in areas with a dry climate, and clay and silt particles will therefore contain little organic material which could act as a reducing agent. A low water table during dry periods also contributes to oxidation of organic matter.

Most rivers have marked seasonal and annual flow variations. The flow velocity increases appreciably with flow volume because the friction per unit volume of water is inversely proportional to the water depth. When water flow is greater than the capacity of the channel, the water flows out over the banks. The water outside the channel will normally be very shallow and have a low flow velocity and fine-grained sediments, which have been transported in suspension, are then deposited as what we call *overbank sediments*. Overbank sediment may build up into elevated banks called *levees*. The resulting soil along modern rivers