Chapter 1 The Earth and the Universe

Exploring the Universe

On a fine bright night when you look up at the sky, it seems to be studded with stars. Little do you realise that each of the stars is far bigger than the earth on which we live. Some of the larger ones have been estimated to be many millions of times the size of the earth. These stars are not scattered regularly in space: they occur in clusters, better described as *galaxies* or *nebulas*. Each galaxy may contain as many as 100 million stars. It is believed that the earth's own galaxy (the *Milky Way*) alone contains as many as 100,000 million stars.

The stars appear small to us even through a telescope because they are so far away. The light from the nearest star travelling at the speed of light (i.e. 186,000 miles per second) takes something like four years to reach us. A ray of light from the sun takes about eight minutes to reach the earth. Light takes only a second to reach us from the moon.

The Solar System

The solar system comprises the Sun and its nine planets (Fig. 1.) which are believed to have been developed from the condensation of gases and other lesser bodies. All the planets revolve round the Sun in *elliptical orbits*. Like the earth, they shine only by the reflected light of the sun. The Sun has a surface temperature of 6,000°C. (10,800°F.) and increases to 20 million°C. (36 million°F.) in the interior. All over its surface are fiery gases that leap up in whirls of glowing flames like a volcano in eruption. In size, the Sun is almost unimaginable. It is about 300,000 times as big as the earth!

Amongst the nine planets, Mercury is the smallest and closest to the sun, only 36 million miles away. It thus completes its orbit in a much shorter space of time than does Earth. A year in Mercury is only 88 days. Venus, twice the distance away from the sun, is the next closest planet. It is often considered as *'Earth's twin'* because of their close proximity in size, mass (weight) and density. But no other planet is in any way comparable to Earth which has life and all the living things we see around us. Like many other planets, the Earth has a natural *satellite*, the Moon, 238,900 miles away, that revolves eastward around the Earth once in every 27 days.

The fourth planet from the sun is Mars which has dark patches on its surface and is believed by most professional astronomers to be the next planet after Earth to have the possibility of some plant life. Much attention has been focused on Mars to explore the possibilities of extending man's influence to it. Next comes Jupiter, the largest planet in the solar system. Its surface is made up of many gases like hydrogen, helium, and methane. It is distinguished from other planets by its circular light and dark bands, and the twelve satellites that circle round it. As it is more than 485 million miles from the Sun, its surface is very cold, probably about -200°F. (-130°C.).

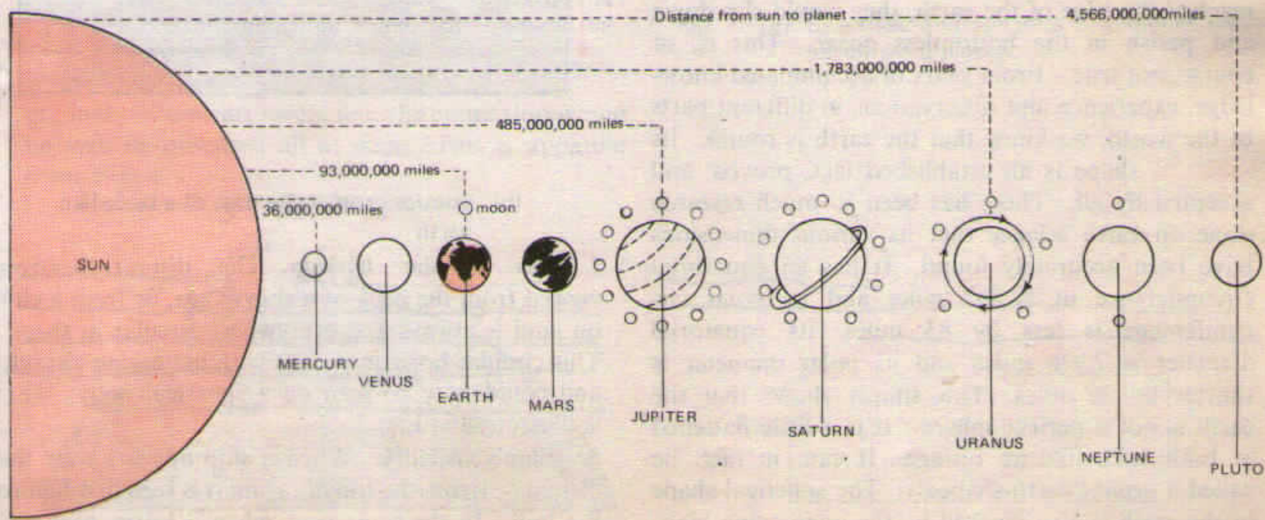


Fig. 1 The Solar System—the Sun and the nine Planets

Another unique planet is Saturn which has three rings and nine satellites around it. In size, it is the second largest after Jupiter. It is so far from the Sun that it takes $29\frac{1}{2}$ years to complete its orbit. The seventh planet, Uranus, was not known to astronomers until the late eighteenth century when it was first seen as a faint bluish-green disc through a very powerful telescope. It is another giant planet, 50 times larger than Earth and 15 times as heavy. Unlike other planets, Uranus orbits around the sun in a clockwise direction from east to west with five satellites revolving round it.

The two outermost planets in the solar system, Neptune and Pluto are just visible with telescopes. Their discoveries were the result of mathematical calculations on their irregular gravitational effects on neighbouring planetary bodies. Neptune closely resembles Uranus, except that it has only two known satellites and is probably much colder. Pluto is smaller than Earth. As the orbits of the planets are not circular but elliptical, the distance of Pluto from the Sun during *perihelion* (i.e. when it is closest to the Sun) is 2,766 million miles, and at *aphelion* (i.e. when it is farthest from the Sun) is 4,566 million miles. A year in Pluto is no less than 247 years on earth! Due to their very recent discovery and their extreme remoteness from the earth, very little is so far known about these last two planets.

The Shape of the Earth

In the olden days, sailors feared to venture far into the distant ocean because they thought the earth was as flat as a table. They thought that when they reached the edge of the earth, they would slip down and perish in the bottomless ocean. This is, of course, not true. From years of accumulated knowledge, experience and observations in different parts of the world, we know that the earth is round. Its spherical shape is an established fact, proved, and accepted by all. There has been so much research done on earth science that its various dimensions have been accurately found. It has an equatorial circumference of 24,897 miles and its polar circumference is less by 83 miles. Its equatorial diameter is 7,926 miles and its polar diameter is shorter by 26 miles. This simply shows that the earth is not a perfect sphere. It is a little flattened at both ends like an orange. It can, in fact, be called a *geoid* ('earth-shaped'). The spherical shape of the earth is also masked by the intervening highlands and oceans on its surface.

Evidence of the Earth's Sphericity

There are many ways to prove that the earth is spherical. The following are some of them.

1. Circum-navigation of the earth. The first voyage around the world by Ferdinand Magellan and his crew, from 1519 to 1522 proved beyond doubt that the earth is spherical. No traveller going round the world by land or sea has ever encountered an abrupt edge, over which he would fall. Modern air routes and ocean navigation are based on the assumption that the earth is round (Fig. 2).

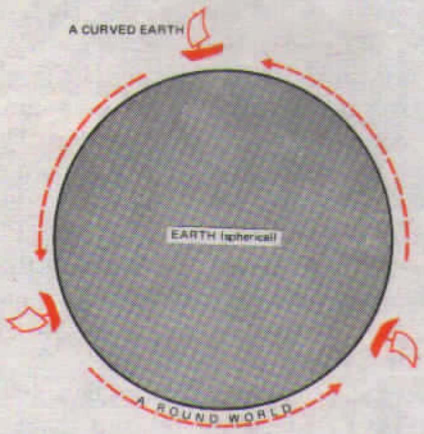


Fig. 2 (a) Circumnavigation of the earth

(b) Abrupt drop at the edge of a table-like earth

2. The circular horizon. The distant horizon viewed from the deck of a ship at sea, or from a cliff on land is always and everywhere circular in shape. This circular horizon widens with increasing altitude and could only be seen on a spherical body. This is illustrated in Fig. 3.

3. Ship's visibility. When a ship appears over the distant horizon, the top of the mast is seen first before the hull. In the same way, when it leaves harbour, its disappearance over the curved surface is equally

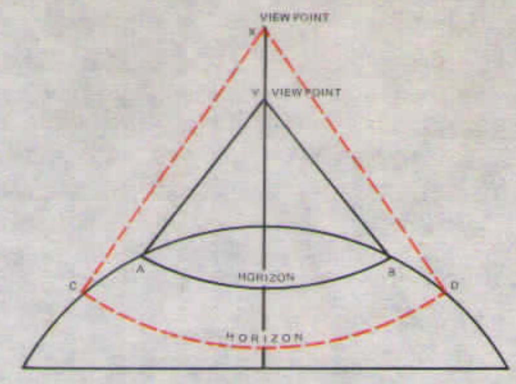
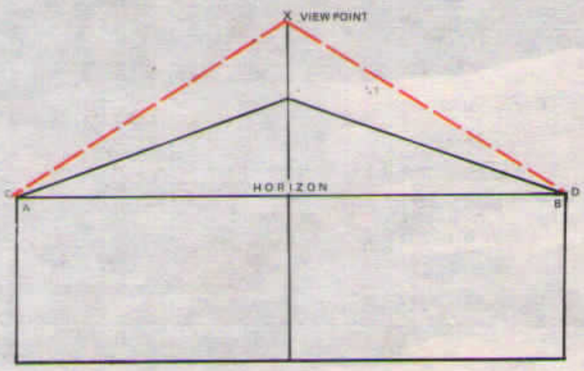


Fig. 3 (a) Increasing altitude widens the circular horizon. Viewed from Y the horizon would be AB but from a higher viewpoint (X) a wider horizon (C, D) would be seen



(b) Visible horizon remains the same regardless of altitude. If the earth were flat the horizon seen from either Y or X would be the same

gradual. If the earth were flat, the entire ship would be seen or obscured all at once. This is apparent from Fig. 4.

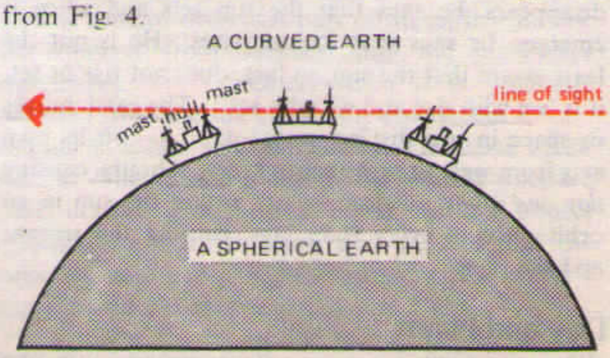


Fig. 4 (a) The mast of a ship is seen before the hull on curved horizon

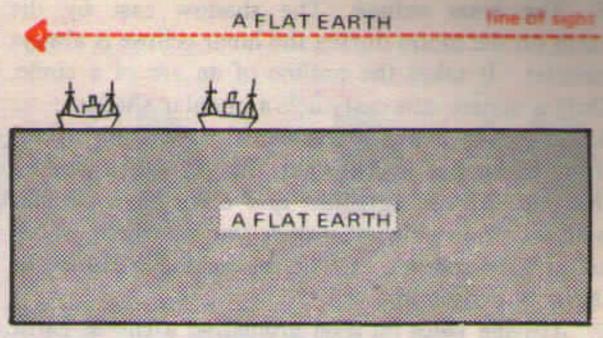


Fig. 4 (b) A flat earth, the entire ship is seen at once on a flat surface

4. Sunrise and sunset. The sun rises and sets at different times in different places. As the earth rotates from west to east, places in the east see the sun earlier than those in the west. If the earth were flat, the whole world would have sunrise and sunset at the same time. But we know this is not so. Fig. 5 illustrates this.

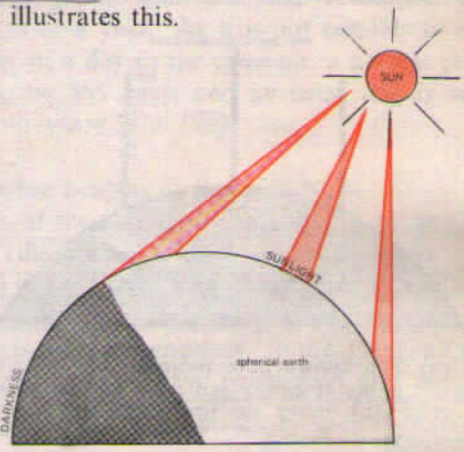
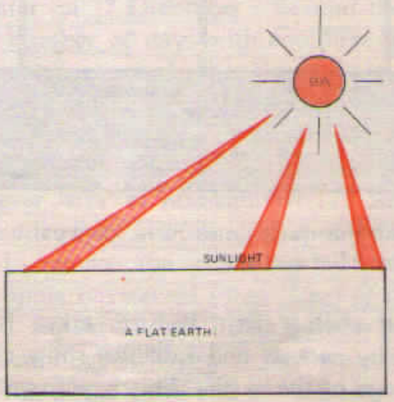


Fig. 5 (a) Sun rises and sun sets at different times for different places



(b) The whole world will have sun rise or sun set at the same time

5. The lunar eclipse. The shadow cast by the earth on the moon during the lunar eclipse is always circular. It takes the outline of an arc of a circle. Only a sphere can cast such a circular shadow.

6. Planetary bodies are spherical. All observations from telescopes reveal that the planetary bodies, the Sun, Moon, satellites and stars have circular outlines from whichever angle you see them. They are strictly spheres. Earth, by analogy, cannot be the only exception.

7. Driving poles on level ground on a curved earth. Engineers when driving poles of equal length at regular intervals on the ground have found that they do not give a perfect horizontal level. The centre pole normally projects slightly above the poles at either end because of the curvature of the earth, as illustrated in Fig. 6. Surveyors and field engineers therefore have to make certain corrections for this inevitable curvature, i.e. 8 inches to the mile.

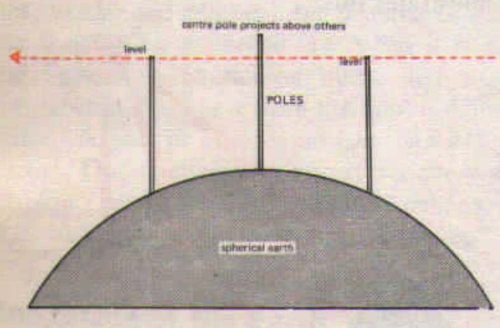
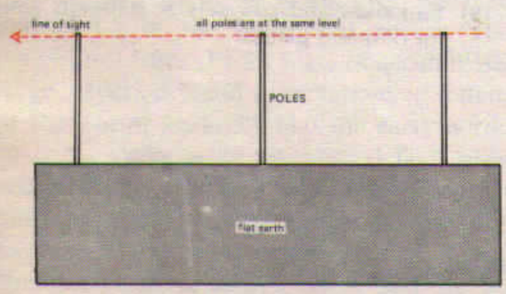
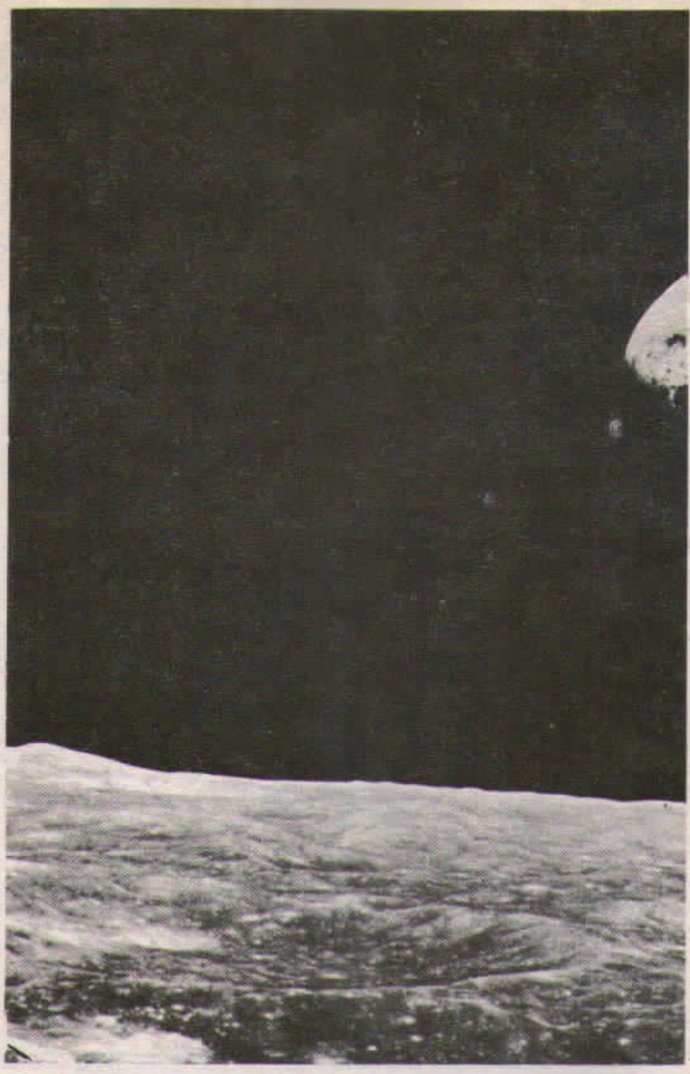


Fig. 6 (a) The centre pole projects well above the poles at either end on a curved surface



(b) All the three poles have identical heights on a flat surface

8. Aerial photographs. Pictures taken from high altitudes by rockets and satellites show clearly the curved edge of the earth. This is perhaps the most convincing and the most up-to-date proof of the earth's sphericity.



The Earth's Movement

Man is always conscious of the *'apparent movement of the sun'* and little realizes that the earth on which he stands is constantly in motion. When the sun disappears, he says that the sun sets and when it emerges, he says that the sun rises. He is not the least aware that the sun, in fact, does not rise or set, it is 'we who rise and we who set'! The earth moves in space in two distinct ways: it *rotates* on its own axis from west to east once in every 24 hours, causing *day and night*; it also *revolves* round the sun in an orbit once in every $365\frac{1}{4}$ days, causing the *seasons* and the *year*.

Day and Night

When the earth *rotates* on its own axis, only one portion of the earth's surface comes into the rays of

The earth viewed from the moon. The picture was taken on the Apollo 8 mission of 1968 which prepared the way for the moon landing *Camera Press*

the sun and experiences daylight. The other portion which is away from the sun's rays will be in darkness. As the earth rotates from west to east, every part of the earth's surface will be brought under the sun at some time or other. A part of the earth's surface that emerges from darkness into the sun's rays experiences sunrise. Later, when it is gradually obscured from the sun's beams it experiences sunset. The sun is, in fact, stationary and it is the earth which rotates. The illusion is exactly the same as when we travel in a fast-moving train. The trees and houses around us appear to move and we feel that the train is stationary. Fig. 7 explains the earth's rotation and the causes of day and night.

The Earth's Revolution

When the earth *revolves* round the sun, it spins on an elliptical orbit at a speed of 18.5 miles per second

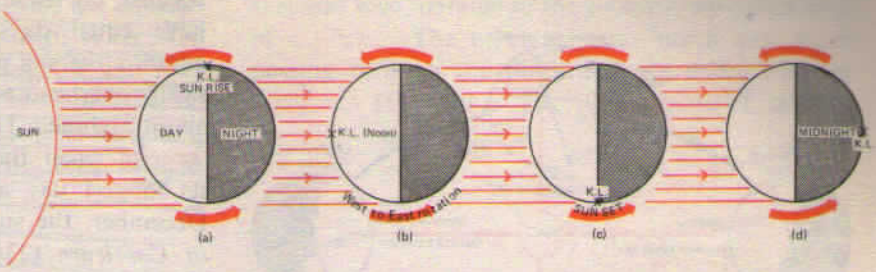


Fig. 7 (a) Kuala Lumpur emerges from darkness into daylight at sun rise when the earth rotates into the sun's rays
(b) The sun is directly overhead at Kuala Lumpur or midday
(c) Kuala Lumpur passes from daylight into darkness at sunset when the earth rotates away from the sun
(d) Kuala Lumpur is directly away from the sun at mid-night

or 66,600 m.p.h. One complete revolution takes 365¼ days or a year. As it is not possible to show a quarter of a day in the calendar, a normal year is taken to be 365 days, and an extra day is added every four years as a *Leap Year*.

1. Varying Lengths of Day and Night

The axis of the earth is *inclined* to the plane of the ecliptic (the plane in which the earth orbits round the sun) at an angle of 66½°, giving rise to different seasons and varying lengths of day and night (Fig. 8). If the axis were perpendicular to this plane, all parts of the globe would have equal days and nights at all times of the year, but we know this is not so. In the northern hemisphere in winter (December) as we go *northwards*, the hours of darkness steadily increase. At the Arctic Circle (66½°N.), the sun never 'rises' and there is darkness for the whole day in mid-winter on 22 December. Beyond the Arctic Circle the number of days with complete darkness increases, until we reach the North Pole (90°N.) when half the year will have darkness. In the summer (June) conditions are exactly reversed. Daylight increases as we go polewards. At the Arctic Circle, the sun never 'sets' at mid-summer (21 June) and there is a complete 24-hour period of continuous daylight. In summer the region north of the Arctic Circle is popularly referred to as *'Land of the Midnight Sun'*. At the North Pole, there will be six months of continuous daylight. Fig. 8(a) illustrates the revolution of the earth and its inclination to the plane of the ecliptic which cause the variation in the length of day and night at different times of the year.

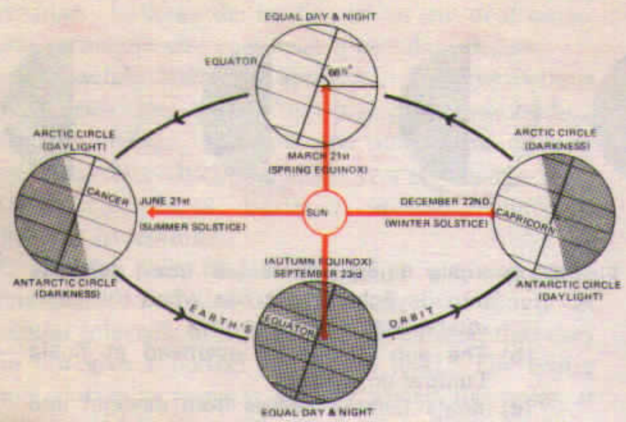
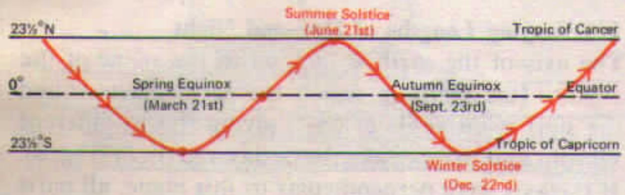


Fig. 8 (a) The revolution of the earth and its effects on seasons and the variations of lengths of day and night



(b) A simplified diagram showing the annual movement of the sun and the causes of the seasons

In the southern hemisphere, the same process takes place, except that the *conditions are reversed.* When it is summer in the northern hemisphere, the southern continents will experience winter. Mid-summer at the North Pole will be mid-winter at the South Pole.

2. The Altitude of the Midday Sun

In the course of a year, the earth's revolution round the sun with its axis inclined at 66½° to the plane of the ecliptic changes the apparent altitude of the midday sun. The sun is *vertically overhead at the equator* on two days each year. These are usually 21 March and 22 September though the date changes because a year is not exactly 365 days. These two days are termed *equinoxes* meaning 'equal nights' because on these two days all parts of the world have equal days and nights. After the March equinox the sun appears to move north and is vertically overhead at the *Tropic of Cancer* (23½°N.) on about 21 June. This is known as the *June or summer solstice,* when the northern hemisphere will have its longest day and shortest night. By about 22 December, the sun will be overhead at the *Tropic of Capricorn* (23½°S.). This is the *winter solstice* when the southern hemisphere will have its longest day and shortest night. The Tropics thus mark the limits of the overhead sun, for beyond these, the sun is *never overhead* at any time of the year. Such regions are marked by distinct seasonal changes—spring, summer, autumn and winter. Beyond the Arctic Circle (66½°N.) and the Antarctic Circle (66½°S.) where darkness lasts for 6 months and daylight is continuous for the remaining half of the year, it is always cold; for even during the short summer the sun is never high in the sky. Within the tropics, as the midday sun varies very little from its vertical position at noon daily, the four seasons are almost indistinguishable. Days and nights are almost equal all the year round Fig. 8(b).

3. Seasonal Changes and their Effects on Temperature

Summer is usually associated with much heat and brightness and winter with cold and darkness. Why should this be so? In *summer,* the sun is higher in the sky than in winter. When the sun is overhead its rays fall almost vertically on the earth, concentrating its heat on a small area; temperature therefore rises and summers are always warm. In *winter* the oblique rays of the sun, come through the atmosphere less directly and have much of their heat absorbed by atmospheric impurities and water vapour. The sun's rays fall faintly and spread over a great area. There is thus little heat, and temperatures remain low.

In addition, days are longer than nights in summer and more heat is received over the *longer daylight* duration. Nights are shorter and less heat is lost. There is a net gain in total heat received and temperature rises in summer. *Shorter days* and *longer nights* in winter account for the reverse effects.

Dawn and Twilight

The brief period between sunrise and full daylight is called dawn, and that between sunset and complete darkness is termed twilight. This is caused by the fact that during the periods of dawn and twilight the earth receives diffused or refracted light from the sun whilst it is still below the horizon. Since the sun rises and sets in a vertical path at the equator the period during which refracted light is received is short. But in temperate latitudes, the sun rises and sets in an oblique path and the period of refracted light is longer. It is much longer still at the poles, so that the winter darkness is really only twilight most of the time. (Fig. 9).

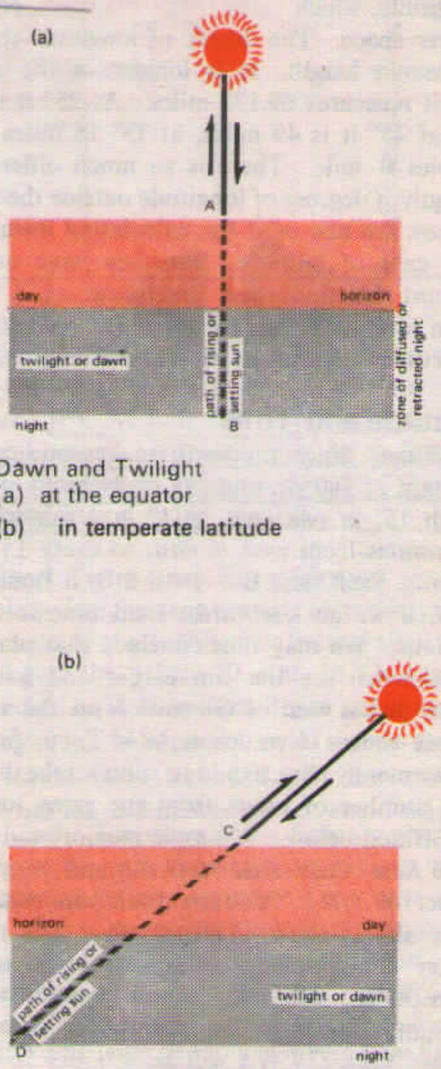


Fig. 9 Dawn and Twilight
(a) at the equator
(b) in temperate latitude

At the equator the sun rises and sets almost vertically so the time it takes to pass through the 'twilight zone' (A, B) will be shorter than for temperate latitudes where the sun rises and sets obliquely. Here the time taken to pass through the twilight zone (C, D) is longer

Mathematical Location of Places on the Globe

The earth's surface is so vast that unless a mathematical method can be used, it is impossible to locate any place on it. For this reason, imaginary lines have been drawn on the globe. One set running east and west, parallel to the equator, are called lines of latitude. The other set runs north and south passing through the poles and are called lines of longitude (Fig. 10). The intersection of latitude

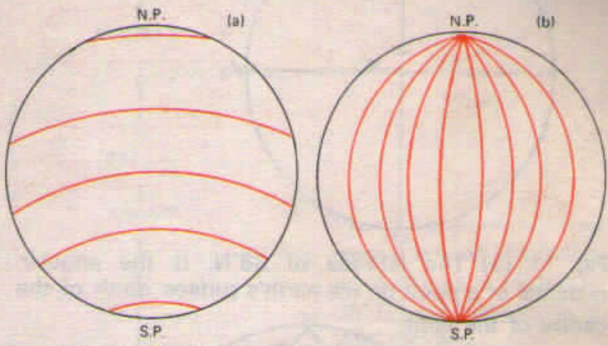


Fig. 10 (a) Parallels of latitude
(b) Meridians of longitude

and longitude pin-points any place on the earth's surface, (Fig. 11c.). For example Delhi is 28°37′ N. and 77°10′ E.; London is 51°30′ N. and 0°5′W, and Sydney is 33°55′S. and 151°12′E. We shall examine more closely how latitude and longitude are determined and the role they play in mathematical geography.

Latitude

Latitude is the angular distance of a point on the earth's surface, measured in degrees from the centre of the earth as shown in Fig. 10(a). It is parallel to a line, the *equator*, which lies midway between the poles. These lines are therefore called *parallels of latitude*, and on a globe are actually circles, becoming smaller polewards. The equator represents 0° and the North and South Poles are 90°N. and 90°S. Between these points lines of latitude are drawn at intervals of 1°. For precise location on a map, each degree is sub-divided into 60 minutes and each minute into 60 seconds. The most important lines of latitude are the equator, the Tropic of Cancer (23½°N.), the Tropic of Capricorn (23½°S.), the Arctic Circle (66½°N.) and the Antarctic Circle (66½°S.). As the earth is slightly flattened at the poles, the linear distance of a degree of latitude at the pole is a little longer than that at the equator. For example at the equator (0°) it is 68.704 miles, at 45° it is 69.054 miles and at the poles it is 69.407 miles. The average is taken as 69 miles. This is a useful figure and can be used for calculating distances to any place. Bombay is 18·55° N; it is therefore 18·55 × 69 or 1280 miles from the equator. With the aid of your atlas find the approximate distance of the following places from the equator: Singapore, Calcutta, Paris, New York, Buenos Aires, and Auckland.

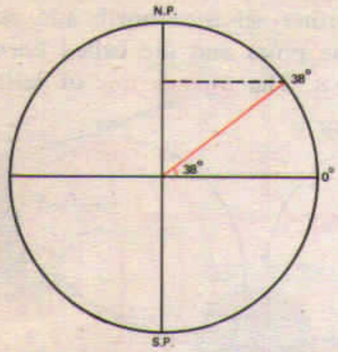
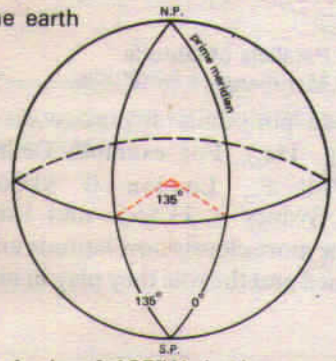
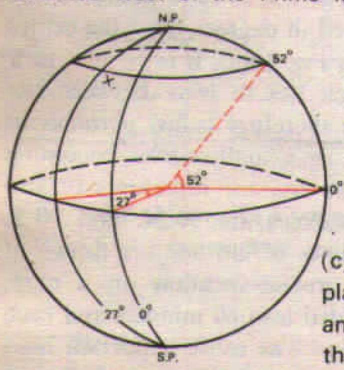


Fig. 11 (a) The latitude of 38°N. is the angular distance of a point on the earth's surface north of the centre of the earth



(b) The longitude of 135°W. is the angular distance west of the Prime Meridian



(c) The precise location of place X is latitude 52°N. and longitude 27°W. where they intersect

Longtitude

Longitude is an angular distance, measured in *degrees* along the equator east or west of the *Prime* (or First) *Meridian*, as indicated in Fig. 11(b). On the globe longitude is shown as a series of semi-circles that run from pole to pole passing through the equator. Such lines are also called meridians. Unlike the equator which is centrally placed between the poles, any meridian could have been taken to begin the numbering of longitude. It was finally decided in 1884, by international agreement, to choose as the zero meridian the one which passes through the Royal Astronomical Observatory at *Greenwich*, near London. This is the Prime Meridian (0°) from which all other meridians radiate eastwards and westwards up to 180°. Since the earth is *spherical* and has a circumference calculated at 25,000 miles, in linear distance each of the 360 degrees of longitude is 25,000÷360 or 69·1 miles. As the parallels of latitude become shorter polewards, so the meridians of longitude, which converge at the poles, enclose a narrower space. The degree of longitude therefore decreases in length. It is longest at the equator where it measures 69.172 miles. At 25° it is 62.73 miles, at 45° it is 49 miles, at 75° 18 miles and at the poles 0 mile. There is so much difference in the length of degrees of longitude outside the tropics, that they are not used for calculating distances as in the case of latitude. But they have one very important function, they determine local time in relation to G.M.T. or *Greenwich Mean Time*, which is sometimes referred to as World Time.

Longitude and Time

Local Time. Since the earth makes one complete revolution of 360° in one day or 24 hours, it passes through 15° *in one hour* or 1° in 4 minutes. The earth rotates from *west to east*, so every 15° we go *eastwards*, local time is advanced by 1 hour. Conversely, if we go *westwards*, local time is retarded by 1 hour. We may thus conclude that places east of Greenwich see the sun earlier and gain time, whereas places west of Greenwich see the sun later and lose time. If we know G.M.T., to find local time, we merely have to add or subtract the difference in the number of hours from the given longitude, as illustrated below. A simple memory aid for this will be *East–Gain–Add (E.G.A.)* and *West–Lose–Subtract (W.L.S.)*. You could coin your own rhymes for the abbreviations. Hence when it is noon, in London (Longitude 0°5W.), the local time for Madras (80°E.) will be 5 hours 20 minutes ahead of London or 5.20 p.m. But the local time for New York (74°W.) will be 4 hours 56 minutes behind London or 7.04 a.m. We can put it in another way, when Londoners are having lunch, Indians will have dinner and New Yorkers will have breakfast. (Fig. 12). This is difficult to believe, but it is true. The rotation of the earth round the sun means that at any point in time different places will experience a different time of day.

There are many ways of determining the longitude of a place. The simplest way is to compare the local time with G.M.T. by listening to B.B.C. radio.

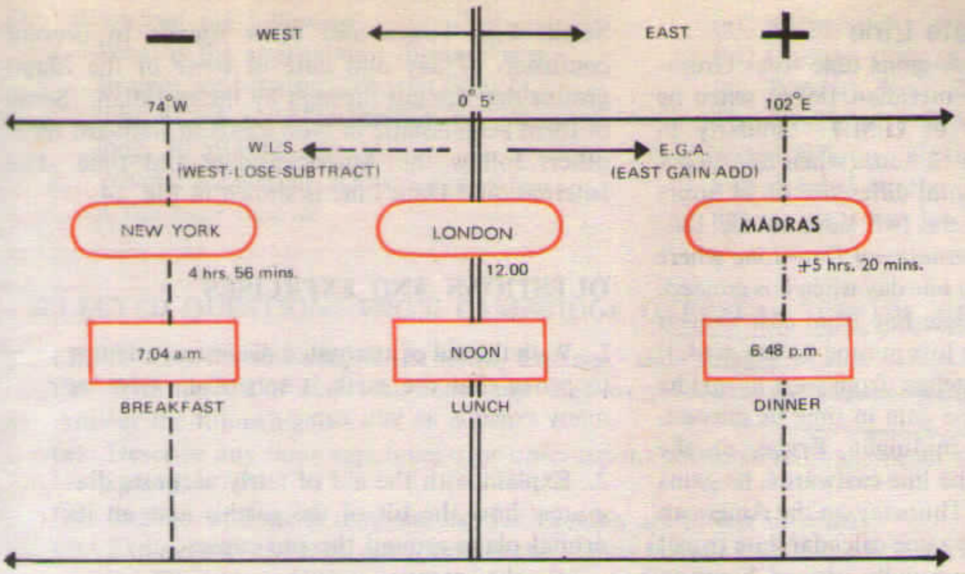


Fig. 12 Longitude and time — when it is noon in London, it is 5.20 p.m. in Madras (80° E.) and 7.04 a.m. in New York (74° W.).

For example: the captain of a ship in the midst of the ocean wants to find out in which longitude his ship lies. If G.M.T. is 8.00 a.m. and it is noon in the local region, it means that he is four hours ahead of Greenwich, and must be east of Greenwich. His longitude is 4 × 15° or 60°E.

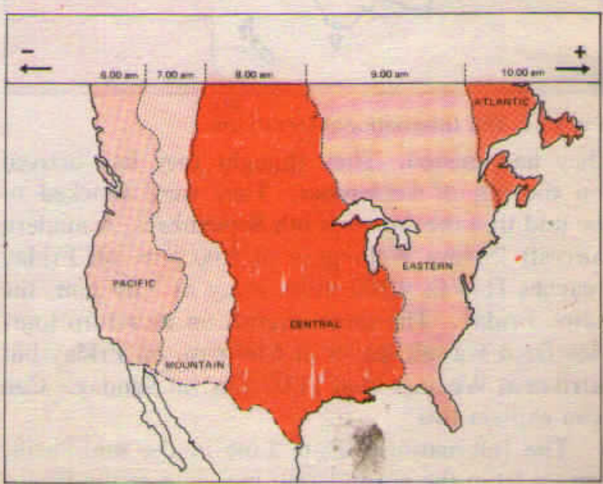
Standard Time and Time Zones

If each town were to keep the time of its own meridian, there would be much difference in local time between one town and the other. 10 a.m. in Georgetown, Penang would be 10.10 in Kota Bharu (a difference of $2\frac{1}{2}$° in longitude). In larger countries such as Canada, U.S.A., China, India and U.S.S.R. the confusion arising from the differences alone would drive the people mad. Travellers going from one end of the country to the other would have to keep changing their watches if they wanted to keep their appointments. This is impracticable and very inconvenient.

To avoid all these difficulties, a system of standard time is observed by all countries. Most countries adopt their standard time from the central meridian of their countries. The Indian Government has accepted the meridian of 82·5° east for the standard time which is 5 hrs. 30 mins. ahead of Greenwich Mean Time. The whole world has in fact been divided into 24 Standard Time Zones, each of which differs from the next by 15° in longitude or one hour in time. Most countries adhere to this division but due to the peculiar shapes and locations of some countries, reasonable deviations from the Standard Time Zones cannot be avoided (Fig. 13).

Larger countries like U.S.A., Canada and U.S.S.R. which have a great east-west stretch have to adopt several time zones for practical purposes. U.S.S.R. the largest country, which extends through almost 165° of longitude is divided into eleven time zones. When it is 10.00 p.m. on a Monday night in Leningrad, it will be almost 7.00 a.m. the following Tuesday morning in Vladivostock. Travellers along the Trans-Siberian Railway have to adjust their watches almost a dozen times before they reach their destination. Both Canada and U.S.A. have five time zones—the Atlantic, Eastern, Central, Mountain and Pacific Time Zones. The difference between the local time of the Atlantic and Pacific coasts is nearly five hours (Fig. 13).

Fig. 13 The five time zones of North America



The International Date Line

A traveller going eastwards gains time from Greenwich until he reaches the meridian 180°E. when he will be 12 hours ahead of G.M.T. Similarly in going westwards, he loses 12 hours when he reaches 180°W. There is thus a total difference of 24 hours or a whole day between the two sides of the 180° meridian. This is the *International Date Line* where the date changes by exactly one day when it is crossed. A traveller crossing the date line from *east to west loses* a day (because of the loss in time he has made); and while crossing the dateline from *west to east* he gains a day (because of the gain in time he encountered). Thus when it is midnight, Friday on the Asiatic side, by crossing the line eastwards, he gains a day; it will be midnight Thursday on the American side, i.e. he experiences the same calendar date twice! When Magellan's ship eventually arrived home in Spain in 1522 after circumnavigating the world from the Atlantic Ocean to the Pacific Ocean and westwards across the International Date Line, the crew knew nothing about adding a day for the one

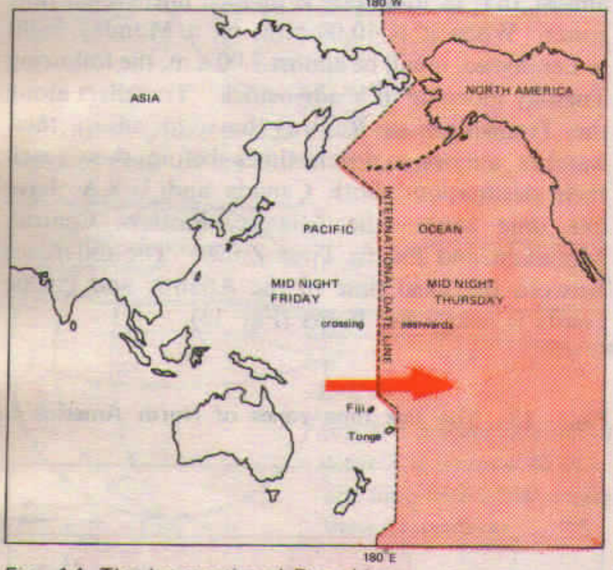


Fig. 14 The International Date Line

they had missed. They thought they had arrived on the 5th of September. They were shocked to be told that the date was 6th September. A modern aircraft leaving Wellington at 5.00 p.m. on Friday reaches Hawaii 4,100 miles away at 2.00 p.m. the same Friday. The same aircraft on its return journey from Hawaii leaves at 6.00 p.m. on Friday but arrives at We.ington at 11.00 a.m. on Sunday. Can you explain this?

The International Date Line in the mid-Pacific curves from the normal 180° meridian at the Bering Strait, Fiji, Tonga and other islands to prevent confusion of day and date in some of the island groups that are cut through by the meridian. Some of them keep Asiatic or New Zealand standard time, others follow the American date and time. The International Date Line is shown in Fig. 14.

QUESTIONS AND EXERCISES

1. With the aid of annotated diagrams, attempt to prove that the earth is spherical. Give as many reasons as you can.

2. Explain with the aid of fairly accurate diagrams, how the tilt of the earth's axis on its orbital plane around the sun causes:
   - (a) the seasons
   - (b) the variations in the length of day and night
   - (c) the altitude of the midday sun to change at different times of the year.

3. Explain the differences between any *three* of the following:
   - (a) perihelion and aphelion
   - (b) parallels of latitude and meridians of longitude
   - (c) the earth's rotation and the earth's revolution
   - (d) solstice and equinox
   - (e) Standard Time and Greenwich Mean Time

4. Explain any *three* of the following terms connected with the earth and its planetary relations:
   - i. galaxy
   - ii. Pime Meridian
   - iii. elliptical orbit
   - iv. International Date Line

5. *Either:* Give an explanatory account of the following.
   - (a) Daylight increases as we go polewards in summer in the northern hemisphere.
   - (b) The period of twilight in Britain is longer than in Malaysia.
   - (c) A ship crossing the International Date Line at midnight on Wednesday eastwards finds that it is midnight, Tuesday, on the American side.

Or: Work out the following.

i. What is the approximate distance in a straight line between Cairo (lat. 30°0 N., long. 31°5'E.) and Durban (lat. 29°57'S., long. 30°59'E.)?

ii. When it is 2.00 p.m. in Greenwich, what is the local time of

(a) Sydney (long. 151°E.)
(b) Chicago (long. 87°30'W.)
(c) Bombay (long. 73°E.)

iii. The captain of a ship observed that it was local noon. He turned on the radio and listened to the 7.00 a.m. B.B.C. news. What was his longitude?

SELECTED QUESTIONS FROM CAMBRIDGE OVERSEAS SCHOOL CERTIFICATE PAPERS

1. (a) Explain the meaning of the terms 'Equinox' and 'Solstice'.
   (b) With the aid of diagrams, show how they are related to the movements of the earth. (1967)
2. Answer the following:
   (a) Describe any *three* experiments or observations which support the belief that the earth is roughly a sphere.
   (b) Explain why mean temperatures for London are lowest in winter.
   (c) Explain why the local clock time in the Samoa Islands (171°W.) was noon on 1st November when in the Fiji Islands (178°E.), it was 11.00 a.m. on 2nd November. (1966)
3. Explain the following:
   (a) Polar air routes follow great circles.
   (b) When it is noon at Cairo (30°E.), the local time in New York (75°W.) is 5.00 a.m.
   (c) On 21st March at noon, it was observed that the shadow cast by a wall 4 ft. 8 ins. high pointed northward and was 7 in. long. The observer was able to calculate his latitude to be about 7°N. (1965)
4. Select *two* of (a), (b), (c) and draw diagrams to illustrate your answers:
   (a) i. Calculate the longitude of the position of a ship whose navigation officer observes that Greenwich Mean Time is 14.16 hours when the local time is noon.
   ii. Explain the geographical facts which enable you to make the calculation.
   (b) Explain fully why 25th December in New Zealand may be one of the hottest days of the year.
   (c) Why must a traveller, when crossing North America from New York to the west coast, alter his watch at special places.(1964)
5. With the aid of annotated diagrams, explain the following:
   (a) The apparent daily movement of the sun and its changes during the year as observed
   i. at the Equator.
   ii. at a place 50°N.
   (b) The relationship between latitude and the angle of elevation of the noonday sun.(1963)
6. Explain the effect of:
   (a) Latitude on temperature.
   (b) Latitude on the length of day and night.
   (c) *Either:* Altitude on temperature.
   Or: Longitude on time. (1961)

Chapter 2 The Earth's Crust

The Structure of the Earth

In order to understand the geography of the external landforms of the earth, it is essential that we have some idea of what lies within the earth's crust. It is not possible to know exactly how the earth was formed about 4,500 million years ago, but from the evidence of volcanic eruptions, earthquake waves, deep-mine operations and crustal borings the following facts are quite clear.

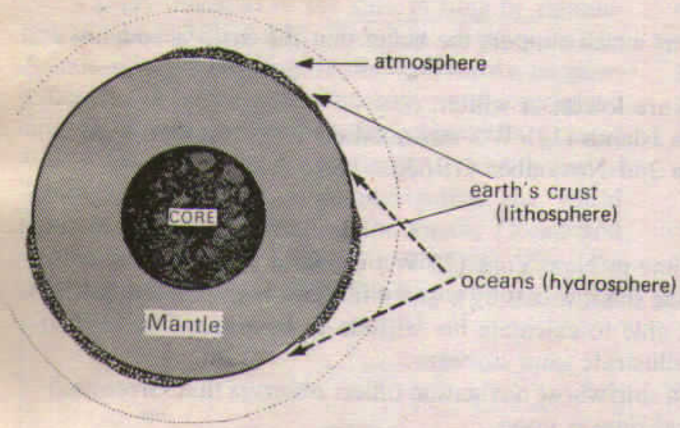


Fig. 15 A section showing the structure and composition of the earth

The earth is made up of several concentric layers (Fig. 15). The outer layer is the earth's crust—the lithosphere—which comprises two distinct parts. The upper part consists of granitic rocks and forms the continents. Its main mineral constituents are *si*lica and *al*umina so it is collectively referred to as the *sial*. It has an average density of 2.7. The lower part is a continuous zone of denser basaltic rocks forming the ocean floors, comprising mainly silica, *i*ron and *ma*gnesium. It is therefore called *sima* and has an average density of 3.0. The sial and the sima together form the earth's crust which varies in thickness from only 3–4 miles beneath the oceans to as much as 30 miles under some parts of the continents. Since the sial is lighter than the sima, the continents can be said to be 'floating' on a sea of denser sima. This is illustrated in Fig. 16.

Immediately beneath the crust or lithosphere is the mantle (or *mesosphere*) about 1,800 miles thick, composed mainly of very dense rocks rich in *olivine*. The interior layer is the *core*, (or *barysphere*) 2,160 miles in radius, and is made up mainly of iron (*Fe*) with some *nickel* and is called *nife*. The temperature

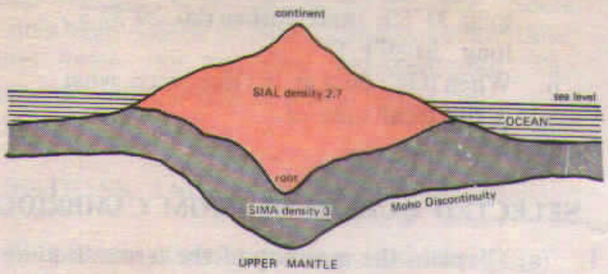


Fig. 16 A section showing how the continent (SIAL) floats on the denser SIMA

here is estimated to be as high as 3,500°F., and the core is subject to extremely high pressure. Under such conditions, the core could be expected to be in a liquid state. But recent studies through earthquake waves have suggested that the innermost part of the core is probably a crystalline or solid mass.

Parts of the earth's crust are immersed by oceans and seas. These form the hydrosphere. Extending skywards for over fifteen miles, the earth is enveloped by a mass of gases which make up the atmosphere.

The Classification of Rocks

The earth's crust is made up of various types of rocks, differing from one another in texture, structure, colour, permeability, mode of occurrence and degree of resistance to denudation. A knowledge of these rocks is of paramount importance to geologists, who study the composition and physical history of the earth, but the geographer, too, needs a basic knowledge of the most common rocks and their relationship with landforms. Rocks also form the basis for soil, and determine to some extent the type of natural vegetation and land use, so we must have a fair acquaintance with the rocks around us.

Generally speaking, all rocks may be classified into *three* major groups—*igneous, sedimentary and metamorphic*, according to their origin and appearance.

Igneous Rocks

Igneous rocks are formed by the cooling and solidification of molten rock (magma) from beneath the earth's crust. They are normally crystalline in structure. They do not occur in strata (layers) nor do they contain fossils. Igneous rocks may be sub-divided on the basis of mineral composition. When they contain a high proportion of silica they are said to be acid. Acid igneous rocks, such as granite, are less dense and are lighter in colour than basic rocks. These contain a greater proportion of basic oxides, e.g. of iron, aluminium or magnesium, and are thus denser and darker in colour.

In terms of origin there are *two* main classes of igneous rocks.

1. Plutonic rocks. These are igneous rocks, formed at some depth in the earth's crust. They have cooled and solidified slowly so that large, easily-recognized crystals have been able to form. These intrusive rocks, such as granite, diorite and gabbro, are exposed at the surface by the processes of denudation and erosion.

2. Volcanic rocks. These are molten rocks poured out of volcanoes as lavas. They *solidify rapidly* on the earth's surface and the crystals are small.

Basalt is a common volcanic or extrusive rock and forms lava flows, lava sheets and lava plateaux, e.g. those of Antrim in Northern Ireland, the Deccan Plateau in India and the Columbia-Snake Plateau in U.S.A. Some kinds of basalt solidify in a very peculiar manner to form long *polygonal columns*. A well-known example is the columnar basalt of the Giant's Causeway in Antrim. Some of the molten lava may push its way to the surface through clefts and passages, solidifying as *vertical* dykes or *horizontal* sills. Their origin and occurrence will be discussed in greater detail in Chapter 3.

Most igneous rocks are extremely hard and resistant. For this reason, they are quarried for road-making and polished as monuments and gravestones.

Sedimentary Rocks

Sedimentary rocks are formed from sediment accumulated over long periods, usually under water. They are distinguished from the other rock types in their characteristic layer formation and are termed stratified rocks. The strata may vary in thickness from a few inches to many feet. The rocks may be coarse or fine-grained, soft or hard. The materials that form sedimentary rocks may be brought by streams, glaciers, winds or even animals. They are non-crystalline and often contain fossils of animals, plants and other micro-organisms. Sedimentary rocks are thus the most varied in their formation of all rocks. Sedimentary rocks are classified according to their age and different kinds of rocks formed during the same period are grouped together. It is more useful to know the characteristics of the various kinds of rocks.

Sedimentary rocks may be classified under *three* major categories in accordance with their origin and composition.

1. Mechanically formed sedimentary rocks. These rocks have been formed from the accumulation of materials derived from other rocks which have been cemented together. Sandstones are probably the most familiar sedimentary rocks. They are made from sand grains, often quartz fragments derived from granites. Their texture, composition and colour vary tremendously. Many types of sandstones have been quarried for building purposes or for making grindstones. A coarser type of sandstone is known as *grit*. When larger pebbles are firmly cemented to form a rock it is called conglomerate when the pebbles are rounded, or breccia when the fragments are angular. The finer sedimentary materials form clay, widely used for brick-making, shale or mudstone. Sand and gravel may occur in uncemented form.

2. Organically formed sedimentary rocks. These rocks are formed from the remains of living organisms such as corals or shellfish, whose fleshy parts have been decomposed, leaving behind the hard shells. The most common rocks formed in this way are of the calcareous type. They include limestones and chalk.

The carbonaceous rocks are also organically formed but from vegetative matter—swamps and forests. The pressure of overlying sediments has compressed the plant remains into compact masses of *carbon* which eventually become peat, lignite or coal, all of which bear great economic value.

3. Chemically formed sedimentary rocks. Such rocks are precipitated chemically from solutions of one kind or another. Rock salts are derived from strata which once formed the beds of seas or lakes. *Gypsum* or calcium sulphate is obtained from the evaporation of salt lakes, such as the Dead Sea, which have a very high salinity. In similar ways, *potash* and *nitrates* may be formed.

Metamorphic Rocks

All rocks whether igneous or sedimentary may become metamorphic or changed rocks under great heat and pressure. Their original character and appearance may be greatly altered by such forces, particularly during intense earth movements. In this manner, clay may be metamorphosed into slate, limestone into marble, sandstone into quartzite, granite into gneiss, shale into schist and coal into graphite.

An isolated limestone hill near Kuala Lumpur. Compare this hill with the limestone features shown in Chapter 7
Jabatan Penerangan

The Influence of Rock Types on Landscape

The appearance and characteristic features of landforms are greatly influenced by the underlying rock type. Softer rocks like clay and shale are worn down much faster than harder rocks like granite.

Within West Malaysia the resistant granites form the high ground of the Main Range and the Eastern Range, where several peaks rise to over 2,000 feet. The landscape is one of smooth slopes and rounded hill-tops. The highest peak in West Malaysia, Gunong Tahan (7,186 feet) is composed of even more resistant quartzite. Shales, schists and sandstones, being less resistant, form the much lower, rounded hills. Recent river sediments form flat plains. The limestones, resistant because of their permeability, form prominent steep-sided hills such as those near Ipoh and in Perlis.

Earth Movements and the Major Landforms

The face of the earth is constantly being reshaped by the agents of denudation—running water, rain, frost, sun, wind, glaciers and waves, so that our present landforms are very varied and diverse. But these agents only modify the pattern of mountains, plateaux and plains which have been modelled by movements of the earth's crust.

Since the dawn of geological time, no less than nine orogenic or mountain building movements have taken place, folding and fracturing the earth's crust. Some of them occurred in Pre-Cambrian times between 600–3,500 million years ago. The three more recent orogenics are the Caledonian, Hercynian and Alpine. The Caledonian about 320 million years ago raised the mountains of Scandinavia and Scotland, and is represented in North America. These ancient mountains have been worn down and no longer exhibit the striking forms that they must once have had. In a later period, during the Hercynian earth movements about 240 million years ago, were formed such ranges as the Ural Mountains, the Pennines and Welsh Highlands in Britain, the Harz Mountains in Germany, the Appalachians in America as well as the high plateaux of Siberia and China. These mountains have also been reduced in size by the various sculpturing forces.

We are now living in an era very close to the last of the major orogenic movements of the earth, the Alpine, about 30 million years ago. Young fold mountain ranges were buckled up and overthrust on a gigantic scale. Being the most recently formed, these ranges, such as the Alps, Himalayas, Andes and Rockies (shown in Fig. 17) are the loftiest and the most imposing. Their peaks are sometimes several miles high. But the time will come when these lofty ranges will be lowered like those that existed before them. From the eroded materials, new rocks will be formed, later to be uplifted to form the next generation of mountains.

Types of Mountains

Mountains make up a large proportion of the earth's surface. Based on their mode of formation, *four* main types of mountains can be distinguished.

1. Fold mountains. These mountains are by far the most widespread and also the most important. They are caused by large-scale earth movements, when stresses are set up in the earth's crust. Such stresses may be due to the increased load of the overlying rocks, flow movements in the mantle, magmatic intrusions into the crust, or the expansion or contraction of some part of the earth. When such stresses are initiated, the rocks are subjected to compressive forces that produce wrinkling or

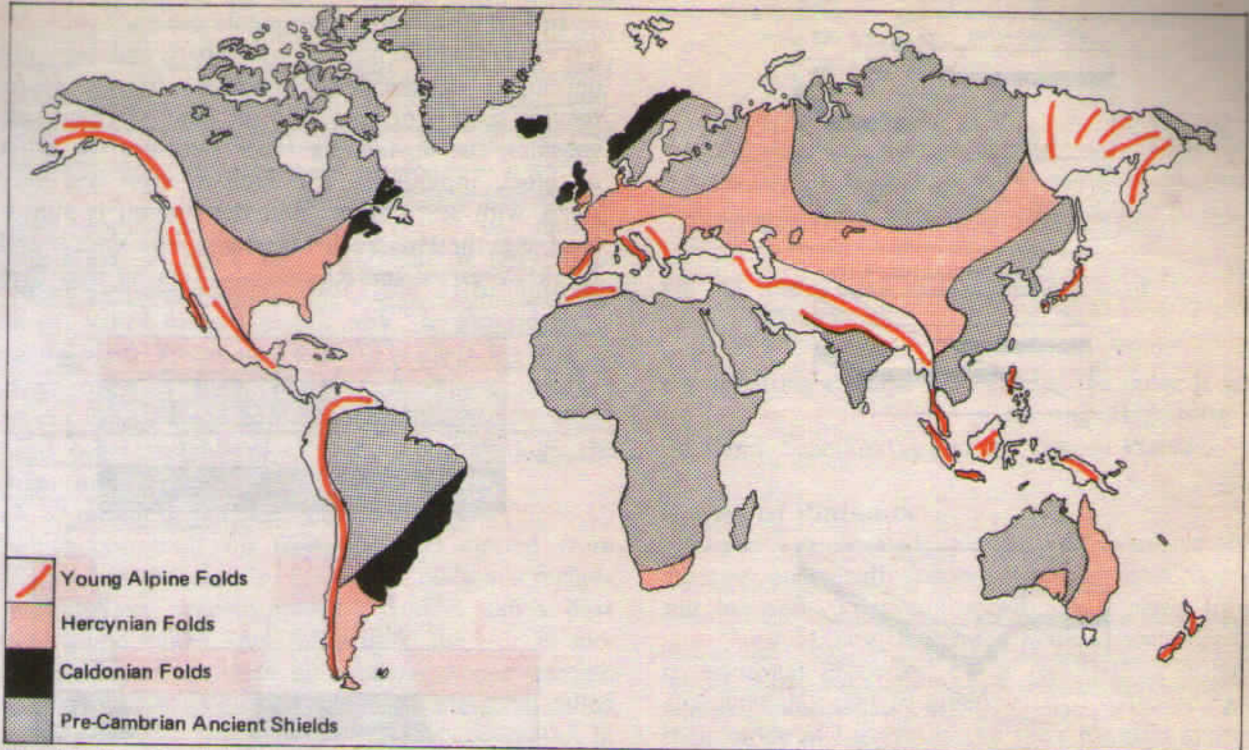


Fig. 17 Structural divisions of the earth

folding along the lines of weakness. As illustrated in Fig. 18(a) and (b) folding effectively shortens the earth's crust, creating from the original level surface a series of 'waves'. The upfolded waves are called anticlines and the troughs or downfolds are synclines. The formation of up- and downfolds closely resembles that of the wrinkles of a table-cloth when it is pushed from either one or both sides of the table.

In the great fold mountains of the world such as

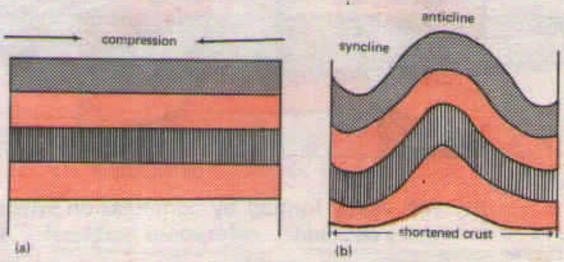


Fig. 18 (a) The horizontal strata of the earth's crust before folding
(b) Compression shortens the crust forming fold mountains

the Himalayas, Rockies, Andes and Alps, due to the complexity of the compressional forces, the folds developed much more complicated forms. When the crest of a fold is pushed too far, an overfold is formed (Fig. 19). If it is pushed still further, it becomes a recumbent fold (Fig. 19). In extreme cases, fractures may occur in the crust, so that the upper part of the recumbent fold slides forward over the lower part along a thrust plane, forming an overthrust fold. The over-riding portion of the thrust fold is termed a nappe (Fig. 19). Since the rock strata have been elevated to great heights, sometimes measurable in miles, fold mountains may

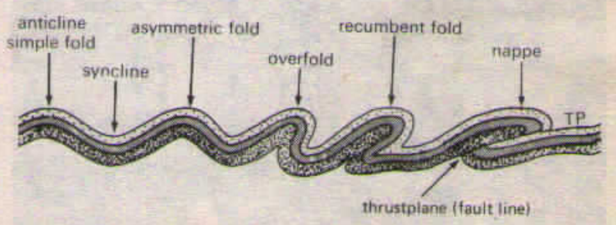


Fig. 19 Types of folding

be called mountains of elevation. The fold mountains are also closely associated with volcanic activity. They contain many active volcanoes, especially in the Circum-Pacific fold mountain system. They also contain rich mineral resources such as tin, copper, gold and petroleum.

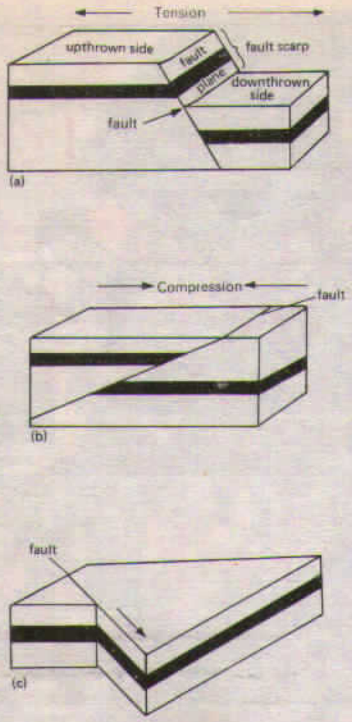


Fig. 20 Normal, reverse and transcurrent faults

2. Block mountains. When the earth's crust bends folding occurs, but when it cracks, faulting takes place (Fig. 20). Faulting may be caused by tension or compression, forces which lengthen or shorten the earth's crust, causing a section of it to subside or to rise above the surrounding level. Figs. 21(a) and (b) explain how faulting causes horsts or block mountains and their counterparts graben or rift valleys.

Minor faulting in sedimentary rocks of the Kenny Hill Series. Two small faults have distorted the strata
G.C. Morgan

In Fig. 21(a) earth movements generate tensional forces that tend to pull the crust apart, and *faults* are developed. If the block enclosed by the faults remains as it is or rises, and the land on either side subsides, the upstanding block becomes the horst or block mountain. The faulted edges are very steep, with scarp slopes and the summit is almost level, e.g. the Hunsruck Mountains, the Vosges and Black Forest of the Rhineland. Tension may also

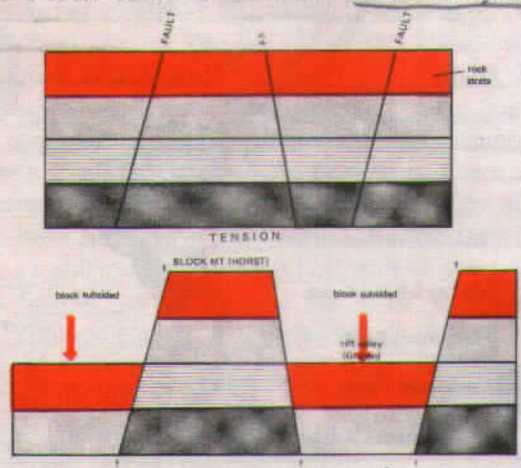
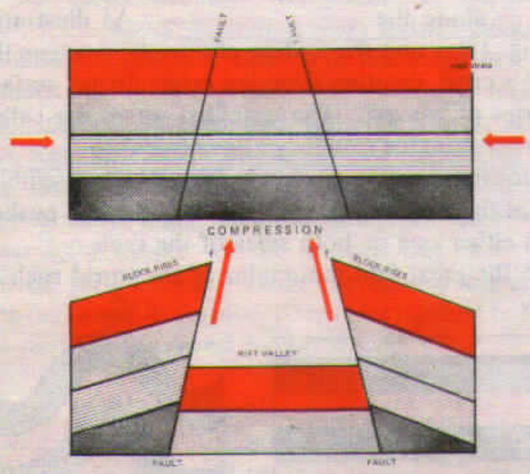
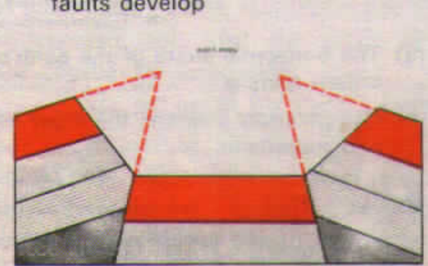


Fig. 21 (a) Block mountain (horst) formed by tension when faults develop



(b) Rift valley formed by compression when faults develop



(c) Later stage when overhanging sides are worn back cause the central portion to be let down between two adjacent fault blocks forming a graben or rift valley, which will have steep walls. The East African Rift Valley system is 3,000 miles long, stretching from East Africa through the Red Sea to Syria.

Compressional forces set up by earth movements may produce a thrust or reverse fault and shorten the crust. A block may be raised or lowered in relation to surrounding areas. Fig. 21(b) illustrates a rift valley formed in this way. In general large-scale block mountains and rift valleys are due to tension rather than compression. The faults may occur in series and be further complicated by tilting and other irregularities. Denudation through the ages modifies faulted landforms.

3. **Volcanic mountains.** These are, in fact, volcanoes which are built up from material ejected from fissures in the earth's crust. The materials include molten lava, volcanic bombs, cinders, ashes, dust and liquid mud. They fall around the vent in successive layers, building up a characteristic volcanic cone (Fig. 22). Volcanic mountains are often called mountains of accumulation. They are common in the Circum-Pacific belt and include such volcanic peaks as Mt. Fuji (Japan) Mt. Mayon (Philippines), Mt. Merapi (Sumatra), Mt. Agung (Bali) and Mt. Catopaxi (Ecuador). Further details are given in Chapter 3.

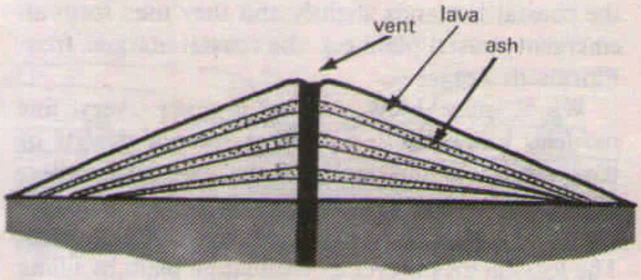


Fig 22 A volcano or 'mountain of accumulation' with successive layers of lava

4. **Residual mountains.** These are mountains evolved by denudation. Where the general level of the land has been lowered by the agents of denudation some very resistant areas may remain and these form residual mountains, e.g. Mt. Manodnock in U.S.A. Residual mountains may also evolve from plateaux which have been dissected by rivers into hills and valleys like the ones illustrated in Fig. 23. Here the ridges and peaks are all very similar in height. Examples of *dissected plateaux*, where the

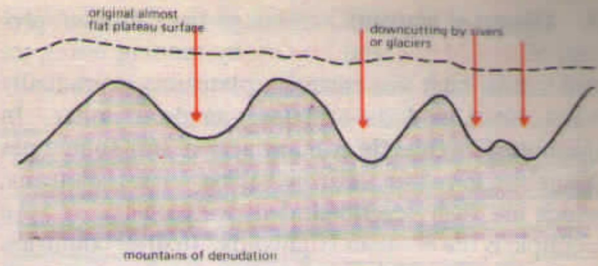


Fig. 23 Residual mountains or mountains of denudation.

down-cutting streams have eroded the uplands into mountains of denudation, are the Highlands of Scotland, Scandinavia and the Deccan Plateau.

Types of Plateaux

Plateaux are elevated uplands with extensive level surfaces, and usually descend steeply to the surrounding lowland. They are sometimes referred to as tablelands. Like all highlands, plateaux are subjected to erosional processes. As a result, their original characteristics may be greatly altered. According to their mode of formation and their physical appearance, plateaux may be grouped into the following types.

1. **Tectonic plateaux.** These are formed by earth movements which cause uplift, and are normally of a considerable size, and fairly uniform altitude. They include continental blocks like the Deccan Plateau in India. Some of the tectonic plateaux may be *tilted* like the Meseta of central Iberia, or *faulted* like the Harz of Germany.

When plateaux are enclosed by fold mountains, they are known as intermont plateaux. Examples are the Tibetan Plateau between the Himalayas and the Kunlun, and the Bolivian Plateau between two ranges of the Andes. Intermont plateaux are some of the highest and the most extensive plateaux in the world.

2. **Volcanic plateaux.** Molten lava may issue from the earth's crust and spread over its surface to form successive sheets of *basaltic lava*. These soldify to form a lava plateau. Some of the better known volcanic plateaux are the Antrim Plateau of Northern Ireland and the north-western part of the Deccan Plateau. The most remarkable plateau built by lava is the Columbia-Snake Plateau which covers an area almost twice as big as Malaysia. Each layer of the lava flow is over 100 feet thick and the entire depth of successive lava layers is estimated to be almost a mile.

3. **Dissected plateaux.** Through the continual process of weathering and erosion by running water, ice and winds, high and extensive plateaux are gradually worn down, and their surfaces made irregular. In the humid highlands, stream action and sometimes glaciation cut deep, narrow valleys in the plateaux, which are then described as dissected plateaux. An example is the Scottish Highlands. In drier countries, vertical corrasion by rivers and abrasion by winds will dissect the plateau into steep-sided tabular masses termed mesas and buttes, intersected by deep canyons. This is a common feature of arid and semi-arid areas, e.g. in the south-western U.S.A.

Many of the world's plateaux have *rich mineral resources* and have been actively mined. The African Plateau yields gold, diamonds, copper, manganese and chromium. In the Brazilian Plateau, there are huge resources of iron and manganese, particularly in the Minas Gerais area. The Deccan Plateau has deposits of manganese, coal and iron and the plateau of Western Australia is rich in gold and iron.

Types of Plains

A plain is an area of lowland, either level or undulating. It seldom rises more than a few hundred feet above sea level. There may be low hills which will give a typical rolling topography. The plains usually form the best land of a country and are often intensively cultivated. Population and settlements are normally concentrated here, and when plains are traversed by rivers, as most of them are, their economic importance may be even greater, e.g. the Indo-Gangetic plain, the Mississippi plain and the Yang-tze plain. Some of the most extensive temperate plains are *grasslands* like the Russian Steppes, the North American Prairies, and the Argentinian Pampas. Plains may be grouped into *three* major types based on their mode of formation.

1. **Structural plains.** These are the structurally depressed areas of the world, that make up some of the most extensive natural lowlands on the earth's surface. They are formed by horizontally bedded rocks, relatively undisturbed by the crustal movements of the earth. They include such great plains as the Russian Platform, the Great Plains of U.S.A. and the central lowlands of Australia.

2. **Depositional plains.** These are plains formed by the deposition of materials brought by various agents of transportation. They are comparatively level but rise gently towards adjacent highlands. Their fertility and economic development depend greatly on the types of sediments that are laid down.

Some of the largest depositional plains are due to deposition by large rivers. Active erosion in the upper course results in large quantities of alluvium being brought down to the lower course and deposited to form extensive alluvial plains, flood plains and deltaic plains. They form the most productive agricultural plains of the world, intensively tilled and very densely populated. The Nile delta of Egypt is noted for rice and cotton cultivation, the Ganges delta for rice and jute growing, while the plain of North China, where the Hwang Ho has spread out a thick mantle of alluvium, supports a wide range of crops.

Glaciers and ice-sheets may deposit a widespread mantle of unsorted fluvio-glacial sands and gravels in the outwash plain or may drop *boulder clay*, a mixture of various sizes of boulders and clay, to form a till plain or drift plain. Outwash plains are usually barren lands, e.g. some parts of Holland and northern Germany, but boulder clay may be very valuable farming land e.g. the Mid-West of the U.S.A. and East Anglia in England.

In coastal regions, *waves* and *winds* often drive beach materials, mud, sand or shingle, landwards and deposit them on the coastal plain to form marine swamps, mud-flats, tidal and estuarine lowlands. An appreciable portion of the coastal lowlands of Belgium, the Netherlands and the Gulf Coast of U.S.A. were formed in this way. Uplift may raise the coastal lowlands slightly and they then form an emergent coastal plain e.g. the coastal margins from Florida to Texas.

Winds may blow *aeolian deposits*—very fine particles known as loess—from interior deserts or barren surfaces and deposit them upon hills, valleys or plains forming a *loess plateau*, as in north-west China, or a *loess plain*, as in the Pampas of Argentina. The loess helps to level an undulating plain by filling up grooves and depressions. Many of the loess-covered plains in the world are fertile agricultural regions.

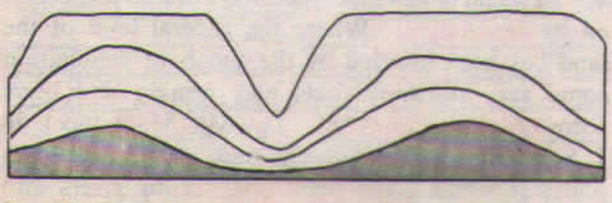


Fig. 24 Peneplain
In the formation of a peneplain in humid conditions the hills are both lowered and worn back to give an undulating lowland

3. Erosional plains. These plains are carved by the agents of erosion. Rain, rivers, ice and wind help to smooth out the irregularities of the earth's surface, and in terms of millions of years, even high mountains can be reduced to low undulating plains. Such *plains of denudation* are described as peneplains a word meaning 'almost-plains'.

Rivers, in their course from source to sea, deepen their valleys and widen their banks. The projecting spurs are cut back so that the level ground bordering the river is constantly widened. At the same time the higher land between the rivers is gradually lowered (Fig. 24).

In *glaciated regions*, glaciers and ice-sheets scoured and levelled the land forming ice-scoured plains. Hollows scooped out by the ice are now filled by lakes. There are extensive ice-scoured plains in northern Europe and northern Canada. Finland is estimated to have 35,000 lakes, occupying 10% of the total land surface of the country.

In arid and semi-arid regions, wind deflation sweeps away much of the eroded desert materials, lowering the level of land and forming extensive plains, e.g. the gravelly or stony desert plains called reg in Africa. *Mechanical weathering* in arid and semi-arid areas *wears back* the mountain slopes to leave a gently sloping pediments or pediplains (Fig. 25).

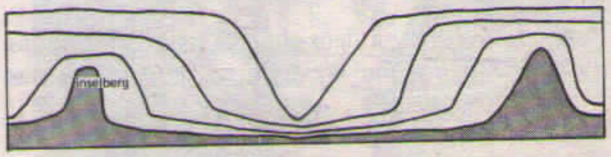


Fig. 25 Pediplain
In the formation of a pediplain in arid or semi-arid conditions the hills are worn back to form a gently sloping plain but some steep hills remain. These are called inselbergs

QUESTIONS AND EXERCISES

1. *Either:* Attempt a classification of mountains according to their mode of formation.
   Or: Explain why a knowledge of rocks and their structures is essential in the interpretation of landforms.

2. With the aid of diagrams, explain the difference in appearance and formation of any *three* of the following:
   (a) folds and faults
   (b) dissected plateau and intermont plateau
   (c) alluvial plain and peneplain
   (d) sima and sial
   (e) lithosphere and mantle

3. What is a sedimentary rock? In what way is it different from igneous rocks? Describe the various sources from which sedimentary rocks may be derived. (Quote actual examples of sedimentary rocks to support your answer.)

4. For each of the following:
   a young fold mountain
   a rift valley
   a loess plain
   (a) Draw a simple diagram to show its characteristic relief.
   (b) Explain its origin.
   (c) Name and locate a region where such a feature may be found.

5. *Either:* Describe and explain the following selected landforms
   (a) Antrim Plateau
   (b) Russian Platform
   (c) Scottish Highlands
   Or: Explain the meaning of any *four* of the following terms connected with the study of landforms and the earth's crust.

basalt, orogenesis, recumbent fold, fossiliferous rocks, horst, syncline.

Chapter 3 Vulcanism and Earthquakes

Landforms Associated with Vulcanic Activities

Vulcanic activities have a profound influence on the earth's landforms. Solid, liquid or gaseous materials may find their way to the surface from some deep-seated reservoir beneath. Molten magma is mobile rock that forces its way into the planes of weakness of the crust to escape quietly or explosively to the surface. The resultant landforms depend on the strength and fluidity of the magma, the types of cracks, faults and joints that it penetrates, and the manner in which it escapes to the surface. Magma while thrusting its way up to the surface may cool and solidify within the crust as plutonic rocks resulting in intrusive landforms. Magmas that reach the surface and solidify, form extrusive landforms. Rocks formed by either plutonic or volcanic activity are called igneous rocks.

Landforms of Igneous Intrusions

Perhaps the commonest intrusive landforms are *sills* and *dykes*. When an intrusion of molten magma is made horizontally along the bedding planes of sedimentary rocks, the resultant intrusion is called a sill. Denudation of the overlying sedimentary strata will expose the intrusion which will resemble a lava flow, or form a bold escarpment like the Great Whin Sill of N.E. England. Similar intrusions when injected vertically as narrow walls of igneous rocks within the sedimentary layers are termed as dykes. Because of their narrowness, dykes seldom dominate the landscape. When exposed to denudation they may appear as upstanding walls or shallow trenches, depending on whether they are more or less resistant than the rocks in which they are emplaced. Examples of dykes are the Cleveland Dyke of Yorkshire, England and hundreds of others in the Isles of Mull and Arran in Scotland. A large, very resistant dyke of quartzite forms a long ridge to the north of Kuala Lumpur.

Igneous intrusions on a larger scale are the various types of '–liths': *laccoliths, lopoliths, phacoliths* and *batholiths* (Fig. 26). The names may sound difficult; they are, in fact, all variations of igneous intrusions placed differently in the earth's crust, and soldifying within the upper layers of the crust. A laccolith is a large blister or igneous mound with a *dome-shaped* upper surface and a level base fed by a pipe-like conduit from below. It arches up the overlying strata of sedimentary rocks, e.g. the laccoliths of the Henry Mountains, in Utah U.S.A.

A lopolith is another variety of igneous intrusion with a *saucer shape*. A shallow basin is formed in the midst of the country rocks. The Bushveld lopoliths of Transvaal, South Africa are good examples.

A phacolith is a lens-shaped mass of igneous rocks occupying the crest of an *anticline* or the

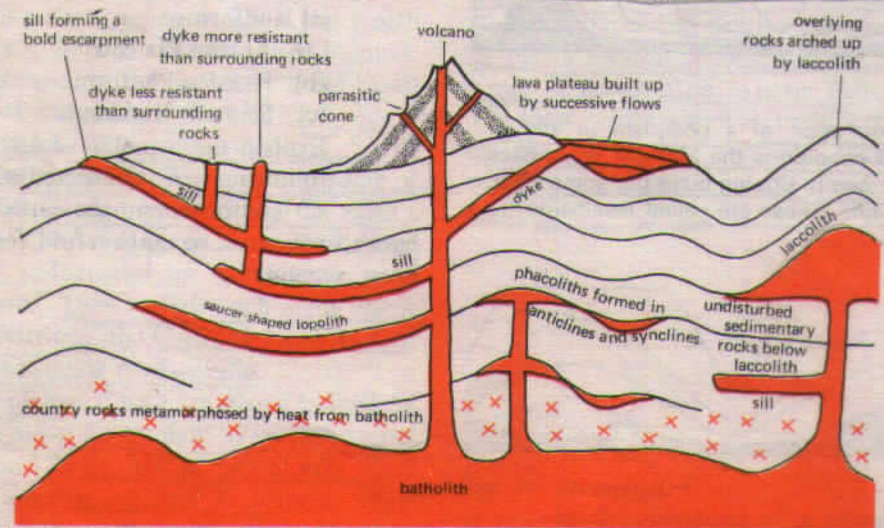


Fig. 26 Intrusive landforms of igneous intrusions in volcanic regions (showing sill, dyke, laccolith, lopolith phacolith and batholith)

bottom of a *syncline* and being fed by a conduit from beneath. An example of a phacolith is Corndon Hill in Shropshire, England.

A batholith is a huge mass of igneous rocks, usually *granite*, which after removal of the overlying rocks forms a massive and resistant upland region such as the Wicklow Mountains of Ireland, the uplands of Britanny, France and the Main Range of West Malaysia. Their precise mode of origin is still a matter of controversy. It is generally believed that large masses of magma rising upwards *metamorphosed* the country rocks with which they came into contact. These metamorphosed rocks together with the solidified magma give rise to extensive batholiths, sometimes hundreds of miles in extent. They are the most spectacular of the intrusive landforms.

The Origin of Volcanoes

The ancient Greeks believed that volcanic eruptions occurred when Vulcan, the God of the Underworld, stoked his subterranean furnace beneath Vulcano, a small volcanic island off Sicily, from which the present word volcano is derived. Of course, we no longer believe this is true. Geologists and vulcanologists have ascertained that volcanic activity is closely connected with *crustal disturbances*, particularly where there are zones of weakness due to deep faulting or mountain folding. As temperature increases with increasing depth below the earth's crust, at an average rate of about 1°F. for every 65 feet of descent, the interior of the earth can be expected to be in a semi-molten state, comprising solid, liquid and gaseous materials, collectively termed *magma*.

Mt. Mayon, Philippines, in eruption

The magma is heavily charged with gases such as carbon dioxide, sulphurated hydrogen, and small proportions of nitrogen, chlorine and other volatile substances. The gases and vapour increase the mobility and explosiveness of the *lavas* which are emitted through the orifice or vent of a volcano during a volcanic eruption. There are two main types of *lavas*.

1. **Basic lavas.** These are the hottest lavas, about 1,000°C. (1,830°F.) and are highly fluid. They are dark coloured like *basalt*, rich in iron and magnesium but poor in silica. As they are poured out of the volcano, they flow *quietly* and are not very explosive. Due to their high fluidity, they *flow readily* with a speed of 10 to 30 miles per hour. They affect *extensive* areas, spreading out as *thin sheets* over great distances before they solidify. The resultant *volcano* is gently sloping with a wide diameter and forms a flattened shield or dome (Fig. 27).

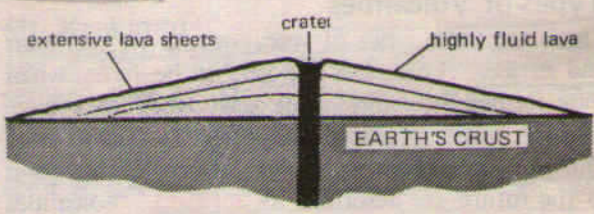


Fig. 27 Lava dome or shield volcano

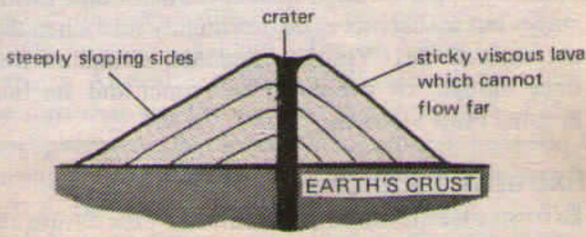


Fig. 28 Acid lava cone

2. Acid lavas. These lavas are highly viscous with a high melting point. They are *light-coloured*, of low density, and have a high percentage of silica. They *flow slowly* and seldom travel far before solidifying. The resultant cone is therefore steep-sided. The rapid congealing of lava in the vent obstructs the flow of the out-pouring lava, resulting in loud explosions, throwing out many *volcanic bombs* or *pyroclasts* (Fig. 28). Sometimes the lavas are so viscous that they form a spine or plug at the crater like that of Mt. Pelee in Martinique (Fig. 29). Some spines are very resistant and while most of the material of very old volcanoes is removed by erosion the spine may remain, e.g. Puy de Dome, France.

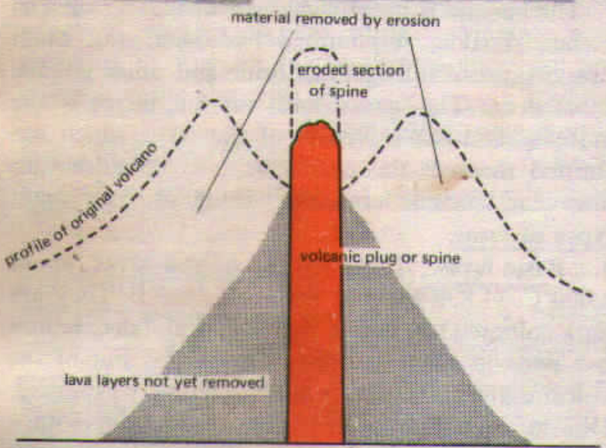


Fig. 29 A volcanic plug or spine after prolonged exposure to erosion. The plug is more resistant and remains after most of the volcanic materials have been worn away.

Types of Volcanoes

There are three types of volcanoes: *active*, *dormant* and *extinct*. Volcanoes are said to be active when they frequently erupt or at least when they have erupted within recent time. Those that have been known to erupt and show signs of possible eruption in the future are described as dormant. Volcanoes that have not erupted at all in historic times but retain the features of volcanoes are termed extinct. All volcanoes pass through active, dormant and extinct stages but we can never be thoroughly sure when they are extinct. Mt. Vesuvius and Mt. Krakatau were once thought by people to be extinct and yet both erupted most violently.

Extrusive Landforms

Extrusive landforms are determined by the nature and composition of the lava and other ejected materials that reach the surface of the earth. The fluid *basic lava*, flowing for long distances produces extensive lava plains and basalt plateaux, such as the great lava plains of the Snake Basin, U.S.A. The basalt plateaux are found in many continents, e.g. the north-western part of the Deccan Plateau and in Iceland.

Volcanic cones are most typical of the extrusive features. The highly fluid lavas build up lava domes or shield volcanoes with gently rising slopes and broad, flattened tops. The volcanoes of Hawaii have the best developed lava domes. The spectacular Mauna Loa and Kilauea are so accessible that they have been closely studied. Kilauea has a very steep-walled caldera into which the active vent pours red hot lava forming the *lava-pit* of Halemaumau. Thousands of lava fountains rise and fall in the dazzling pit.

The less fluid lavas that explode more violently form ash and cinder cones with large central craters and steep slopes. They are typical of small volcanoes, occurring in groups and seldom exceeding 1,000 feet in height, such as Mt. Nuovo, near Naples and Mt. Paricutin in Mexico. The lava flows are so viscous that they solidify after a short distance. When they are confined in valleys, they form lava tongues and *lava-dammed lakes* when they dam a river valley. Other minor features that may be associated with lava obstructions include lava bridges and lava tunnels.

A volcanic region may be strewn with solid materials that were hurled from the vent of the volcano. The very fine particles are the volcanic dust which may be shot so high into the sky that it travels round the world several times before it eventually comes to rest. The dust or ash falls as 'black snow' and can bury houses and people. The coarser fragmental rocks are collectively called pyroclasts and include cinders or *lapilli*, *scoria*, *pumice* and *volcanic bombs*.

The highest and most common volcanoes have composite cones. They are often called strato-volcanoes. The cones are built up by several eruptions of lava, ashes and other volcanic materials from the main conduit which leads down a reservoir of magma. Each new eruption adds new layers of ashes or lava to the sides of the volcano, which grows steadily in height. From the main conduit, subsidiary dykes or pipes may reach the surface as feeders to parasitic cones. Lava escapes through them to the sides of the main cones (Fig. 30). Mt. Etna in Sicily has hundreds of such parasitic cones. Another interesting composite volcano is Mt. Stromboli whose frequent eruptions that make the summit

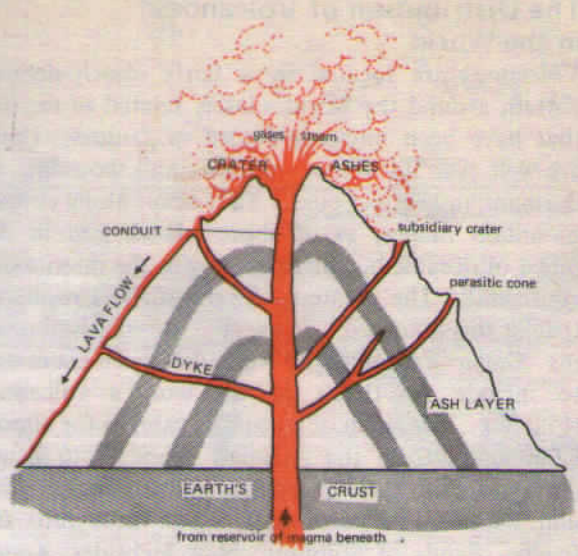


Fig. 30 A composite cone

glow have earned for it the name *'Lighthouse of the Mediterranean'*. Other well known composite volcanoes include Mt. Vesuvius, Mt. Fuji, Mt. Popacatapetl and Mt. Chimborazo.

During an eruption material from the top of the cone is blown off or collapses into the vent widening the orifice into a large crater. Some volcanoes may have greatly enlarged depressions called calderas, which may be several miles across. These are the result of violent eruptions accompanied by the subsidence of much of the volcano into the magma beneath (Fig. 31). Water may collect in the crater or the caldera forming crater or caldera lakes, e.g. Lake Toba in Sumatra.

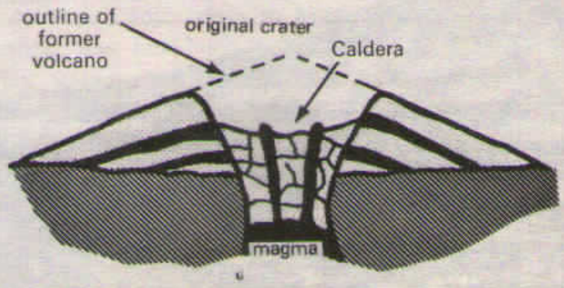


Fig. 31 A caldera. A violent eruption weakens the structure of the volcano and after eruption has ceased much of the volcano subsides into the magma reservoir beneath. The depression may later be filled with water to form a lake.

Some Volcanic Eruptions

In the history of mankind perhaps the most disastrous eruptions were those of Mt. Vesuvius, Mt. Krakatau and Mt. Pelee.

Mt. Vesuvius

Mt. Vesuvius, standing 4,000 feet above the Bay of Naples, erupted violently on 24 August A.D. 79 taking the people who lived around it by complete surprise. White-hot lava flowed from parasitic cones. In the midst of a thundering explosion, the highly gaseous magma escaped as gigantic luminous clouds in cauliflower form and shot up to great heights before it fell to earth as pyroclasts and ashes. The city of Pompeii, located to the south-west, was buried beneath twenty feet of volcanic ashes which were later cemented by the torrential downpours of heavy rain that accompanied the violent eruption. In a similar way, the city of Herculaneum on the west was completely overwhelmed by a mudflow of ashes and cinders almost 50 feet thick, washed down by torrential rain from the slopes of Vesuvius. Almost the entire population of the two cities was buried alive.

After this, minor eruptions occurred from time to time but the fertility of the sólidified Volcanic ashes tempted many farmers to begin anew on the slopes of Vesuvius. Then came the catastrophic eruption of December 1631 when an avalanche comprising red hot volcanic debris, pasty lava and highly energized gases ruined fifteen towns and killed 4,000 inhabitants. The ashes that descended on Naples were estimated to be a foot thick.

Mt. Krakatau

The greatest volcanic explosion known to men is perhaps that of Mt. Krakatau in August 1883. Krakatau is a small volcanic island in the Sunda Straits, midway between Java and Sumatra. Dense black clouds of ashes shot 20 to 50 miles high, and were brought down as mud by the torrential rain which fell over the adjacent islands. So much magma was ejected from the underlying reservoir that two-thirds of the island collapsed and disappeared forming a huge submarine caldera. The explosion could be heard in Australia, almost 3,000 miles away. The fine dust that was thrown into the upper part of the atmosphere travelled several times around the world, causing brilliant sunsets and glowing sky in many parts of the globe. Though Krakatau itself was not inhabited and nobody was killed by the lava flows, the vibration set up enormous waves over 100 feet high which drowned 36,000 people in the coastal districts of Indonesia.

After remaining dormant for almost half a century, an eruption in 1927 pushed up a cinder cone from the submarine floor, culminating in a summit of 220 feet above sea level by 1952. This new volcanic island was named Anak Krakatau, meaning 'the child of Mt. Krakatau'.

Mt. Pelee

The eruption of Mt. Pelee of the West Indies in May 1902 was the most catastrophic of modern times. The volcano erupted white-hot lava and super-heated steam which swept down the slope at an amazing speed as a *nuee ardente* (glowing avalanche). St. Pierre, the capital of Martinique, lying on the path of the lava, was completely destroyed within minutes. Its entire population of 30,000, except two of them, was killed almost instantly. Even the sea was boiling and all the ships in the harbour were wrecked.

The ejection of volcanic materials continued for several months until a vertical spine rose from the crater, almost a thousand feet high by the middle of 1903. The spine was formed by the pasty lava, partially solidified in the neck of the volcano. Part of the spine, however, crumbled under continual weathering as well as internal forces.

The Distribution of Volcanoes in the World

Volcanoes are located in a fairly clearly-defined pattern around the world, closely related to regions that have been intensely folded or faulted. There are well over 500 active volcanoes and thousands of dormant and extinct ones. They occur along coastal mountain ranges, as off-shore islands and in the midst of oceans, but there are few in the interiors of continents. The greatest concentration is probably that in the **Circum-Pacific region,** popularly termed the *'Pacific Ring of Fire'*, which has been estimated to include two-thirds of the world's volcanoes (Fig. 32). The chain of volcanoes extends for almost 2,000 miles from the Aleutian Islands into Kamchatka, Japan, the Philippines, and Indonesia (Java and Sumatra in particular), southwards into the Pacific islands of Solomon, New Hebrides, Tonga and North Island, New Zealand. On the other side of the Pacific, the chain continues from the Andes to Central America (particularly Guatemala, Costa Rica and Nicaragua), Mexico and right up to Alaska. It is said that there are almost 100 active volcanoes in the Philippines, 40 in the Andes, 35 in Japan, and more than 70 in Indonesia.

In contrast, the *Atlantic coasts* have comparatively few active volcanoes but many dormant or extinct volcanoes, e.g. Madeira, Ascension, St. Helena, Cape

Mt. Mayon seen from the town of Legaspi, southern Luzon. *Philippine Tourist and Travel Association*

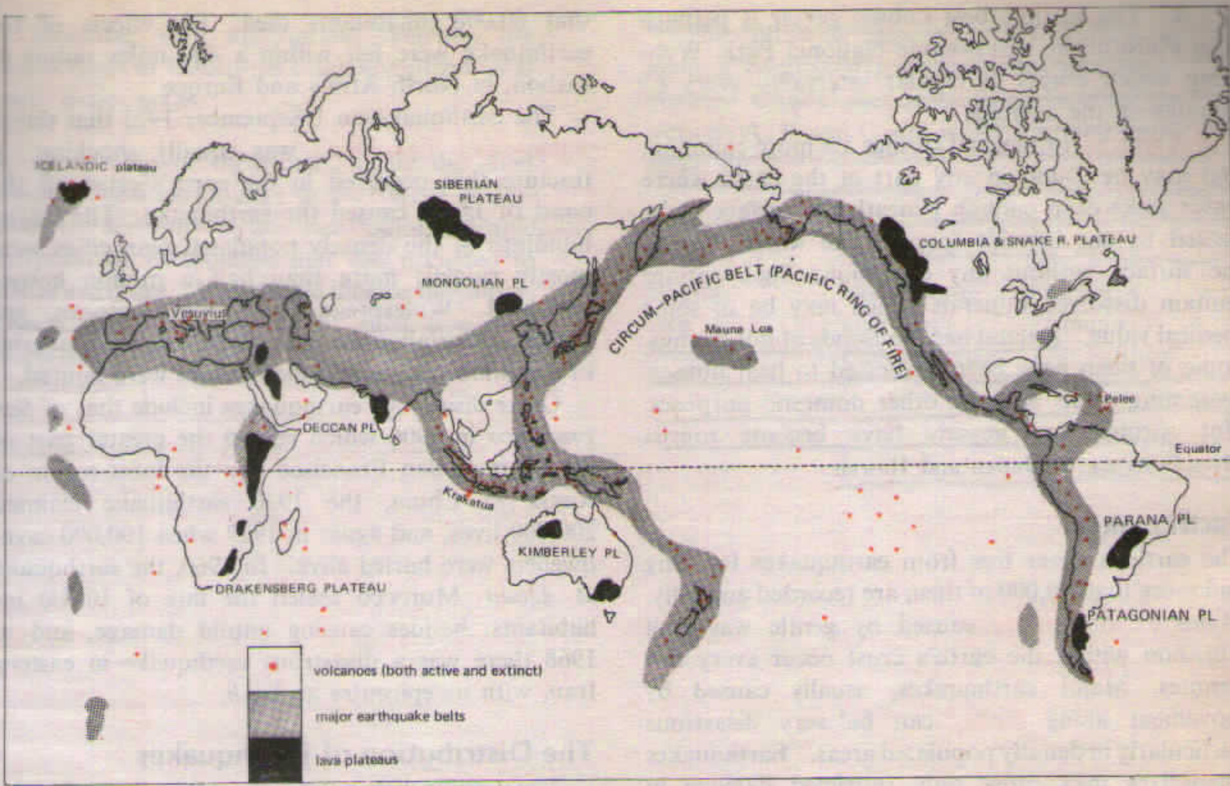


Fig. 32 World distribution of volcanoes, lava plateaux and earthquakes

Verde Islands and Canary Islands, but those of Iceland and the Azores are active. Volcanoes of the Mediterranean region are mainly associated with the Alpine folds, e.g. Vesuvius, Etna, Stromboli, Vulcano and those of the Aegean islands. A few continue into Asia Minor (Mt. Ararat, Mt. Elbruz). The Himalayas have, surprisingly, no active volcano at all.

In *Africa* some volcanoes are found along the East African Rift Valley, e.g. Mt. Kilimanjaro and Mt. Kenya, both probably extinct. The only active volcano of West Africa is Mt. Cameroon. There are some volcanic cones in Madagascar, but active eruption has not been known so far. The *West Indian islands* have experienced some violent explosions in recent times, e.g. Mt. Pelee in Martinique, and in St. Vincent further south. The Lesser Antilles are made up mainly of volcanic islands and some of them still bear signs of volcanic liveliness. Elsewhere in the interiors of continents—Asia, North America, Europe and Australia, active volcanoes are rare.

Geysers and Hot Springs

Geysers are fountains of hot water and superheated steam that may spout up to a height of 150 feet from the earth beneath. The phenomena are associated with a thermal or volcanic region in which the water below is being heated beyond boiling-point (100°C. or 212°F.). The jet of water is usually emitted with an explosion, and is often triggered off by gases seeping out of the heated rocks (Fig. 33). Almost all the world's geysers are confined to three major areas: Iceland, the Rotorua district of North Island, New Zealand and Yellowstone Park of

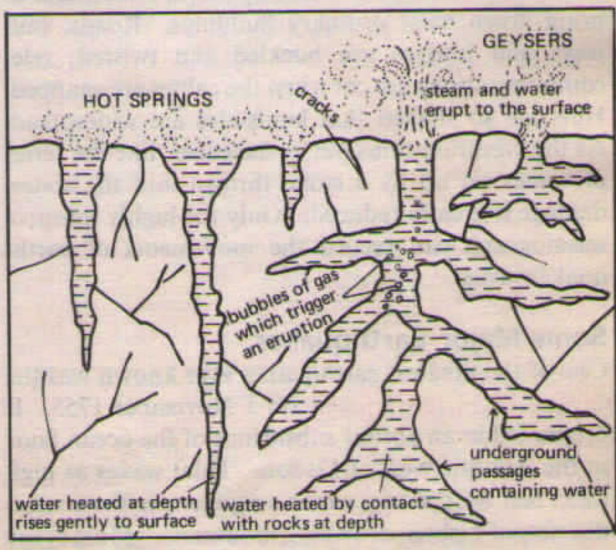


Fig. 33 Hot springs and geysers

U.S.A. The world's best known geyser is perhaps 'Old Faithful' in Yellowstone National Park, Wyoming which erupts at regular intervals—every 63 minutes on the average.

Hot springs or thermal springs are more common, and may be found in any part of the earth where water sinks deep enough beneath the surface to be heated by the interior forces. The water rises to the surface without any explosion. Such springs contain dissolved minerals which may be of some medical value. Iceland has thousands of hot springs. Some of them have been harnessed to heat houses, swimming pools and for other domestic purposes. Hot springs and geysers have become tourist attractions e.g. in Japan and Hawaii.

Earthquakes

The earth is never free from earthquakes for long and more than 50,000 of them are recorded annually. Minor earth tremors caused by gentle waves of vibration within the earth's crust occur every few minutes. Major earthquakes, usually caused by movement along faults, can be very disastrous particularly in densely populated areas. Earthquakes themselves may cause only restricted damage in the regions of occurrence, but their after-effects can be very catastrophic. They produce gigantic tidal waves, called tsunamis by the Japanese, which flood towns and drown thousands of people. Fires break out beyond control as gas mains are shattered and buildings collapse. In severe earthquakes, fissures gape open, and the ground writhes and undulates in the passage of the 'surface waves'. A wave height of a quarter of an inch in the upheaval is sufficient to bring down most ordinary buildings. Roads, railways and bridges are buckled and twisted; telecommunications are cut when the cables are snapped. Hills are so shaken that landslides are widespread. As the vibration thins out at the edges, like the series of waves set up by a stone thrown into the water, damage is greatly reduced. Only the highly sensitive seismograph can record the movements of earthquake waves.

Some Major Earthquakes

One of the greatest earthquakes ever known was the Great Lisbon Earthquake on 1 November 1755. It originated in an abrupt subsidence of the ocean floor in the Atlantic west of Lisbon. Tidal waves as high as 35 feet were set up which swept across the coastal districts of Lisbon, drowning thousands. Most of the buildings collapsed completely and it was estimated that 60,000 inhabitants died. The effects of the earthquake were felt within a 400 miles radius of Lisbon, in North Africa and Europe.

The earthquake on 1 September 1923 that shook Tokyo and Yokohama was equally shocking. A fracture that occurred in the earth's crust off the coast of Japan caused the earthquake. The fragile buildings of the densely populated twin cities were mostly ruined; more than half a million houses collapsed. Widespread fires from factories, gas mains, oil installations and kitchens killed a quarter of a million people and many more were injured.

Other disastrous earthquakes include that of *San Francisco* in 1906 which ruined the greater part of the heart of San Francisco. In the loess region of *Kansu* in China, the 1920 earthquake claimed 200,000 lives, and again in 1927 when 100,000 cave-dwellers were buried alive. In 1960, the earthquake at *Agadir*, Morocco sealed the fate of 10,000 inhabitants, besides causing untold damage, and in 1968 there was a disastrous earthquake in eastern Iran, with its epicentre at *Kakh*.

The Distribution of Earthquakes

The world's distribution of earthquakes coincides very closely with that of volcanoes. Regions of greatest seismicity are Circum-Pacific areas, with the epicentres and the most frequent occurrences along the *'Pacific Ring of Fire'*. It is said that as many as 70 per cent of earthquakes occur in the Circum-Pacific belt. Another 20 per cent of earthquakes take place in the *Mediterranean-Himalayan belt* including Asia Minor, the Himalayas and parts of north-west China. Elsewhere, the earth's crust is relatively stable and is less prone to earthquakes, though nowhere can be said to be immune to earth tremors.

QUESTIONS AND EXERCISES

1. With the aid of annotated diagrams, write a comparative account of landforms resulting from intrusive and extrusive igneous activities.

2. Distinguish the difference in appearance and origin of any *three* of the following pairs of terms associated with vulcanicity.
   (a) sills and dykes
   (b) cinder cones and lava domes
   (c) geysers and hot springs
   (d) crater and caldera
   (e) laccolith and lopolith

3. Describe, with appropriate sketches, the major types of landforms originating from acid and basic lavas.

4. On a map of the world, locate the chief volcanic and earthquake areas. Write a descriptive account of any *one* major volcanic eruption or earthquake that has occurred in historical times. You should include the causes, effects and consequences of such a named occurrence.

5. The following terms are in one way or another connected with volcanoes and earthquakes. Choose *one* term from each of the sections A, B and C and write what you know about them:

Section A	*Section B*	*Section C*
magma	basalt plateau	Vulcano
lava	lava plain	Tsunami
pyroclasts	parasitic cones	'Old Faithful'

Chapter 4 Weathering, Mass Movement and Groundwater

The earth's crust is constantly undergoing geological changes caused by internal forces, which create new relief features. Orogenesis build new mountain ranges, uplift or depression of particular areas is caused by folding or faulting, and volcanic disturbances also modify the landscape. Meanwhile external forces are working vigorously to wear away the surface, and the interaction of these constructive and destructive forces gives rise to the great diversity of present-day landforms. The process of wearing away the earth causes a general lowering and levelling out of the surface. It is known as denudation and is carried out in four phases.

i. *Weathering:* the gradual disintegration of rocks by atmospheric or weather forces;
ii. *Erosion:* the active wearing away of the earth's surface by moving agents like running water, wind, ice and waves;
iii. *Transportation:* the removal of the eroded debris to new positions;
iv. *Deposition:* the dumping of the debris in certain parts of the earth, where it may accumulate to form new rocks.

All four phases of the denudation process are taking place simultaneously in different parts of the world at different rates, much depending on the nature of the relief, the structure of the rocks, the local climate and interference by man.

This chapter describes the work of weathering and the features it produces, while Chapters 5 to 10 deal with erosion, transportation and deposition by water, wind, ice and waves.

Weathering

The work of weathering in breaking up the rocks is of two kinds, namely chemical, and physical or mechanical weathering, but the processes involved in each are closely interrelated.

1. Chemical weathering

Chemical weathering is the basic process by which denudation proceeds. It is the extremely slow and gradual decomposition of rocks due to exposure to air and water. Air and water contain chemical elements, which though they may be in small quantities, are sufficient to set up chemical reactions in the surface layers of exposed rocks. Such reactions may weaken or entirely dissolve certain constituents of the rock, thus loosening the other crystals and weakening the whole surface. For example, in Malaysia, the surface of granite which has been exposed to the weather is found to be pitted and rough. This is because the granite is made of three main minerals: quartz, felspar and mica. The felspar is more quickly weathered than the quartz and thus the felspar crystals are worn away. The quartz crystals are eventually loosened in this way and form a coarse sandy residue.

When the surface of a rock is weathered some of the material which is loosened is removed by erosive agents such as wind or running water thus exposing a fresh surface to weathering, but much of the weathered material or *regolith* (remains of the rock) may stay in position forming the basis of soil. Regolith is simply the mineral remains of decomposed rocks, but soil contains organic materials, such as the roots of plants, fallen leaves, small animals such as worms, bacteria and so on. It is the organic content of soil which makes it fertile and allows crops to be grown.

When a soil cover exists, chemical weathering of the underlying rocks does not cease; on the contrary it is usually enhanced. This is because the soil absorbs rain-water and keeps the underlying rocks in contact with this moisture. The rain-water absorbs organic acids from the soil and thus becomes a stronger weathering agent than pure rain-water acting on bare rock.

There are three major chemical weathering processes.

(a) Solution. Many minerals are dissolved by water, especially when, as with rain-water, it contains enough carbon dioxide to make it a weak acid. Solution is the most potent weathering process in limestone regions because the rain-water attacks and dissolves the calcium carbonate of which the rock is chiefly formed. The dissolved calcium carbonate is carried away by the water, joints and cracks in the rock are quickly widened and whole systems of caves and passages are worn out (see Chapter 8). Limestone, however, is by no means the only rock to suffer from solution. All rocks are subject to solution to some extent, though the process is much slower than with limestone. The rate at which solution takes place is affected not only by the mineral composition of the rock but also by its structure. Sedimentary rocks often have pore-spaces between the grains in which air and water can lodge and thus attack the rock. The

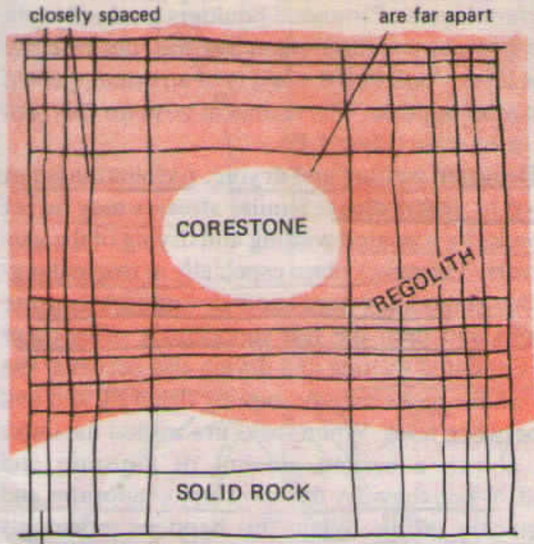


Fig. 4.1 Differential weathering in a rock such as granite where unevenly spaced joints may give rise to corestones and certain blocks remain unweathered. In jointed rocks, temperature change cracks up rectangular blocks.

density of joints or cracks in the rock is also crucial to the speed of weathering. This factor is very clearly seen in Malaysia in the weathering of granite. In tropical countries, where the heavy rainfall and warm climate both promote rapid chemical reactions, weathering often proceeds very rapidly. This produces the very deep regoliths or soils overlying the solid rocks. Often these regoliths contain core-stones. These are pieces of solid rock which have resisted weathering while a'' the surrounding rock has been weathered. They are more resistant because they have fewer joints or cracks to harbour moisture and are thus more slowly weathered by solution processes (Fig. 4.1 and Plate 4.A).

Rates of weathering are also affected by climate. Warm wet climates promote rapid chemical weathering, while dry climates inhibit chemical weathering. Dry climates, however, provide good conditions for physical or mechanical weathering.

(b) Oxidation. Oxidation is the reaction of oxygen in air or water with minerals in the rock. For example, most rocks contain a certain amount of iron, which when it comes in contact with air is changed to iron oxide, familiar brownish crust or rust. Iron oxide crumbles easily and is fat more easily eroded than the original iron. It is thus removed, loosening the overall structure of the rocks and weakening them.

4.A A solid corestone embedded in weathered material which has been exposed in a road cutting near Tampin, Negri Sembilan *G.C. Morgan*

(c) Decomposition by organic acids. Within the soil which covers most rocks are bacteria whch thrive on decaying plant or animal material. These bacteria produce acids which, when dissolved in water, help to speed up the weathering of the underlying rocks. In some cases micro-organisms and plants like mosses or lichens can live on bare rock, so long as the surface is damp. These absorb chemical elements from the rocks as food and also produce organic acids. They are thus agents of both chemical and mechanical weathering.

2. Physical or Mechanical weathering

Mechanical weathering is the physical disintegration of a rock by the actual prising apart of separate particles. This can happen even with completely fresh rock but the processes of physical weathering are able to work much more easily when the surface of the rock has already been weakened by the action of chemical weathering. Mechanical weathering takes place in several ways.

(a) Repeated temperature changes. In deserts, rocks are exposed to the blazing sun during the day and are intensely heated. The outer layers expand much faster than the cooler interior of the rocks and tend to pull away from the rest. At nightfall the temperature drops rapidly and the outer layers contract more rapidly than the interior, setting up internal stresses. Such stresses, repeated every day for months

4.B When corestones are exposed to tropical weather conditions they are subject to repeated wetting and drying which cause the outer layers to peel off. This sandstone boulder shows several layers have split off in some areas. *G.C. Morgan*

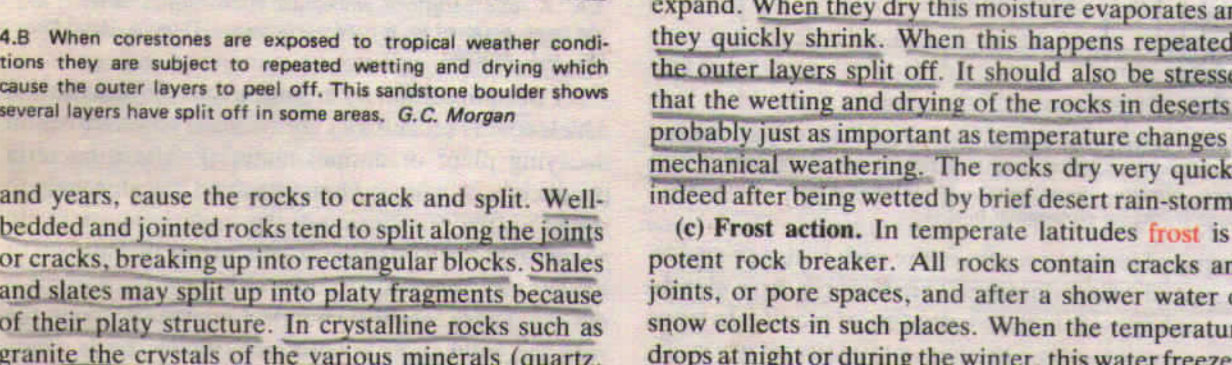
and years, cause the rocks to crack and split. Well-bedded and jointed rocks tend to split along the joints or cracks, breaking up into rectangular blocks. Shales and slates may split up into platy fragments because of their platy structure. In crystalline rocks such as granite the crystals of the various minerals (quartz, mica, felspar) will expand and contract at different rates, enhancing the stresses and accelerating the disintegration of the rocks. Fragments broken from large rock outcrops fall by gravity to the foot of the slope. They may form screes or may form a litter of angular chips and small boulders on the flatter ground.

Stresses and pressures will naturally be greatest near the surface and where there are sharp angles in the rocks. Rectangular blocks are thus gradually rounded by the splitting away of sharp corners. When the surface layers of rounded boulders gradually split off the process is called *onion peeling*, because the various layers look like the layers of an onion, peeled off one after another. The technical term for this process is *exfoliation* (Plate 4.B).

(b) Repeated wetting and drying. Exfoliation is not confined to desert areas. Similar stresses may be set up in rocks by repeated wetting and drying of the surface layers. This takes place especially in tropical regions, like Malaysia, where short downpours saturate the rocks and then the hot sun quickly dries them again. Repeated wetting and drying also occurs at the coast, where rocks may be rapidly dried by sun and wind between tides. When rocks are wetted the outer layers absorb a certain amount of moisture and expand. When they dry this moisture evaporates and they quickly shrink. When this happens repeatedly the outer layers split off. It should also be stressed that the wetting and drying of the rocks in deserts is probably just as important as temperature changes in mechanical weathering. The rocks dry very quickly indeed after being wetted by brief desert rain-storms.

(c) Frost action. In temperate latitudes frost is a potent rock breaker. All rocks contain cracks and joints, or pore spaces, and after a shower water or snow collects in such places. When the temperature drops at night or during the winter, this water freezes. When water freezes it expands by one-tenth its volume and exerts a bursting pressure of almost 140 kg per square cm (2,000 lb. to the square inch). Repeated freezing of this kind will deepen and widen the original cracks and crevices and break the rock into angular fragments (Fig. 4.2). On mountain peaks this process creates sharp pinnacles and angular outlines. Such peaks are described as *frost-shattered*

Fig. 4.2 Frost action as an agent of mechanical weathering



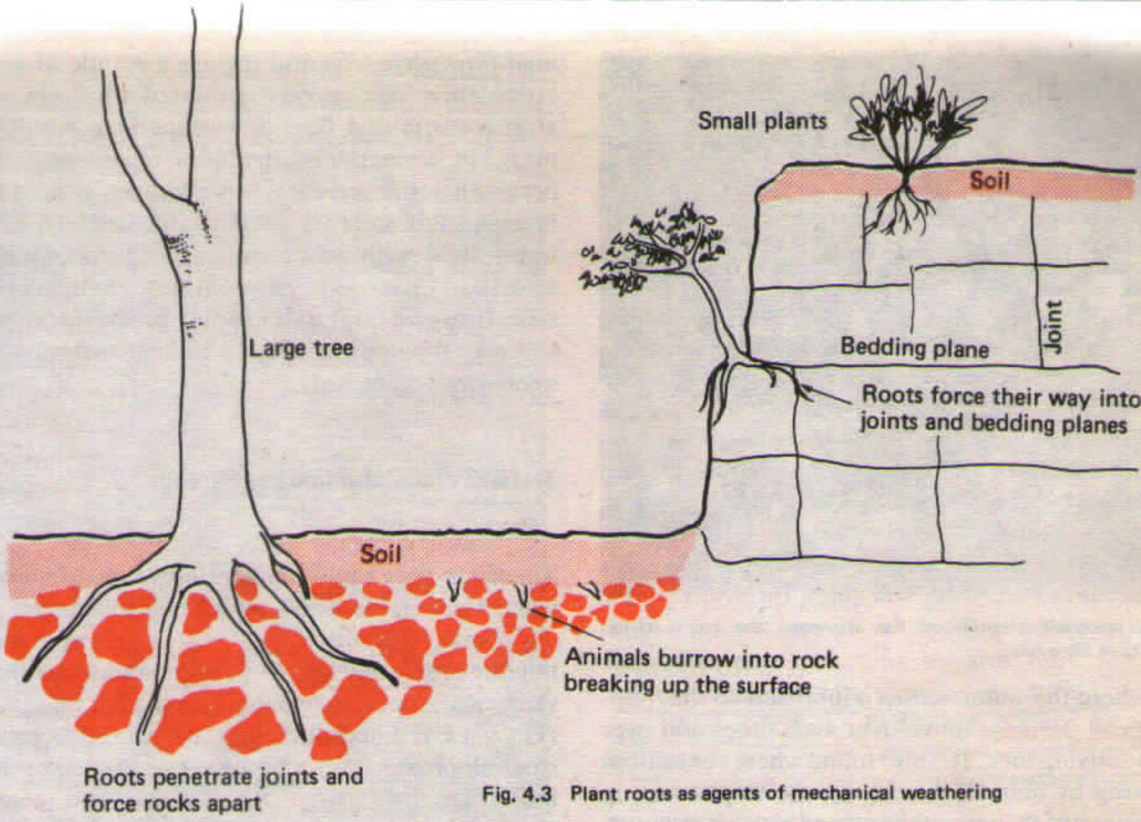


Fig. 4.3 Plant roots as agents of mechanical weathering

peaks. Angular fragments of rock are prised from mountain-sides or cliff faces and fall to the foot of the slope where they accumulate to form screes.

(d) Biotic factors. Small fragments of rock loosened by either chemical or mechanical weathering lodge in cracks and crevices in the rock and plants may sprout in such crevices. As they grow their roots penetrate the rocks below, usually along joints and other lines of weakness, prising them apart. You have often come across large trees growing near roads or the courtyards of houses that finally prise open the concrete or paving stones above their roots. The process is just the same on a smaller scale in a natural setting (Fig. 4.3).

Men, in the course of mining, road construction and farming, also contribute to mechanical weathering by excavating the rocks and rendering them more vulnerable to the agents of denudation.

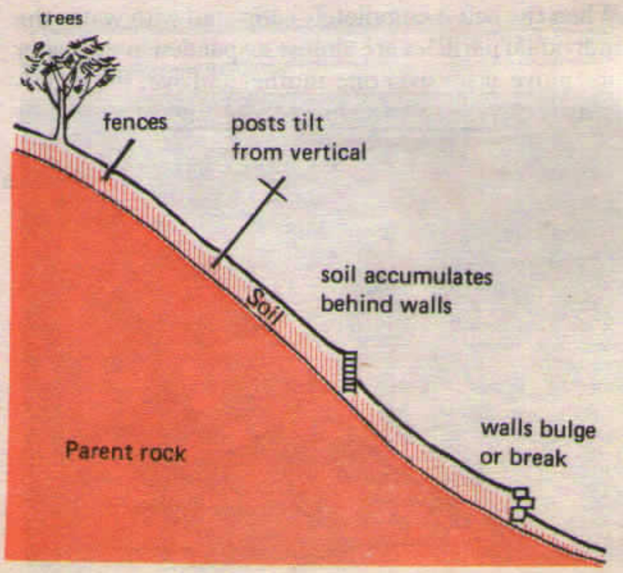
Mass Movement

Mass movement is the movement of weathered materials down a slope due to *gravitational forces*. The movement may be gradual or sudden, depending on the gradient of the slope, the weight of the weathered debris and whether there is any lubricating moisture supplied by rain-water. Several kinds of mass movement are distinguished.

1. Soil Creep

This is a slow, *gradual* but more or less continuous movement of soil down hillslopes. The movement is not very noticeable, especially when the slope is fairly gentle or when the soil is well-covered with grass or other vegetation. Soil creep is most common in damp

Fig. 4.4 Evidences of soil creep



4.C A landslide after flood has damaged the road *Jabatan Penerangan Malaysia*

soils where the water acts as a lubricant so that individual soil particles move over each other and over the underlying rock. It is also found where continuous trampling by animals grazing on the slopes sets up vibrations which loosen the soil and cause it to move. Though the movement is slow and cannot readily be seen in action, the gradual movement tilts trees, fences, posts and so on which are rooted in the soil. The soil is also seen to accumulate at the foot of slope or behind obstacles such as walls, which may eventually be burst by the weight of soil above (Fig. 4.4).

2. Soil Flow (Solifluction)

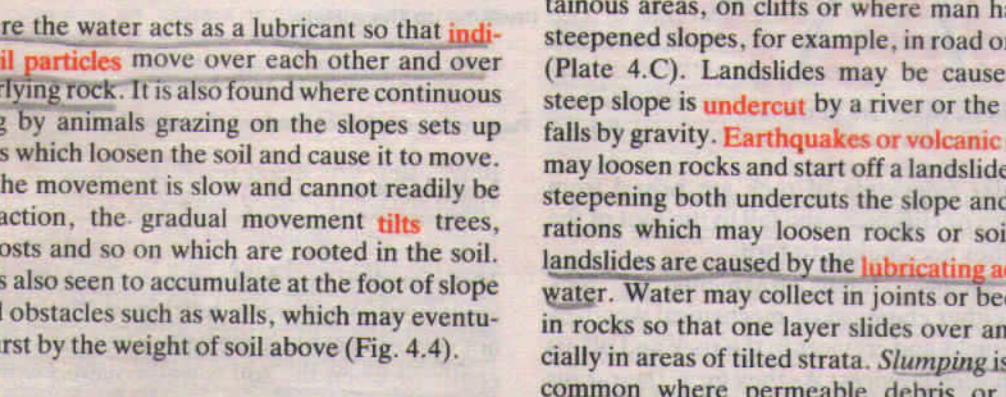
When the soil is completely saturated with water the individual particles are almost suspended in the water and move easily over one another and over the underlying rock. The soil acts like a liquid and a *soil-flow* or *mud-flow* occurs. In arid regions a mantle of weathered debris may become saturated with rain-water after a storm and flow downslope as a semi-liquid mass. In temperate and tundra regions soil flows occur when the surface layers of frozen ground thaw in spring. Soil and rock debris, lubricated by the melt-water, flow easily over the underlying frozen subsoil. In areas of peat soils, the peat absorbs much moisture. However if saturation point is reached the peaty soil may flow downslope. In Ireland such flows are known as *'bog-bursts'*.

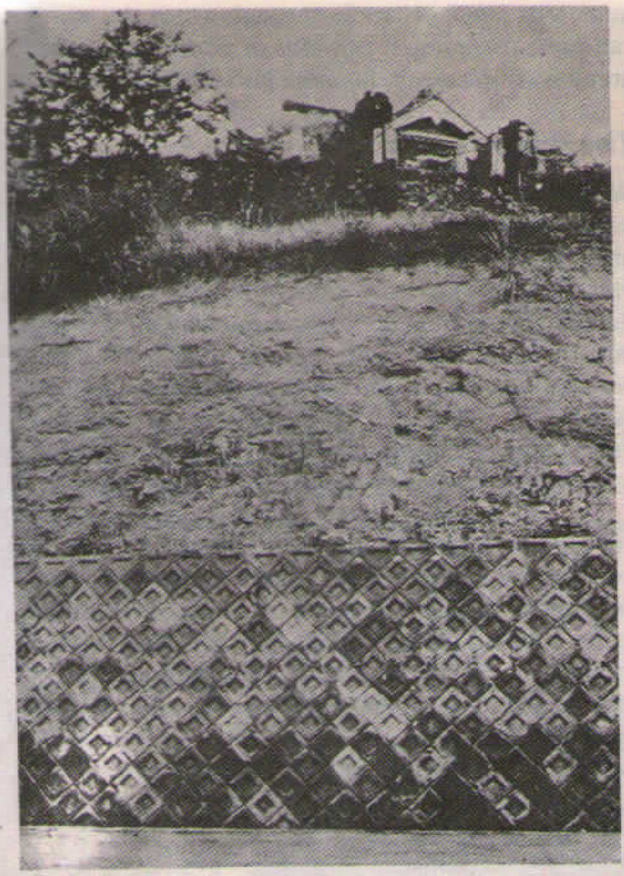
3. Landslides (Slumping or Sliding)

These are very rapid kinds of movement and occur when a large mass of soil or rock falls suddenly. Landslides usually occur on steep slopes such as in mountainous areas, on cliffs or where man has artificially steepened slopes, for example, in road or rail cuttings (Plate 4.C). Landslides may be caused because a steep slope is undercut by a river or the sea so that it falls by gravity. Earthquakes or volcanic disturbances may loosen rocks and start off a landslide. Man-made steepening both undercuts the slope and sets up vibrations which may loosen rocks or soil. But often landslides are caused by the lubricating action of rain-water. Water may collect in joints or bedding planes in rocks so that one layer slides over another, especially in areas of tilted strata. *Slumping* is particularly common where permeable debris or rock layers overlie impermeable strata such as clay. Water sinking through the permeable material is halted by the clay. The damp clay provides a smooth slippery surface over which the upper layers easily slide (Fig. 4.5).

Water may collect at the base of the regolith because it sinks readily into the weathered material

Fig. 4.5 Landslide





4.D An effective way of preventing landslide by building a concrete wall—Taiwan *Goh Cheng Leong*

but more slowly into the solid rock beneath. The water may allow the regolith to slide away from the underlying rock.

Man often enhances the possibility of landslides by clearing natural vegetation for agriculture or housing. Removal of the plant cover allows more water to penetrate the soil and rocks. In areas such as the Cameron Highlands, where steep slopes have been cleared, there is much evidence of minor slumps and slides, the old scars showing up clearly in the tea gardens. Extensive landslides, whether natural or man-induced, can have disastrous consequences, burying villages, railway lines or people. Spectacular landslides have taken place in many parts of the world, including South Wales, British Columbia, Hong Kong and the Cameron Highlands where the village of Ringlet was partially buried in 1961 and several houses were ruined.

Groundwater

The whole process of the circulation of water between the land, sea and atmosphere is known as the *hydrological cycle*. The movement of the water in the atmosphere and its effect on climate are dealt with in Chapters 13 and 14. The seas and oceans are discussed in Chapter 12. The effect of water on the land as an agent of weathering, erosion, transport and deposition is dealt with in this and the following chapters, especially Chapter 5.

When rain falls on the earth it is distributed in various ways. Some is immediately evaporated and thus returns to the atmosphere as water vapour. Some is absorbed by plants and only gradually returned to the atmosphere by *transpiration* from the leaves of plants. Much of it flows directly off slopes to join streams and rivers, eventually reaching the seas and oceans. This is known as run-off A considerable proportion of the water received from rain or snow, however, percolates downwards into the soil and rocks, filling up joints and pore-spaces and forming what is known as goundwater Groundwater plays an important part in weathering and mass movement and is also important as a means of natural water storage. It re-enters the hydrological cycle by way of springs.

The amount of water available to form groundwater depends to some extent on climate In dry climates much precipitation may be quickly evaporated into the dry atmosphere and little moisture may percolate into the ground. In very humid conditions, where the surface of the ground may already be moist, much water may be moved as run-off. In moderately humid areas water both runs off and sinks into the ground. The proportion of the rainfall absorbed as groundwater may depend on the season of the year.

More important, however, is the nature of the

4.E A severe flood in Kuala Kangsar (Malaysia) in 1967—the main street of the town was under 4-6 m (15-20 feet) of water *Jabatan Penerangan Malaysia*

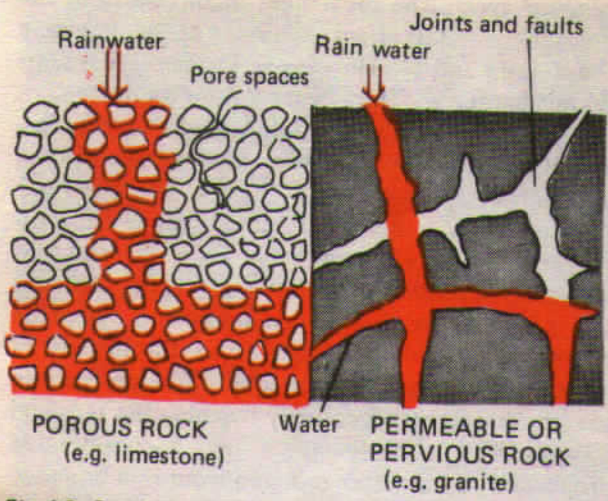


Fig. 4.6 Porosity and permeability of rocks

rocks and how easily they absorb and retain water. Various rocks and soils differ greatly in their porosity and permeability; the amount of groundwater present and the depth at which it lies are governed by these characteristics. Porous rocks are those, like sandstone, which have many pore-spaces between the grains. Water is easily absorbed by such rocks and may be stored in the pore-spaces. Permeable or pervious rocks are those which allow water to pass through them easily (Fig. 4.6). Thus most porous rocks are also permeable. However some rocks are porous but impermeable. Clay, for example, is highly porous since it is made up of innumerable very fine particles with pore-spaces between them. It thus absorbs a great deal of water. However, the pore-spaces are so small that the water does not move easily through the rock, which is thus impermeable. On the other hand, granite which is a crystalline rock and consequently non-porous is often pervious. Its individual crystals absorb little or no water but the rock may have numerous *joints or cracks* through which the water can pass, rendering it pervious or permeable. Some granites are, however, far more pervious than others.

The Water-Table

Water which seeps through the ground moves downward under the force of gravity until it reaches an impermeable layer of rock through which it cannot pass. If there is no ready outlet for the groundwater in the form of a spring, the water accumulates above the impermeable layer and saturates the rock. The permeable rock in which the water is stored is known as the aquifer (Fig. 4.7). The surface of the saturated area is called the *water-table*. The depth of the *water-table* varies greatly according to relief and to the type of rocks. The water-table is far below the surface of hill-tops but is close to the surface in valleys and flat low-lying areas where it may cause *waterlogging* and swampy conditions. The depth of the water-table also varies greatly with the seasons. When plenty of rain is available to augment groundwater supplies the water-table may rise, but in dry periods, no new supplies are available, and the water-table is lowered as groundwater is lost through seepages and springs (Fig. 4.7).

Fig. 4.8(a) Spring seeps from edge of pervious rock lying above an inclined impervious strata

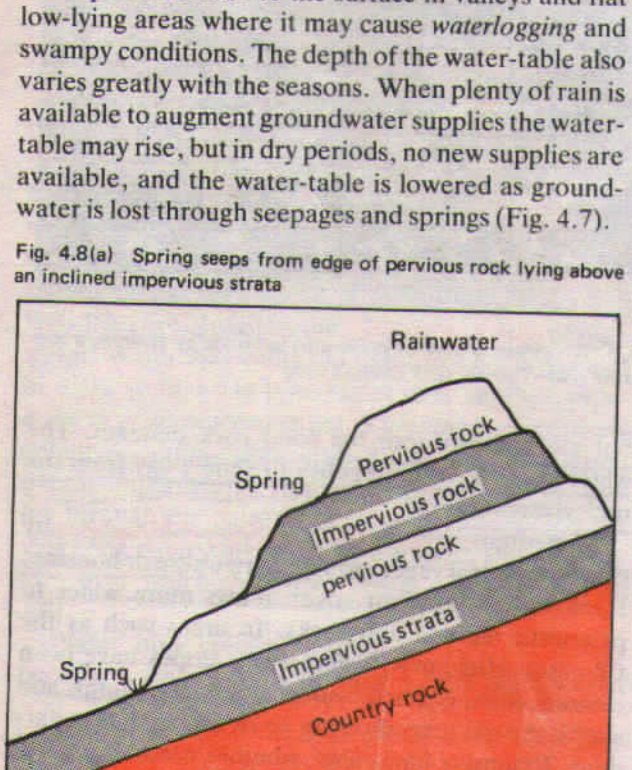
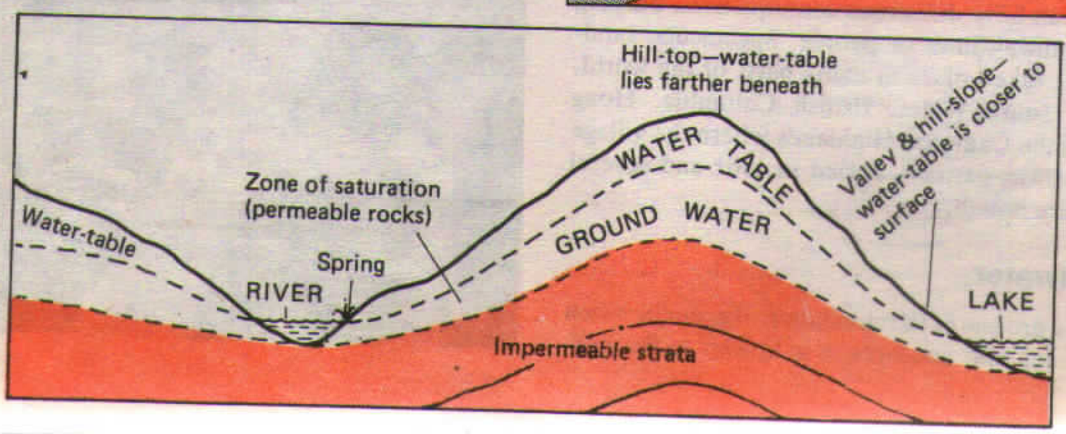


Fig. 4.7 Groundwater table and its relationship to the curvature of the land



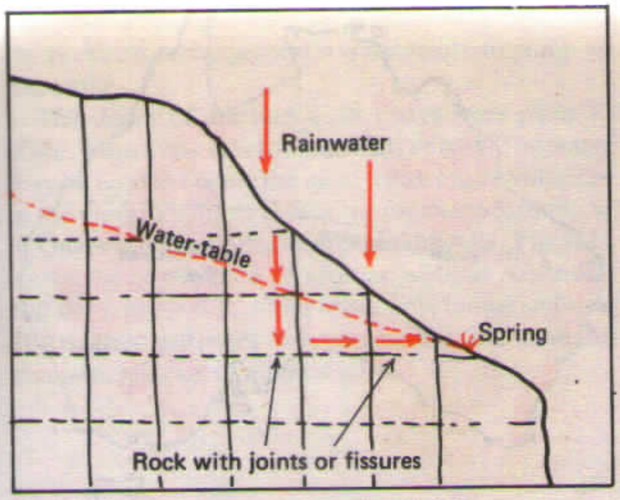


Fig. 4.8(b) Spring emerges from rocks with joints

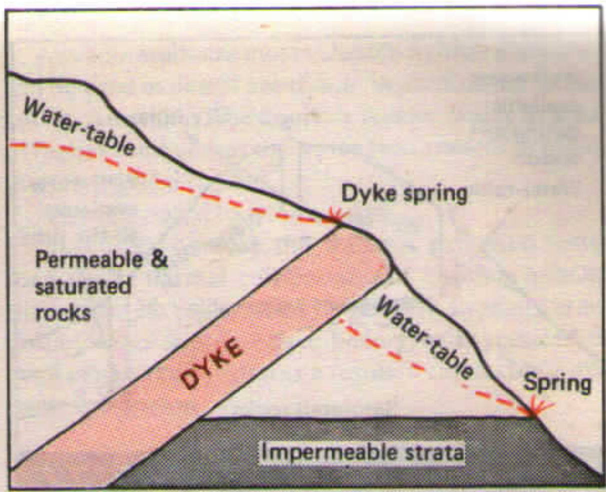


Fig. 4.8(c) A dyke spring

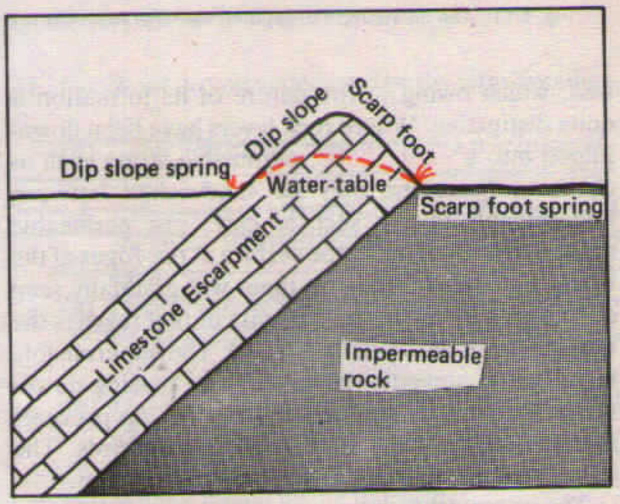


Fig. 4.8(d) Scarp-foot spring and dip-slope spring

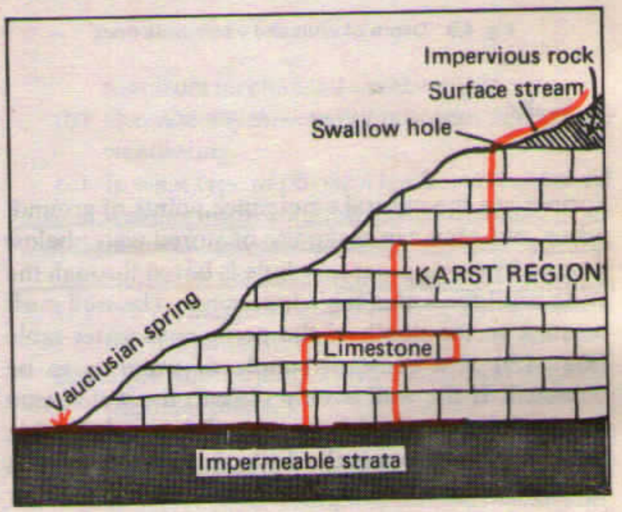


Fig. 4.8(e) Vauclusian spring in karst regions

Springs and Wells

1. Springs

The groundwater stored in the rock is released onto the surface at points where the water-table reaches the surface. A spring is simply an outlet for such water. The water may seep gradually out of the rock or may gush out as a fountain. Springs are of several kinds due to the nature of the rocks and the position of the water-table. The main types are described below.

(a) In areas of *tilted strata*, where permeable and impermeable rocks alternate, water emerges at the base of the permeable layers (Fig.4.8a).

(b) In *well-jointed rocks* water may percolate downwards until it reaches a joint which emerges at the surface. The water may come to the surface through the joint (Fig. 4.8b).

(c) Where a dyke or sill of impermeable rock is intruded through permeable rocks, it causes the water-table to reach the surface and the water issues as a spring (Fig. 4.8c).

(d) In limestone or chalk escarpments, where the permeable rock lies between impermeable strata, water issues at the foot of the scarp as a *scarp-foot spring*, or near the foot of the dip-slope as a *dip-slope spring*, as illustrated in Fig. 4.8d.

(e) In karst regions rivers often disappear underground. They then flow through passages worn in the rock by solution, and may re-emerge when limestone gives place to some impermeable rock. This kind of spring is sometimes called a *vauclusian spring* but is better referred to as a *resurgence* (Fig. 4.8e; see also Chapter 8).

Some other types of springs, e.g. hot springs, mineral springs and geysers are described in Chapter 3.

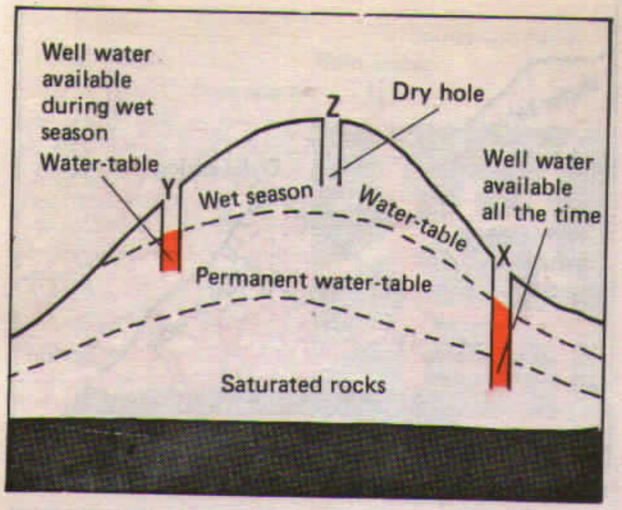


Fig. 4.9 Depth of wells and water-table mark

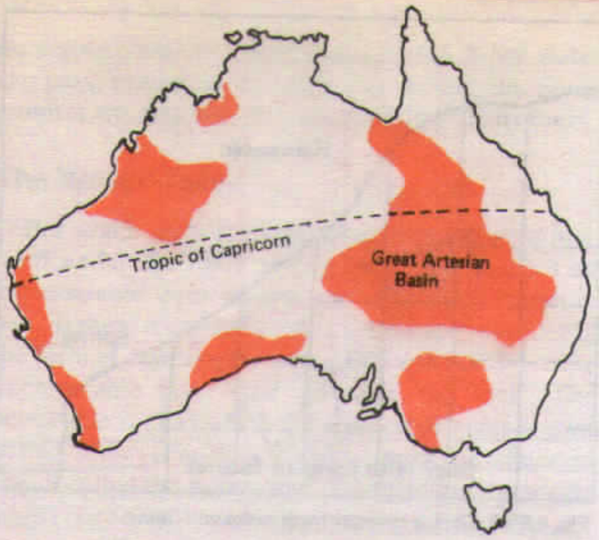


Fig. 4.11 The distribution of artesian basins in Australia

2. Wells

Springs are the natural emergence points of ground water, but Man can make use of stored water below ground by sinking wells. A hole is bored through the earth until the water-table is reached. The well must be sunk to the depth of the permanent water-table (Fig. 4.9) if a constant supply of water is to be obtained. If the well is only sunk to the wet-season depth of the water-table, water will be unobtainable when the level drops in the dry season. When a well is bored, the water usually has to be raised by hand or by mechanical pumping. Wells are particularly important in arid areas where there is little surface water but where the underlying rocks contain ground-water.

A particularly important type of well is the *artesian well*, which owing to the nature of its formation is quite distinctive. Where rock layers have been down-folded into a basin shape, permeable strata such as chalk or limestone may be sandwiched between impermeable layers, such as clay. The permeable rocks may only come to the surface at the edges of the basin, but water falling on them will gradually seep downwards by the force of gravity until it reaches the lowest part of the basin (Fig. 4.10). The impermeable layer below prevents the water from passing downwards while the impermeable layer on top prevents any possibility of the water escaping upwards. The aquifer is thus saturated to the brim of the basin.

The water is thus trapped in the aquifer under great pressure and when a well is bored, the pressure of water downwards from all around the basin is sufficient to force the water up the bore-hole so that it gushes onto the surface like a fountain. After a time

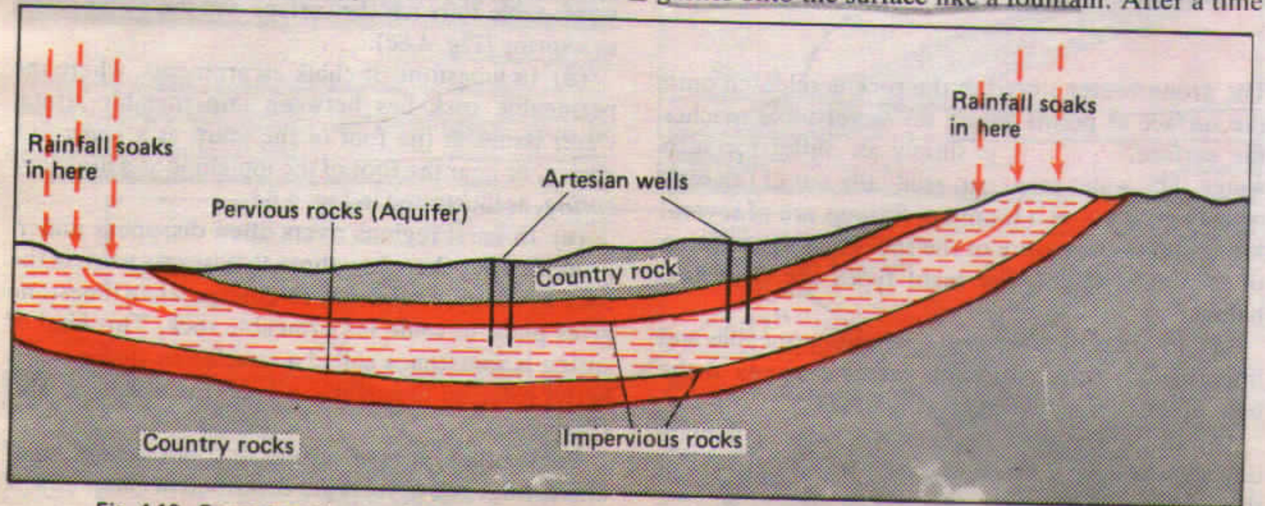


Fig. 4.10 Formation of an artesian basin where a pervious layer (aquifer) is between two impervious strata of rocks

the pressure decreases and it is necessary to pump up the water.

The depth of artesian wells varies from place to place, from a few feet to thousands of feet. The water may be used to supply the needs of an entire village as in the Great Plains of U.S.A. or for sheep farming as in Queensland and other parts of Australia. Fig. 4.11 shows the distribution of artesian wells in Australia. But the water is sometimes unsuitable for agricultural or irrigation purposes as it may be hot or contain an excessive amount of mineral salts.

Artesian wells are most valuable to Man when they can be used in desert areas, e.g. in parts of the Sahara and in Australia. The aquifers receive water in areas of higher rainfall, but the water accumulates in basins underlying arid regions.

All wells bored by Man tend to deplete groundwater resources because the water is extracted faster than under natural conditions and also much faster than it can be replenished by rainfall. In many areas groundwater supplies have been greatly reduced or even exhausted by Man as a result of carelessness and overexploitation.

QUESTIONS AND EXERCISES

1. (a) What do you understand by the term 'weathering'?
   (b) Name 4 natural forces that play a role in weathering.
   (c) Differentiate mechanical weathering from chemical weathering and give examples of each.
2. (a) Describe how gravitational forces and rainwater assist in the mass movement of weathered materials on hill slopes.
   (b) Distinguish soil creep from landslides, and locate places where such occurrences have taken place.
3. (a) What is meant by the following:
      i. hydrological cycle
      ii. water-table
      iii. acquifer.
   (b) For any *two* of the above, discuss their relationship with groundwater.
4. 'While the earth's crust is undergoing constructive changes to create new relief, external forces of nature are working vigorously to level this down.' Discuss.
5. Elaborate on any *three* of the following:
   (a) Exfoliation is the result of temperature changes in deserts.
   (b) Screes accumulate at the foot of steep mountains in temperate lands.
   (c) There are many ways in which springs can be formed.
   (d) Artesian wells have a distinct formation.
6. (a) In what ways are chemical weathering different from mechanical weathering?
   (b) Describe any *three* major processes of chemical weathering.
   (c) In what type of physical landform is chemical weathering by solution most dominant?
   (d) Name a few well-known physical features caused by solution in chemical weathering.
7. (a) Why is mechanical weathering also known as physical weathering?
   (b) State *four* ways by which mechanical weathering takes place.
   (c) In what climatic regions is mechanical weathering by frost action most potent?
8. With reference to examples, carefully distinguish betweeen:
   (a) 'weather' and 'erosion'
   (b) 'porous rocks' and 'pervious rocks'
   (c) 'a spring' and 'a well'
   (d) 'screes' and 'pebbles'.
9. Describe and explain the manner in which a land surface may be changed by
      i. rain;
      ii. frost;
      iii. wind.

   Illustrate your answer with annotated diagrams and specific examples.
10. (a) Explain what happens to precipitation when it falls on the land surface.
    (b) What factors determine the amount of water entering the ground in a particular place?
    (c) Why is the 'underground scenery' better developen in karst regions?

Chapter 5 Landforms Made by Running Water

The Development of a River System

When rain falls, part of it sinks into the ground, some is evaporated back into the atmosphere and the rest runs off as rivulets, brooks, streams and tributaries of rivers that flow down to the sea. This running water forms a potent agent for denuding the earth's surface. Denudation is the *general lowering* of the earth's surface. This takes place because such agents of erosion as rivers, ice, wind and waves wear away the rocks and transport the eroded debris to lower land or right down to the sea. But erosion cannot take place unless the rocks are first weakened or shattered by exposure to the elements. Rain, frost and wind weather the rocks so that they can be eroded more easily. Unlike glaciers and snow, which are confined to the cold and temperate latitudes; waves which act only on coastlines; winds, which are only 'efficient' in deserts; the effect of running water is felt all over the globe *wherever water is present*. Running water is thus the most important single agent of denudation.

The source of a river may be a spring, a lake or a marsh, but it is generally in an *upland* region, where precipitation is heaviest and where there is a slope down which the run-off can flow. The uplands therefore form the catchment areas of rivers. The crest of the mountains is the divide or watershed from which streams flow down the slopes on both sides to begin their journey to the oceans. The initial stream that exists as a consequence of the slope is called the consequent stream. As the consequent stream wears down the surface by deepening its channel downwards, it is joined by several tributaries either *obliquely* or at *right angles* depending on the alignment and the degree of resistance of the rocks.

If the rocks are composed of homogeneous beds of uniform resistance to erosion, the tributaries will join the main valley obliquely as insequent streams. The drainage pattern so evolved will be *tree-like* in appearance, and is therefore described as dendritic drainage, after a Greek word *dendron* meaning 'tree' (Fig. 34). On the other hand, if the rocks are made up of alternate layers of hard and soft rocks, the tributaries tend to follow the pattern of the *rock structure*. If the outcrops of the rocks occur at right angles to the main valley, the tributaries will join it at right angles as subsequent streams.

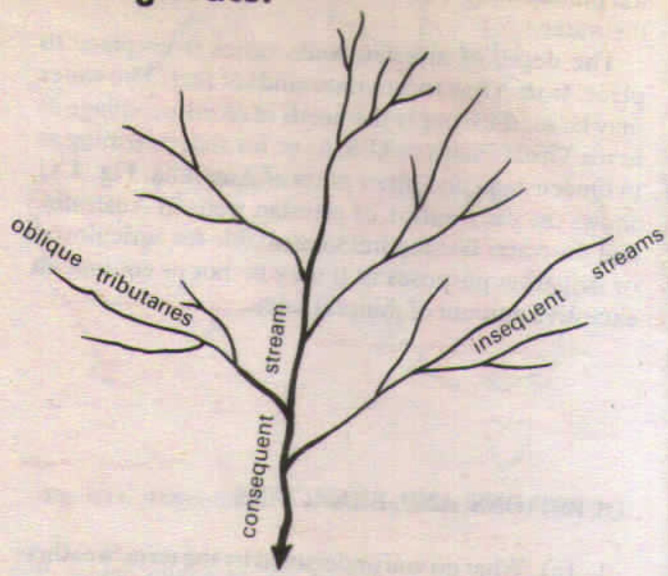


Fig. 34 Dendritic or tree-like drainage pattern developed on homogeneous rock or beds of equal resistance

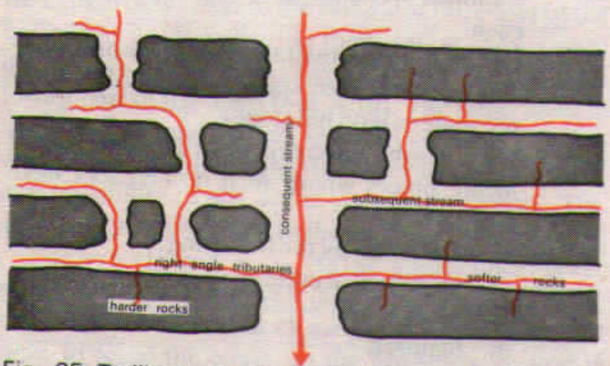


Fig. 35 Trellised or rectangular drainage pattern developed on alternating outcrops of harder and softer rocks

The drainage pattern so developed will be *rectangular* in shape and is called trellised drainage (Fig. 35).

The Mechanism of Humid Erosion

Humid erosion covers the entire scope of sculpturing effects of running water from the action of rainwater to that of the rivers. Mass movements of earth and weathered materials on hill-slopes down to valleys are mainly due to the lubricating action of water which allows a mass of materials to move under gravity. This is particularly acute where the slopes are steep. The *slow* movement of soil down a hill-slope is call soil-creep. A more *sudden* movement due to the lubricating effect or rain-water may cause widespread landslides. In mountainous districts where the roads and railway tracks are cut through steep-sided valleys landslides may obstruct railway lines, cut off road communications and even bury villages and people.

The Processes of River Action

When a river flows it carries with it eroded materials. These comprise the river's load, and may be divided into *three* distinct types.

1. **Materials in solution.** These are minerals which are dissolved in the water.

2. **Materials in suspension.** Sand, silt and mud are carried along suspended in the water as the stream flows.

3. **The traction load.** This includes coarser materials such as pebbles, stones, rocks and boulders, which are rolled along the river bed.

It has been estimated that for every square mile of the earth's surface, more than 200 tons of solid materials in suspension and more than 50 tons of materials in solution are being carried off by running water every year. The Mississippi River which drains an area almost half the size of the United States itself, removes more than two million tons of eroded material into the Gulf of Mexico daily. Consequently the river basins are being lowered, and in the case of swift-flowing rivers like the Irrawaddy, its drainage basin is being lowered by about a foot in every 400 years! During floods the amount of rock debris swept off by rivers is very much greater. We can see this from the mud that colours the river-water during a heavy rain. The ability of a river to move the various grades of materials depends greatly upon the volume of the water, the velocity of the flow and lastly the size, shape and weight of the load. It is said that by doubling the velocity of a river, its transporting power is increased by more than 10 times! It is therefore not surprising to find huge boulders that are 'stranded' in normal times, but may be moved during seasonal floods. The movement of rivers is thus intermittent, acting vigorously in certain parts of the year and remaining less active at other times.

River Erosion and Transportation

In rivers, erosion and transportation go on simultaneously, comprising the following inter-acting processes.

1. **Corrasion or abrasion.** This is the mechanical grinding of the river's traction load against the *banks and bed* of the river. The rock fragments are hurled against the sides of the river and also roll along the bottom of the river. Corrasion takes place, in two distinct ways.

(a) Lateral corrasion. This is the sideways erosion which widens the V-shaped valley.

(b) Vertical corrasion. This is the downward action which deepens the river channel.

2. **Corrosion or solution.** This is the chemical or solvent action of water on soluble or partly-soluble rocks with which the river comes into contact. For example calcium carbonate in limestones is easily dissolved and removed in solution.

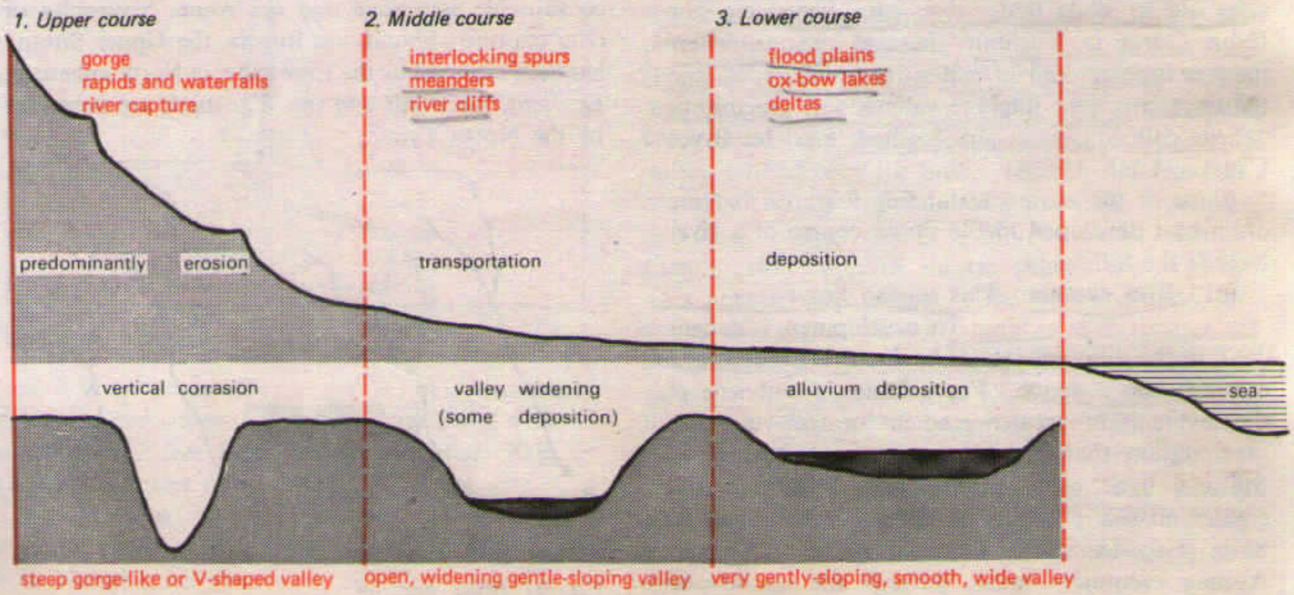


Fig. 36 The graded long profile and typical cross section of a river from source to mouth

3. Hydraulic action. This is the mechanical loosening and sweeping away of materials by the river water itself. Some of the water splashes against the river banks and surges into cracks and crevices. This helps to disintegrate the rocks. The water also undermines the softer rocks with which it comes into contact. It picks up the loose fragments from its banks and bed and transports them away.

4. Attrition. This is the wear and tear of the transported materials themselves when they roll and collide into one another. The coarser boulders are broken down into smaller stones; the angular edges are smoothed and rounded to form pebbles. The finer materials are carried further down-stream to be deposited.

The Course of a River

The course of a river may be divided into *three* distinct parts (Fig. 36). 1. The upper or mountain course (in the stage of youth), 2. The middle or valley course (in the stage of maturity), 3. The lower or plain course (in the stage of old age).

1. The Upper or Mountain Course

This begins at the source of the river near the watershed, which is probably the crest of a mountain range. The river is very swift as it descends the steep slopes, and the predominant action of the river is vertical corrasion. The valley developed is thus deep, narrow and distinctively V-shaped. Down-cutting takes place so rapidly that *lateral corrasion* cannot keep pace. In some cases where the rocks are very resistant, the valley is so narrow and the sides are so steep that gorges are formed e.g. the Indus Gorge in Kashmir. In arid regions, where there is little rainfall to widen the valley sides, and the river cuts deep into the valley-floor, precipitous valleys called canyons are formed, e.g. the Bryce Canyon, Utah, U.S.A.

Some of the more outstanding features that are often best developed in the upper course of a river include the following.

(a) River capture. This is also known as river piracy or river beheading. Its development is dependant on the different rate of back-cutting (headward erosion) into a divide. For instance, if one side of the divide is of greater gradient or receives more precipitation than the other, stream A in Fig. 37 will cut back more rapidly than stream B. Its greater erosive power will succeed in enlarging its basin at the expense of the weaker stream. Stream A may eventually break through the divide and capture or pirate stream B. The bend at which the piracy occured is termed as the elbow of capture. The beheaded stream (Z) is called the misfit. The valley below the elbow is the wind gap, and may be valuable as a road and rail route. Examples of river capture abound. In Burma, the Upper Sittang has been captured by the Irrawaddy; in Northumberland, England, the Blyth and the Wansbeck are beheaded by the North Tyne.

A deep gorge in the Cuzco Department of Peru *Paul Popper*

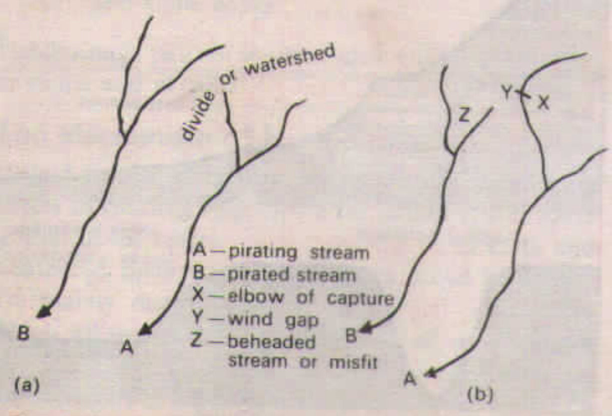


Fig. 37 River capture
(a) before capture (b) after capture

(b) Rapids, cataracts and waterfalls. These are liable to occur at any part of the river course, but they are most numerous in the mountain course where changes of gradient are more abrupt and also more frequent. Due to the *unequal resistance* of hard and soft rocks traversed by a river, the outcrop of a band of hard rock may cause a river to 'jump' or 'fall' downstream. Rapids are formed (Fig. 38). Similar falls of

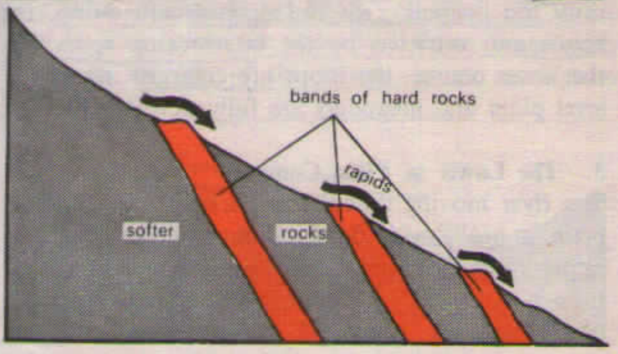


Fig. 38 Rapids, cataracts

greater dimensions are also referred to as *cataracts*, of which there are five along the Nile that interrupt smooth navigation. When rivers plunge down in a sudden fall of some height, they are called waterfalls (Fig. 39). Their great force usually wears out a plunge-pool beneath. Waterfalls are formed in several ways.

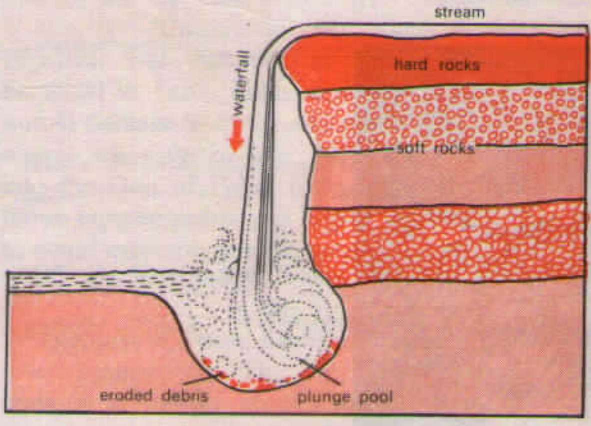


Fig. 39 A waterfall with plunge pool

i. When a bar of resistant rock lies transversely across a river valley, e.g. the Niagara Falls, U.S.A., which is 167 feet high and the Kaieteur Falls in Guyana, 825 feet high.

ii. When a fault-line scarp caused by faulting lies across river, e.g. Victoria Falls on the River Zambezi, plunging 360 feet.

iii. When water plunges down the edge of a plateau like the River Congo which leaps for 900 feet through a series of more than 30 rapids as Livingstone Falls.

iv. Glaciation produces hanging valleys where tributary streams reach the main U-shaped valley below as waterfalls, e.g. the Yosemite Falls of California with a total descent of 2,560 feet.

2. The Middle or Valley Course

In the middle course, lateral corrasion tends to replace vertical corrasion. Active erosion of the banks widens the V-shaped valley. The volume of water increases with the confluence of many tributaries

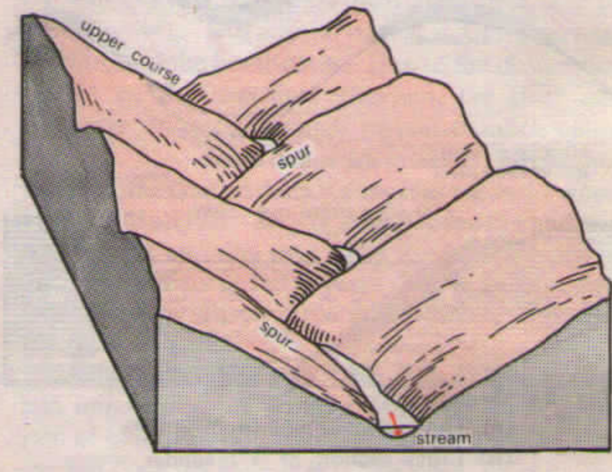


Fig. 40 Interlocking spurs

and this increases the river's load. The work of the river is predominantly transportation with some deposition. Downstream, the interlocking spurs (Fig. 40) that project from both sides of the valley are cut back into a line of bluffs. Rain-wash, soil creep, landslides and gullying gradually widen the valley, cutting back the sides. The river's treble task of valley-cutting, bed-smoothing and debris-removal are being carried out in a more tranquil manner than in the mountain course though the velocity does not decrease. Some of the load is dropped or deposited. Again this depends on the *volume of flow*, for in the event of flood, the river's erosive power and its capability for load-carrying is greatly increased. The more outstanding features associated with the valley course are these.

(a) Meanders. As water flowing under gravity seldom flows straight for any long distance, a *winding* course soon develops. The irregularities of the ground force the river to swing in loops, forming meanders, a term derived from the winding River

Meanderez in Asia Minor. The mechanism of meander formation is illustrated in Fig. 41.

(b) River cliffs and slip-off slopes. When the flow of water PQ (in Fig. 41) enters the bend of the river, it dashes straight into Q, eroding the outer bank into a steep river-cliff at Q. The water piles up on the outside of the bend because of the centrifugal force. A bottom current RS is set up in a corkscrew motion and is hurled back into mid-stream and the inner bank. Shingle is thus deposited here

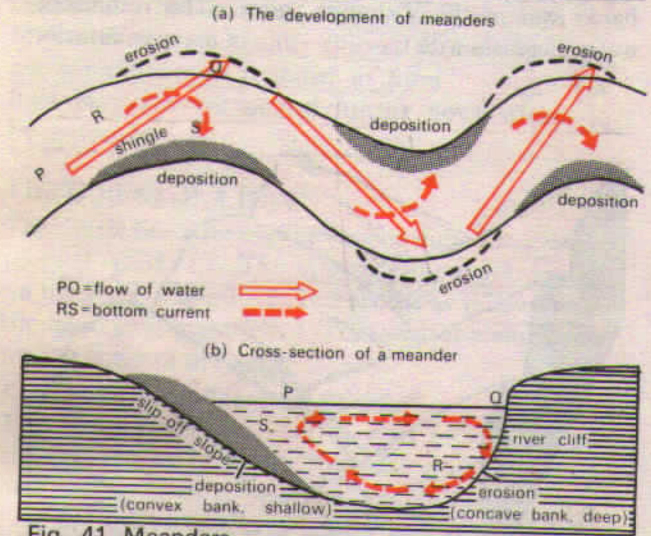


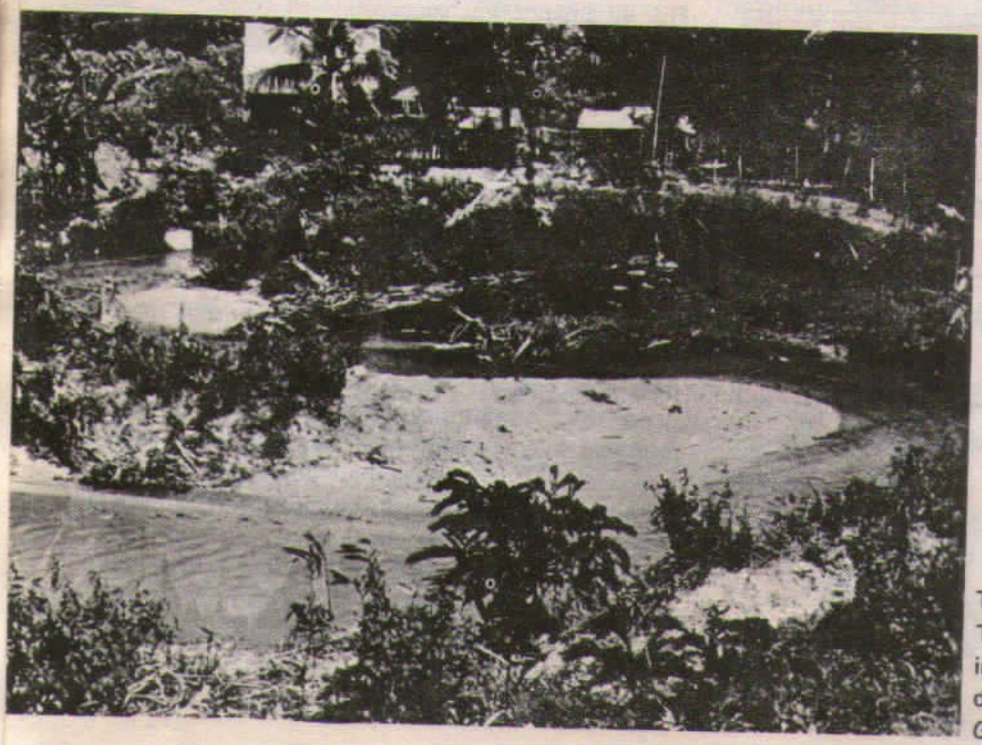
Fig. 41 Meanders
(a) The development of meanders
(b) Cross-section of a meander

at S, where the slip-off slope is very gentle. The outer bank is therefore the bank of continuous erosion and the inner bank is the bank of continual deposition.

(c) Interlocking spurs. As the stream flows on, the meanders migrate progressively outwards with the interlocking spurs alternating with the undercut slopes as shown in Fig. 40. It must be pointed out at this stage that meanders in the middle course are only the beginning of the downstream swing, for bends are restricted by the interlocking spurs. In the lower course, the loops are enlarged across the level plain and meanders are fully developed.

3. The Lower or Plain Course

The river moving downstream across a broad, level plain is heavy with debris brought down from the upper course. Vertical corrasion has almost ceased though lateral corrasion still goes on to erode its banks further. The work of the river is mainly deposition, building up its bed and forming extensive *flood plains*. The volume of water is greatly swelled by the additional tributaries that join the main stream. Coarse materials are dropped and the finer silt is carried down towards the mouth of the river. Large sheets of materials are deposited on the level plain and may split the river into several complicated channels, so that it can be described as a braided stream. Some of the major plain course features are the following.



The Sg. Muara in Negri Sembilan. The river swings from side to side in tight meanders. Note the sand deposited on the slip-off slope
G.C. Morgan

(a) Flood plain. Rivers in their lower course carry large quantities of sediments. During annual or sporadic *floods*, these materials are spread over the low-lying adjacent areas. A layer of sediment is thus deposited during each flood, gradually building up a fertile flood plain (Fig. 42). When the river flows normally its bed is raised through the accumulation of deposits and material is also dropped on the sides forming raised banks called levees. It will not be long before the water level flows dangerously close to the top of the levees. In an attempt to

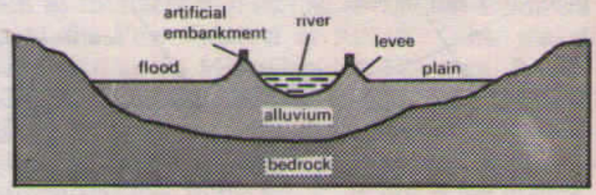


Fig. 42 Section of a flood plain (with levee and artificial embankment)

minimise the risk of floods, artificial embankments are erected on the natural levees, but this allows the river to rise further. When they can no longer withstand the pressure of the flood water, the banks burst, damaging property and drowning thousands. Disastrous floods of this nature frequently occur in the Yang-tze Kiang, Mississippi, Po and Ganges plains. But the best known river for floods is the Hwang-Ho, 'China's Sorrow', where millions have perished. For example, in 1852 the Hwang-Ho breached its bank, killing a million people and did untold damage to farms and properties. The river's course was diverted over 300 miles away, draining into the Gulf of Pohai instead of the Yellow Sea. Nowadays, huge dredgers help to deepen the channels to avoid excessive sedimentation.

(b) Ox-bow lakes. These are also known as cut-offs or bayous in the Mississippi basin. In the lower course of a river, a meander becomes very much more pronounced. The outside bend or concave bank is so rapidly eroded that the river becomes almost a complete circle. There will come a time when the river cuts through the narrow neck of the loop, abandoning an ox-bow lake or *'mortlake'* (meaning dead lake). The river then flows straight. The ox-bow lake will later degenerate into a swamp through subsequent floods that may silt up the lake. It becomes marshy, and eventually dries up (Fig. 43).

(c) Delta. When a river reaches the sea, the fine materials it has not yet dropped are deposited at its mouth, forming a fan-shaped alluvial area called a

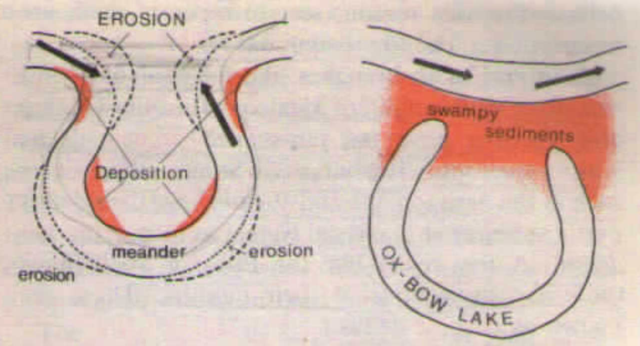


Fig. 43 The formation of an ox-bow lake

delta, a word which originated from the Greek letter Δ which closely resembled the triangular delta of the Nile (Fig. 44). This alluvial tract is, in fact, a seaward extension of the flood-plain. Due to the obstruction caused by the deposited alluvium, the river may discharge its water through several channels called distributaries. Some deltas are extremely large. For instance, the Ganges delta is almost as big as the whole of West Malaysia. Deltas extend sideways and seawards at an amazing rate. The River Po extends its delta by over forty feet a year. The town of Adria, located nearly fifteen miles inland was a seaport in the time of Christ!

Deltas differ much in their size, shape, growth and importance. A number of factors such as the rate of sedimentation, the depth of the river and the sea-bed, and the character of the tides, currents and waves greatly influence the eventual formation of

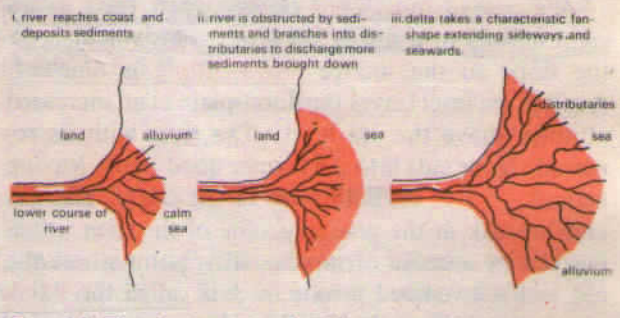
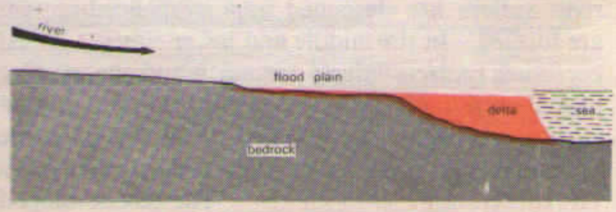


Fig. 44 The formation of deltas
(a) Stages in the formation of a delta



(b) Section through the lower course of a river, showing flood plain and delta deltas. For this reason, several types of delta are recognisible. The Mississippi has a bird's-foot *delta*, with several main branches like the foot of a bird extending into the Gulf of Mexico. The Nile, Ganges and Mekong have the fan-shaped arcuate deltas with numerous distributaries. Some other rivers such as the Amazon, Ob and Vistula have their deltas partly submerged in coastal waters to form estuarine *deltas*. A few rivers like the Ebro of Spain have tooth-like projections at their mouths. These are known as cuspate deltas.

The following summarises the conditions favourable for the formation of deltas.

(i) Active vertical and lateral erosion in the upper course of the river to provide extensive sediments to be eventually deposited as deltas.

(ii) The coast should be sheltered preferably *tideless*.

(iii) The sea adjoining the delta should be shallow or else the load will disappear in the deep waters.

(iv) There should be no large lakes in the river course to 'filter off' the sediments.

(v) There should be no strong current running at right angles to the river mouth, washing away the sediments.

River Rejuvenation

The earth's crust is far from stable and it is not surprising that, in the course of a river's development, parts may be uplifted or depressed, giving rise to certain characteristic features associated with rejuvenation, i.e. being young again.

A negative movement occurs when there is an *uplift of land* or a *fall in sea level*. This will steepen the slope so that active down-cutting is renewed. A fall in sea level leaves the flood-plain at an increased altitude above the sea level. The river with its renewed vigour cuts into the former flood-plain, leaving behind terraces on both sides of the river. There is also a break in the graded profile of the river, often marked by a series of rapids. This point where the old and rejuvenated profile meet is called the knick point or *rejuvenated head* (Fig. 45).

If rejuvenation occurs in the upper-course, the river valleys are deepened and steep-sided gorges are formed. In the middle and lower course vertical corrasion replaces lateral corrasion and the existing meanders are vertically eroded by the rejuvenated stream. A distinct new inner trench is cut in the old valley, and the river develops a deep valley with entrenched or incised meanders. The best developed incised meanders are those of the River Colorado, U.S.A., where the uplift of 7,000 feet in the Tertiary period renewed down-cutting to a fantastic depth. In some parts of the Grand Canyon, the depth is almost a mile. It is 10 miles wide at the top and 300 miles long. Other examples are the River Moselle in Germany, the River Wear at Durham, England, and the Wye Valley, Monmouthshire.

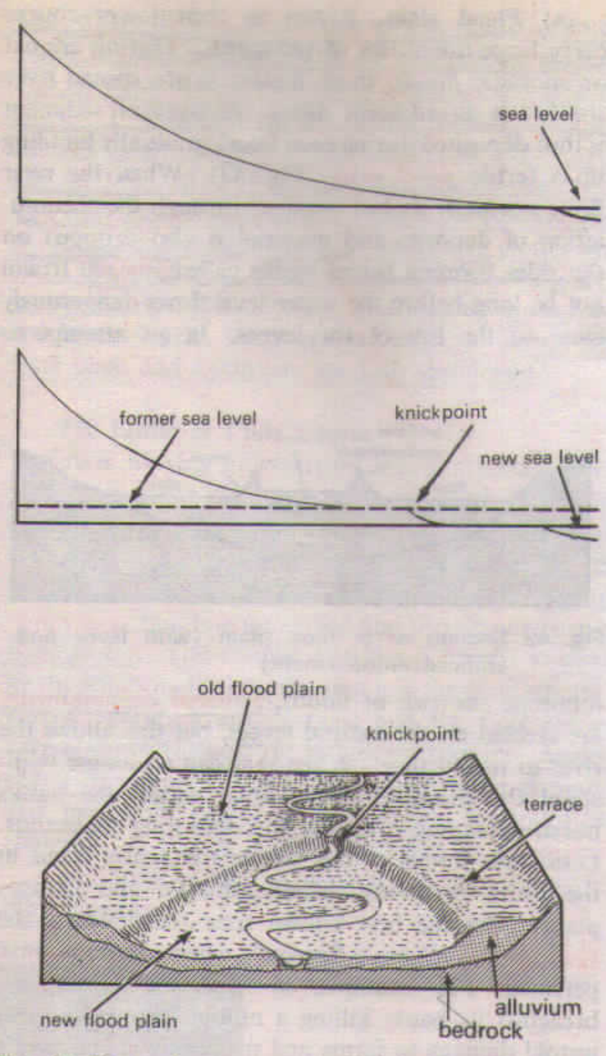


Fig. 45 River terraces and knickpoint due to rejuvenation
The rejuvenated river cuts down into previously deposited sediments to form a new valley leaving terraces at either side. At the head of rejuvenation the river falls to its new valley at a knickpoint

A positive movement occurs when there is a *depression* of land or a *rise in sea level*. This will submerge the lands along the coast, 'drown' the valleys and weaken the erosive power of the river. The flow is checked and large quantities of sediment will be dropped. The lower course of the river may be partly in the sea and features of deposition are shifted upwards to the middle course. The upper course is little affected when there is a rise in sea level. In many areas where the sea has risen this was probably caused by the release of water locked up in the ice masses during the Quaternary Ice Ages.

The Human Aspects of Rivers

In many countries, rivers form the chief highway of commerce and transport. The Yang-tze Kiang is navigable up to a thousand miles from its mouth. The Amazon, the world's greatest river is navigable 2,300 miles up-stream to the foot of the Andes, though it is less extensively used. Even the Nile with its cataracts is navigable for its first 960 miles up to the First Cataract at Aswan. Other major rivers such as the Mississippi, St. Lawrence, Rhine, Danube, Congo, Murray, Darling, Mekong and Irrawaddy all serve as important waterways for their respective countries. Some of them are useful for transporting logs to the saw mills, others are used to export bulky goods and import foodstuffs and raw materials.

But all rivers undertake three closely interrelated activities *erosion, transportation and deposition*. Their work has therefore both advantages and disadvantages from a human point of view. Rapids and waterfalls, interrupt the navigability of a river. By depositing large quantities of sediments in the lower course, the river silts up ports preventing large steamers from anchoring close to the shores. Deltas are thus less satisfactory sites than estuaries for the siting of large ports. Though this can be overcome by the construction of *artificial harbours* or by dredging this is expensive and, in some instances, impracticable. Some rivers change their courses from time to time, others are made difficult for navigation by their seasonal variations in the amount of water discharged, and others may suffer from ill-drained marshes and stagnant waters, leading to ill health and water-borne disease. Many rivers flood, bursting levees and causing untold damage to crops. The floods may add a layer of fertile silt to the flood plain, but excessive flooding as in the Orinoco may discourage people from cultivating crops at all.

On the other hand, the advantages of rivers often outweigh the destruction that they cause. In the upper course, rivers with steep gorges and waterfalls, provide natural sites for the generation of hydro-electric power, leading to the establishment of metallurgical industries, engineering and aluminum smelting, which can be profitably run on cheap, abundant power. *Dams* constructed across rivers hold back flood-water which if allowed to flow downstream unchecked may cause widespread disastrous floods in the lower course, e.g. in the Indus and Ganges plains. In regions of insufficient rainfall such as Egypt and the Chao Phraya basin in Thailand irrigation canals fed by the main stream enable many crops to be successfully cultivated. The upper streams develop river captures and the resultant wind gaps may facilitate construction of upland roads and railways. The river valleys provide a convenient means of land *communication*.

The flood plains of large rivers with their thick mantles of fine silt are some of the richest agricultural areas of the world. They may support very dense populations and a chain of large cities may be strung along their banks. Many deltas are equally fertile, e.g. the Ganges delta accounts for almost all the jute grown for world consumption; the Nile delta produces superior quality cotton and several crops of rice a year. The productive hinterlands are able to support ports such as New Orleans for the Mississippi basin, Rotterdam for the Rhineland and Calcutta for the Indo-Gangetic Plain.

Fresh-water fishing is important along many rivers and lakes. The organic matter brought down by the river waters provides valuable food for fish and for spawning purposes. Rivers supply water for domestic consumption, sewerage and other industrial purposes. In Lancashire, the soft-water from the Millstone Grit is used for washing, dyeing and bleaching textiles. Rivers form the political boundaries between many countries. The Mekong separates Laos from Thailand; and the Yalu forms a well defined border between North Korea and the eastern U.S.S.R.

QUESTIONS AND EXERCISES

1. What are the characteristic features you would expect to find in a river valley at the stage of youth, maturity and old age? Illustrate some of the more outstanding features with diagrams and examples.

2. By reference to specific examples, describe the major constructive and destructive processes at work along the course of a river from its source to its mouth.

3. With the aid of annotated diagrams, explain the constrasting features of any *three* of the

following pairs of features of a river:

(a) dendritic and trellised drainage pattern
(b) rapids and waterfalls
(c) estuary and delta
(d) tributaries and distributaries
(e) river capture and river cliff

4. Explain any *three* of the following statements briefly:

(a) Mass movement of earth is mainly due to the lubricating action of rain-water and gravitional forces.
(b) Vertical corrasion is dominant in the upper course of a river.
(c) The work of the river in the lower course is mainly depositional.
(d) Ports are better sited on estuaries than on deltas.
(e) Incised meanders are features of river rejuvenation.

5. *Either:* Describe and explain with relevant sketches the various types of river deltas

Or: Explain the ways in which river erosion occurs.

Chapter 6 Landforms of glaciation

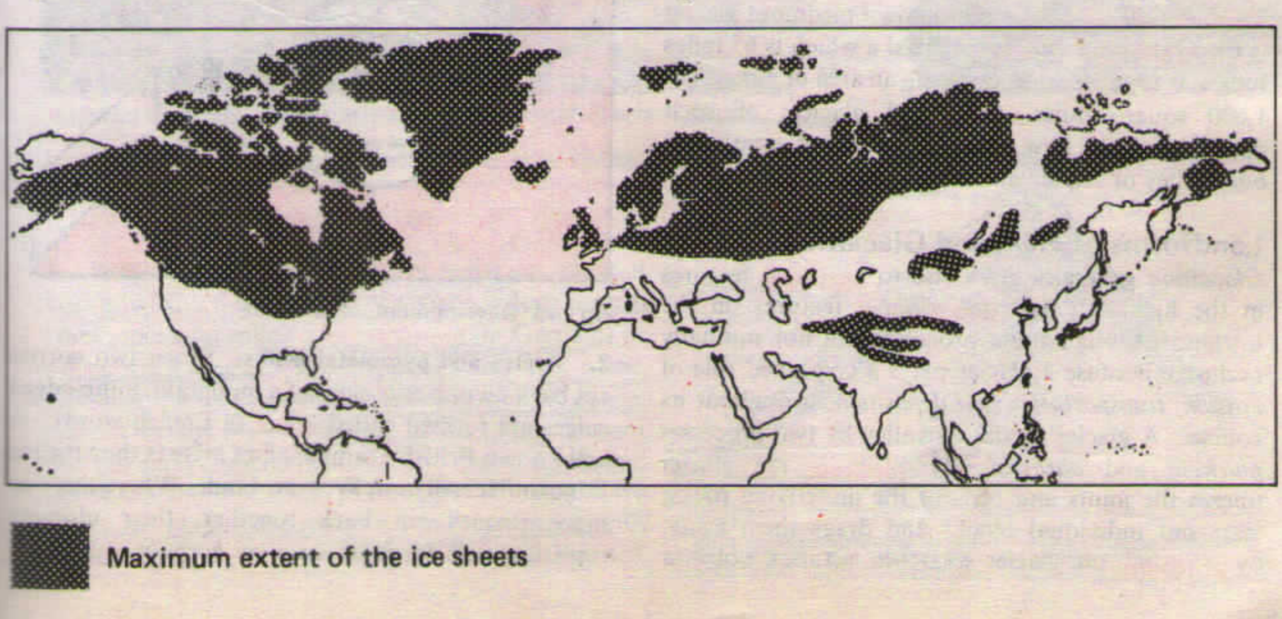
The Ice Age and Types of Ice Masses

During the Pleistocene period or the Ice Ages, about 30,000 years ago, great continental **ice sheets** covered much of the temperate latitudes. It is estimated that more than 12 million square miles of the northern hemisphere were buried by ice, half of which was in North America and the rest in Europe, Greenland and the high mountains of Eurasia (Fig. 46). The warmer climate that followed caused the ice sheets to retreat. Today only two major **ice caps** are still present, in Greenland and Antarctica. The former covers an area of 720,000 square miles while the latter is more than 5 million square miles. They are made up of compact sheets of ice, hardened and crystallised to a depth of over a mile. In Marie Byrd Land, Antarctica, the ice cap was measured and found to be more than 14,000 feet thick! Under such a collosal weight, the land sinks gradually.

From the central dome of the ice cap the ice creeps out in all directions to escape as **glaciers**. The peaks of the loftier mountains project above the surface as **nunataks**. When the ice sheets reach right down to the sea they often extend outwards into the polar waters and float as **ice shelves**. They terminate in precipitous cliffs. When they break into individual blocks, these are called **icebergs**. While afloat in the sea, icebergs assume a tabular or irregular shape and only one-ninth of the mass is visible above the surface. They diminish in size when approaching warmer waters and are eventually melted, dropping the rock debris that was frozen inside them on the sea bed.

Apart from Greenland and Antarctica, glaciation is still evident on the highlands of many parts of the world, which lie above the **snowline**. This varies from sea level in the polar regions to 9,000 feet in the Alps and 17,000 feet at the equator, as on Mt. Kilimanjaro. Permanent **snowfields** are sustained by heavy winter snowfall and ineffective summer melting and evaporation. Where the slopes are gentle and the hollows are sheltered from both direct sunlight and strong winds, any snow that falls is rapidly accumulated. Part of the surface snow may melt during the day, but by nightfall it is refrozen. This process is repeated until it forms a hard, granular substance known as névé (in French) or firn (in German). Owing to gravitational forces, the neve of the upland snowfield is drawn towards the valley below. This is the beginning of the flow of the **glacier**—'river of ice'. It normally assumes a tongue-shape, broadest at the source but becoming narrower downhill. Though the glacier is not a liquid, under the continual pressure from the accumulated snow above, it moves. The rate of movement is greatest in the **middle** where there is little obstruction. The sides and the bottom are

Fig. 46 The extent of continental ice sheets in the Ice Ages



Maximum extent of the ice sheets

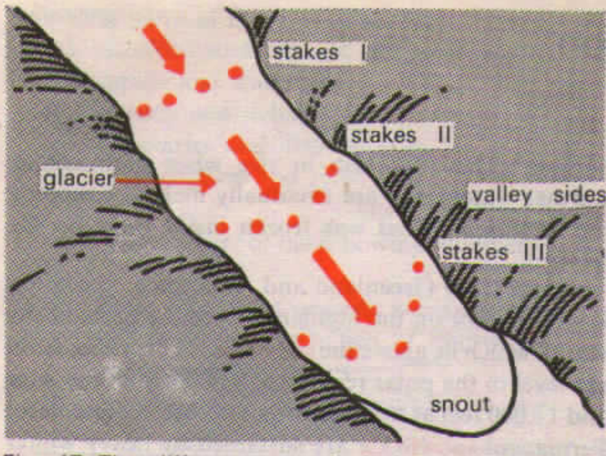


Fig. 47 The different rate of glacial movement. A glacier moves faster in the centre than the sides

held back by friction with the valley side spurs and the valley floor. If a row of stakes is planted across a glacier in a straight line, they will eventually take a curved shape down the valley, showing that the glacier moves faster at the centre than the sides (Fig. 47). In the Alps the average rate of flow is about three feet a day; in Greenland it may be more than fifty feet, but in Antarctica, where there is little heat to melt the ice, glaciers move only a few inches a day! The Aletsch Glacier in the Bernese Oberland of Switzerland is 10 miles long, affording some spectacular sights to Alpine tourists. Though it is the longest glacier in Europe, it is short compared with those of Alaska and the Himalayas which measure more than five times that length!

At the foot of mountain ranges, several glaciers may converge to form an extensive ice-mass called a piedmont glacier. The best known piedmont glacier is the Malaspina Glacier of Alaska which is 65 miles long and 25 miles wide, covering an area of more than 1,600 square miles. Combined glaciers of such dimensions are now rare and in most continents only valley or Alpine glaciers are seen.

Landforms of Highland Glaciation

Glaciation generally gives rise to erosional features in the highlands and depositional features on the lowlands, though these processes are not mutually exclusive because a glacier plays a combined role of *erosion, transportation and deposition* throughout its course. A glacier erodes its valley by two processes *plucking* and *abrasion*. By plucking the glacier freezes the joints and beds of the underlying rocks, tears out individual blocks and drags them away. By abrasion, the glacier scratches, scrapes, polishes and scours the valley floor with the debris frozen into it. These fragments are powerful 'tools' of denudation. Large angular fragments cut deep into the underlying rocks so all glaciated floors bear evidence of striation or scratching. The finer materials smooth and polish the rock surfaces and produce finely ground rock flour. The rate of erosion is determined by several factors such as the velocity of flow, gradient of the slope, the weight of the glacier, the temperature of the ice and the geological structure of the valley.

The characteristic features of a glaciated highland are as follows.

1. Corrie, cirque or cwm. The downslope movement of a glacier from its snow-covered valley-head, and the intensive shattering of the upland slopes, tend to produce a depression where the *firn* or *névé* accumulates. The process of plucking operates on the back-wall, steepening it and the movement of the ice abrades the *floor*, deepening the depression into a a steep, horse-shoe-shaped basin called a cirque (in French). It is also known as a corrie in Scotland and a cwm in Wales (Fig. 48). There is a rocky ridge at the exit of the corrie and, when the ice eventually melts, water collects behind this barrier, to form a corrie lake or tarn

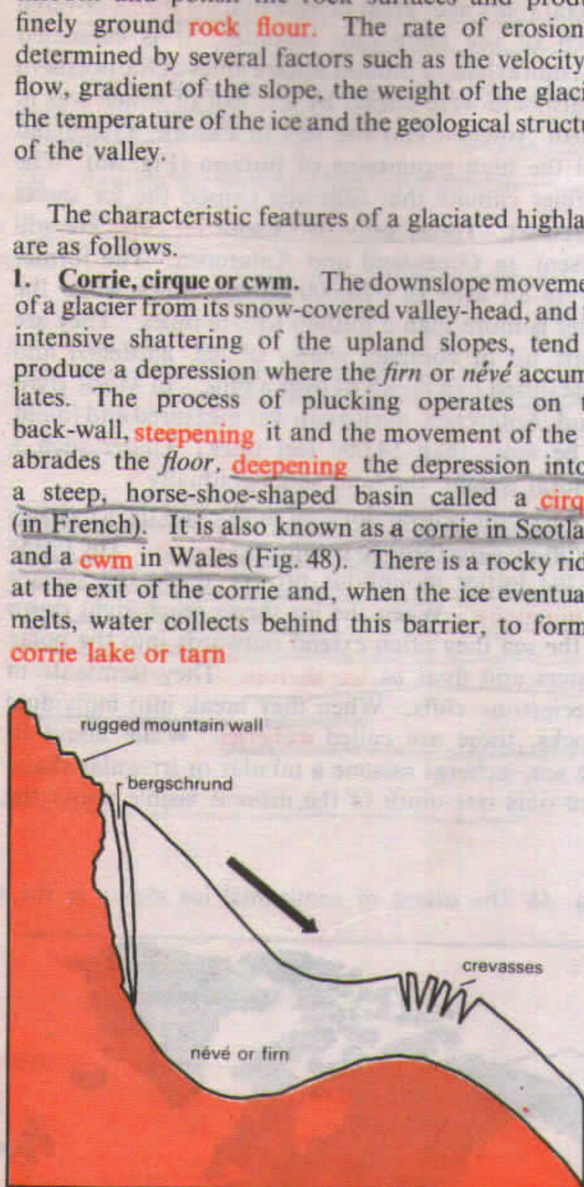


Fig. 48 Development of a corrie

2. Arêtes and pyramidal peaks. When two corries cut back on opposite sides of a mountain, knife-edged ridges are formed called aretes (a French word). A well known British example of an arête is the Striding Edge on Helvellyn in Westmorland. Where three or more cirques cut back together, their ultimate recession will form an *angular horn* or pyramidal

A glacial landscape in Switzerland *Swiss National Tourist Office*

peak. The Matterhorn of Switzerland is a classic example (Fig. 49).

3. **Bergschrund.** At the head of a glacier, where it begins to leave the snowfield of a corrie, a deep vertical crack opens up called a **bergschrund** (in German) or rimaye (in French). This happens in summer when, although the ice continues to move out of the corrie, there is no new snow to replace it. In some cases not one but several such cracks occur. The bergschrund presents a major obstacle to climbers. Further down where the glacier negotiates a bend or a precipitous slope, more **crevasses** or cracks are formed (Fig. 48).

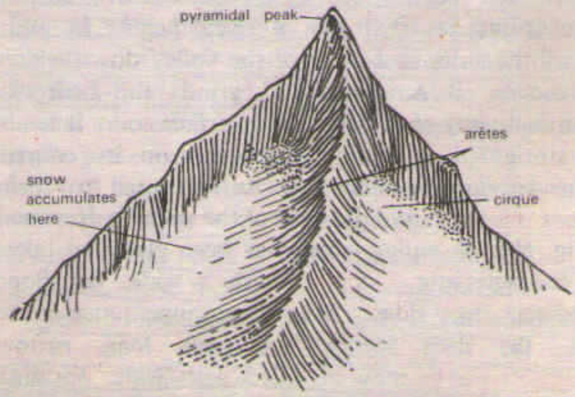


Fig. 49 Cirque, arête and pyramidal peak

A U-shaped valley in Switzerland. The valley sides are steep but the floor is flat. There is a ribbon lake in the valley bottom
Swiss National Tourist Office

4. U-shaped glacial trough. The glacier on its downward journey, fed by ice from several corries like tributaries that join a river, begins to wear away the sides and floor of the valley down which it' moves. It scratches and grinds the bedrock, removing any rock debris and surface soil. It tends to straighten any protruding spurs on its course. The *interlocking spurs* are thus blunted to form **truncated spurs** and the floor of the valley is deepened (Fig. 50). A valley which has been glaciated takes a characteristic **U-shape,** with a wide, flat floor and very steep sides. After the disappearance of the ice, the deep sections of these long, narrow **glacial troughs** may be filled with water forming **ribbon lakes,** such as Loch Ness and Lake Ullswater in Britain. They are sometimes referred to as *trough lakes* or *finger lakes*.

5. Hanging valleys. The main valley is eroded much more rapidly than the tributary valleys as it contains a much larger glacier. After the ice has melted a tributary valley therefore 'hangs' above the main valley so that its stream plunges down as a waterfall (Fig. 50). Such tributary valleys are termed **hanging valleys** and may form a natural head of water for generating hydro-electric power.

6. Rock basins and rock steps. A glacier erodes and excavates the bed rock in an irregular manner. The unequal excavation gives rise to many **rock basins** later filled by lakes in the valley trough.

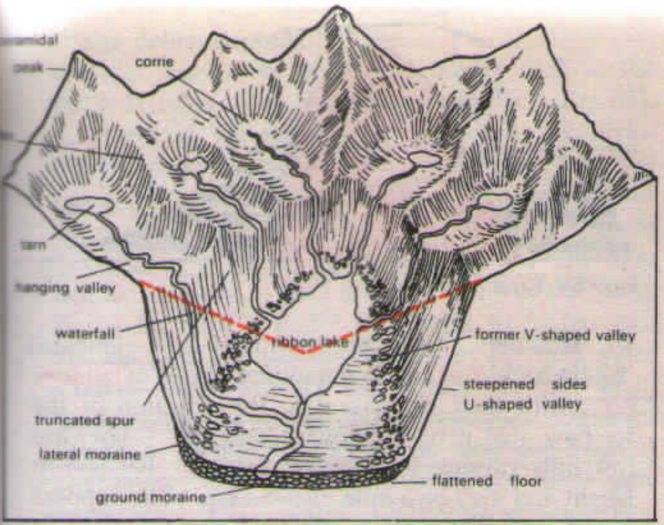


Fig. 50 A glaciated upland

Where a tributary valley joins a main valley, the additional weight of ice in the main valley cuts deeper into the valley floor at the point of convergence forming a rock step. A series of such rock steps may also be formed due to different degrees of resistance to glacial erosion of the bedrocks.

7. **Moraines.** Moraines are made up of the pieces of rock that are shattered by frost action, imbedded in the glaciers and brought down the valley. Those that fall on the sides of the glacier, mainly screes, form lateral moraines. When two glaciers converge, their inside lateral moraines unite to form a medial moraine. The rock fragments which are dragged along beneath the frozen ice are dropped when the glacier melts and spread across the floor of the valley

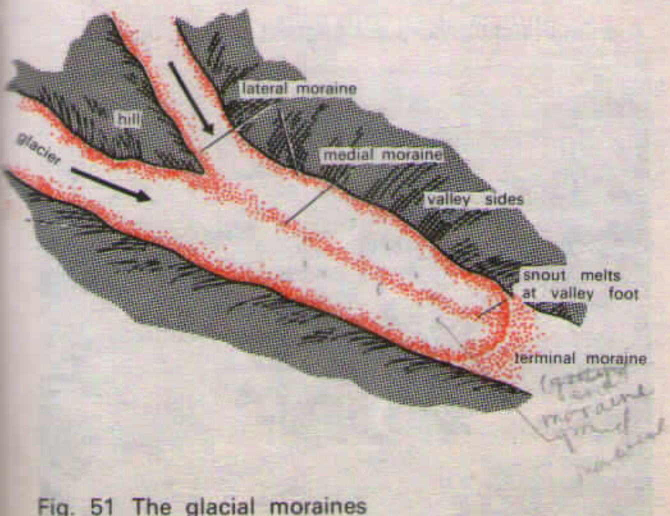


Fig. 51 The glacial moraines

as ground moraine. The glacier eventually melts on reaching the foot of the valley, and the pile of transported materials left behind at the snout is the terminal moraine or *end moraine* (Fig. 51). The deposition of the end moraines may be in several succeeding waves, as the ice may melt back by stages so that a series of recessional moraines are formed.

If the glacier flows right down to the sea it drops its load of moraine in the sea. If sections break off as icebergs, morainic material will only be dropped when they melt (Fig. 52). Where the lower end of the trough is drowned by the sea it forms a deep, steep-sided inlet called a fiord, typical of the Norwegian and south Chilean coasts.

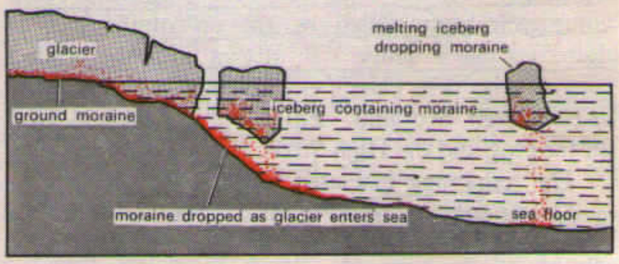


Fig. 52 A glacier ending at the sea

Landforms of Glaciated Lowlands

Landforms of glaciated lowlands are mainly *depositional* in nature, brought about by both *valley glaciers* and *continental ice sheets*. The former leaves behind the eroded materials in only restricted areas. The imprint of ice sheets on the landscape is far more widespread because they advanced through large areas during the Ice Ages, scouring and removing any surface soil and rock debris on their way. As a result, it has been estimated that almost a third of the total land surface of Europe and North America is littered with glacial and fluvio-glacial materials of all descriptions—moraines, boulder clay, tills, drifts, rock-flour, gravels and sands. Many of them are being re-eroded, resorted and redeposited elsewhere by present-day rivers.

Most of the glaciated lowlands have depositional features, but where rock masses project above the level surface, they result in striking features of erosion, such as the roche moutonnee and crag and tail:

1. **Roche Moutonnee.** This is a resistant residual rock hummock. The surface is striated by ice movement. Its upstream side is smoothed by abrasion and its downstream side is roughened by plucking,

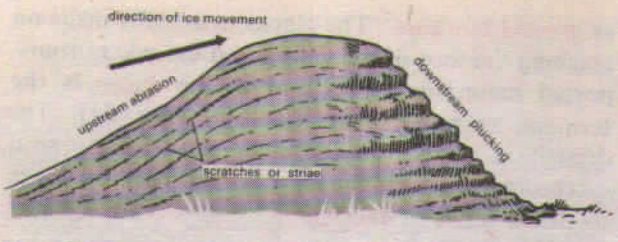


Fig. 53 Roche moutonnee

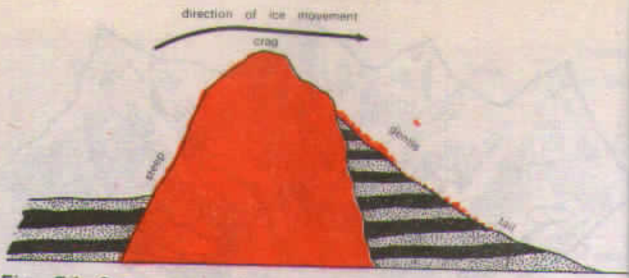


Fig. 54 Crag and tail

and is much steeper. The term roche moutonnee is used to describe such a feature because it resembles a sheepskin-wig once worn in France (Fig. 53). Roches moutonnees are found in both highland and lowland glaciated regions.

2. Crag and Tail. The crag is a mass of hard rock with a precipitous slope on the upstream side, which protects the softer leeward slope from being completely worn down by the on-coming ice. It therefore has a gentle tail, strewn with the eroded rock debris. The classic example is the *Castle Rock of Edinburgh*, Scotland. Edinburgh Castle is located on the crag and the High Street on the tail. (Fig. 54).

The remaining glaciated lowland features are of a depositional nature (Fig. 55). The following are the typical ones.

3. Boulder clay or glacial till. This is an unsorted glacial deposit comprising a range of eroded materials —boulders, angular stones, sticky clay and fine rock flour. It is spread out in sheets, not mounds, and forms gently undulating till or drift plains. The landform is rather monotonous and featureless. The degree of fertility of such glacial plains depends very much on the composition of the depositional materials. Some of the boulder clay plains such as East Anglia and the northern Mid-West of U.S.A. form rich arable lands.

4. Erratics. These are boulders of varying sizes that were transported by ice. They came with the advancing glaciers or ice sheets but when the ice melted, they were left 'stranded' in the regions of deposition. They are called erratics because they are composed of materials entirely different from those of the region in which they are found. Such erratics are thus most useful in tracing the source and direction of the ice movement. Sometimes the erratics may be found perched in precarious positions just as the ice dropped them and they are then termed perched blocks. Examples of such blocks are commonly encountered in both lowland and highland areas in Europe e g. Silurian grits are found perched on the Carboniferous Limestone of the Pennines. Their presence in large numbers is a hindrance to farming.

5. Drumlins. These are swarms of oval, elongated 'whale-back' hummocks composed wholly of boulder clay, with their elongation in the direction of the ice flow, that is on the downstream side. They are low hills varying from a few yards to 400 feet in height and may be a mile or two long. They appear a little steeper at the onset side and taper off at the leeward end. They are arranged diagonally and so are commonly described as having a *'basket of eggs' topography*. Large numbers of them are found in County Down in Northern Ireland and the glaciated plain around the Great Lakes in North America.

6. Eskers. These are long, narrow, sinuous ridges composed of sand and gravel which mark the former sites of sub-glacial melt-water streams. They vary from a few feet to 200 feet in height and may be several miles long. In some parts of Maine, U.S.A., the outstanding eskers form a continuous ridge of 100 miles! They are very numerous in Scandinavia e.g. the Punkaharju Esker of Finland. As eskers are made up of highly porous sand and gravel, water is rapidly drained off from their crests and they may not support many trees, though in Finland they often form tree-covered ridges between lakes.

7. Terminal moraines. These are made up of the

A drumlin field in northern England *J.K. St. Joseph*

coarse debris deposited at the edge of the ice-sheet, to form hummocky and hilly country such as the Baltic Heights of the North European Plain (Fig. 55).

8. Outwash plains. These are made up of fluvio-glacial deposits washed out from the terminal moraines by the streams and channels of the stagnant ice mass. The melt-waters sort and re-deposit the material in a variety of forms from the low hilly heathlands, such as the Luneburg Heath of the North European Plain, to undulating plains, where terraces, alluvial fans and deltaic deposits of the melt-water streams make up the landscape. Kames, small rounded hillocks of sand and gravel may cover part of the plain. Where the deposition takes the form of alternating ridges and depressions, the latter may contain kettle lakes and give rise to characteristic *'knob and kettle'* topography.

The Human Aspects of Glaciated Landforms

Though the Ice Ages were at their height over 30,000 years ago, the effects of glaciation on both landforms and human activities have profound influence in many parts of the world today. Their most striking impact is felt in the temperate regions of Europe and North America which were once under continental ice sheets. Further south and on the high mountains all over the world, slow-moving glaciers are still shaping the landscape in the Alps, Andes, Rockies and Himalayas. Glacial influences on Man's economic activities are both favourable and unfavourable, depending on the intensity of glaciation, the relief of the region and whether the effects are of an erosional or depositional nature.

In *hilly regions* such as the mountain slopes of Scandinavia, ice sheets and glaciers have removed most of the top soil, leaving them quite bare of vegetation. Soils that do exist are so *thin* that they are incapable of supporting effective agriculture. Glacial drifts in the valleys and benches or alps which were not affected by glaciers have good pastures during summer. Cattle are driven up to graze on the grass and return to the valley bottom in winter. This form of animal-migration type of farming is called transhumance. Extensive boulder clay plains such as those of East Anglia and the Mid-West of U.S.A. are some of the most fertile agricultural plains known. The loess plains of Europe and central U.S.A., with a high proportion of humus are good farming land too. On the other hand, the *sandy or gravelly* outwash plains e.g. the heath-covered *geest* of northern Germany, the *marshy boulder clay* deposits of central Ireland, the *barren* ice-scoured surfaces of the Canadian and Baltic Shields are infertile. The

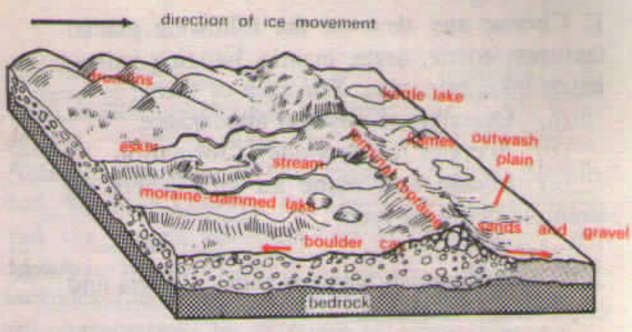


Fig. 55 Glacial depositional features in the outwash plain

presence of numerous erratics and perched blocks in parts of Britain and in Alberta, Canada, many of them of gigantic size obstruct farming and the use of machines. Morainic deposits may dam, or glaciers may hollow out, lakes which greatly inconvenience large scale farming or land development. But when the lakes are eliminated, the old glacial lake beds with their rich alluvium support heavy cropping.

Large lakes formed by former glaciation, e.g. the Great Lakes of North America, make excellent waterways. They may also cut deep overflow channels while draining off, making natural routeways across a mountainous terrain e.g. the Hudson-Mohawk Gap that links the interior with the Atlantic seaboard of U.S.A. On the other hand in regions where drumlins are dominant, the drainage is either poor or much confused.

Terminal and recessional moraines comprise coarse materials of little use to man but fluvio-glacial deposits are not without their economic significance. In the outwash plains, eskers and kames have been excavated to provide sands and gravels for *highway* and *building construction*. The purest sands are extracted to make *moulds* for metal castings. The lake basins of glaciated mountains provide natural reservoirs. In countries like Scandinavia, Switzerland and Canada where there is little available coal, streams and waterfalls that plunge down from hanging valleys or other glaciated uplands are being harnessed to provide hydro-electric power. This has helped to develop many of the chemical and metallurgical industries. With the magnificent scenery provided by the glaciated mountains e.g. the French, Italian and Swiss Alps, large numbers of tourists are attracted to them annually. Skiing, mountain climbing and sight-seeing are all popular with Alpine tourists.

QUESTIONS AND EXERCISES

1. Choose any *three* of the following glacial features: corrie, arete, erratic, hanging valley, kettle lake, nunatak. For each of them:

(a) Describe its physical appearance.

(b) Account for its mode of formation.

(c) Locate and name an area where an example could be seen.

2. (a) Distinguish between valley glaciers and continental ice sheets.

(b) Explain why glaciation in the uplands produced erosional features while that of the lowlands produced mainly depositional features.

3. The following lowland glacial features are all, in fact, small ridges, but are quite different in their process of formation:

(a) State which of them are of erosional or depositional nature.

(b) Pick out their distinctive differences in both appearance and formation.

roche moutonnee, drumlin, esker, crag and tail, kames.

4. Briefly explain any *three* of the following.

(a) Glaciated valleys assume a characteristic U-shaped.

(b) The middle of a glacier moves faster than the sides.

(c) In glaciated lowlands, eskers, kames and other morainic deposits are extensively quarried.

(d) Glacial soils vary greatly in their fertility.

(e) Erratics and perched blocks are the best indicators of the source and direction of ice movement.

5. With the aid of diagrams, attempt to explain the difference between any *three* of the following pairs of terms connected with glaciation.

(a) Valley glacier and piedmont glacier.

(b) Bergschrund and crevasses

(c) Corrie lake and ribbon lake

(d) Interlocking spurs and truncated spurs

(e) Terminal moraine and recessional moraine.

Chapter 7 Arid or Desert Landforms - 1/5th of world's land

Types of Deserts

About a *fifth* of the world's land is made up of deserts, some rocky, others stony and the rest sandy. Deserts that are absolutely barren and where nothing grows at all are rare and they are better known as *'true deserts'.*

If you look at the world map carefully, you will find that there is a certain definite pattern to the location of the world's deserts. You will realise that almost all the deserts are confined within the 15° to 30° parallels of latitude north and south of the equator. They lie in the trade wind belt on the western parts of the continents where Trade Winds are off-shore. They are bathed by cold currents which produce a 'desiccating effect' so that moisture is not easily condensed into precipitation. *Dryness or* aridity is the key note. Such deserts are tropical hot deserts or 'Trade Wind deserts'. They include the great Sahara Desert; Arabian, Iranian and Thar Deserts; Kalahari, Namib, and Atacama Deserts; the Great Australian Desert and the deserts of south-west U.S.A. and northern Mexico. In the continental interiors of the mid-latitudes, the deserts such as the Gobi and Turkestan are characterised by extremes of temperatures.

The work of winds and water in eroding elevated uplands, transporting the worn-off materials and depositing them elsewhere, has given rise to *five* distinct kinds of desert landscape.

1. **Hamada or rocky desert.** This consists of large

A sandy desert area (erg) in Death Valley, California *U.S. Information Service*

stretches of bare rocks, swept clear of sand and dust by the wind. The exposed rocks are thoroughly smoothed and polished. The region is bare and sterile. The best known rocky deserts are those of the Sahara Desert e.g. the Hamada el Homra, in Libya, which covers an area of almost 20,000 square miles.

2. **Reg or stony desert.** This is composed of extensive sheets of angular pebbles and gravels which the winds are not able to blow off. Such stony deserts are much more accessible than the sandy deserts, and large herds of camels are kept there. In Libya and Egypt the term serir is used; elsewhere in Africa, stony deserts are called reg.

3. **Erg or sandy desert.** This is a sea of sand which typifies the popular idea of desert scenery. Winds deposit vast stretches of undulating sand-dunes in the heart of the deserts. The intricate patterns of ripples on the dune surfaces indicate the direction of the winds. The Calanscio Sand Sea in Libya is characteristic of a sandy desert. In Turkestan, sandy deserts are also known as koum.

4. **Badlands.** The term 'badlands' was first given to an arid area in South Dakota, U.S.A., where the hills were badly eroded by occasional rain-storms into gullies and *ravines*. The extent of water action on hill slopes and rock surfaces was so great that the entire region was abandoned by the inhabitants. Deserts with similar features are now referred to as badlands, e.g. the Painted Desert of Arizona, which lies south-east of the Grand Canyon of the Colorado River.

5. **Mountain deserts.** Some deserts are found on highlands such as plateaux and mountain ranges. Erosion has dissected the desert highlands into harsh, serrated outlines of chaotic peaks and craggy ranges. Their steep slopes are cut by wadis (steep-sided, often dry, valleys) and the action of frost has carved out sharp, irregular edges. In the Sahara Desert, the Ahaggar Mountains and the Tibesti Mountains are good examples of desert mountains.

The Mechanism of Arid Erosion

Arid landforms are the results of many combined factors, one reacting upon the other. *Insufficient rainfall* (often less than 5 inches) coming at most irregular periods, coupled with very high temperatures (87°F. is the average) and a *rapid rate of evaporation*, are the chief causes of aridity. Sub-aerial denudation through the processes of *weathering* (mechanical and chemical), *wind action* and the work of *water* have combined to produce a desert landscape that is varied and distinctive.

Weathering. This is the most potent factor in reducing rocks to sand in arid regions. Even though the amount of rain that falls in the desert is small, some manage to penetrate into the rocks and sets up chemical reactions in the various minerals. Intense heating during the day and rapid cooling at night by radiation, set up stresses in the already weakened rocks so that they eventually crack. As heat penetrates rocks slowly when the outer surface of rocks is being heated by the hot sun, the inner rocks remain quite cool. The heating of the rocks causes the outer surface to expand and so prise itself off from the interior rocks, so that it peels off in successive very thin layers. Such an *onion-peeling* process of mechanical weathering is called exfoliation. Angular rock debris is found in abundance as screes at the foot of upstanding rocks. Similarly, when water gets into the cracks and joints of rocks and the temperature at night suddenly drops to below freezing point, the water freezes and therefore expands by 10 per cent of its volume. Successive freezing will prise off fragments of rock which accumulate as screes. These rock fragments become the 'teeth' or *tools* of wind erosion.

Action of winds in deserts. The wind though not the most effective agent of erosion, transportation and deposition, is more efficient in arid than in humid regions. Since there is little vegetation or moisture to bind the loose surface materials, the effects of wind erosion are almost unrestrained.

Wind erosion is carried out in the following ways.

1. **Deflation.** This involves the *lifting and blowing away* of loose materials from the ground. Such unconsolidated sands and pebbles may be carried in the air or rolled along the ground depending on the grain size. The finer dust and sands may be removed miles away from their place of origin, and be deposited even outside the desert margins. Deflation results in the *lowering* of the land surface to form large depressions called deflation hollows. The Qattara Depression of the Sahara Desert lies almost 450 feet below sea level.

2. **Abrasion.** The sand-blasting of rock surfaces by winds when they hurl sand particles against them is called abrasion. The impact of such blasting results in rock surfaces being scratched, polished and worn away. Abrasion is most effective at or near the base of rocks, where the amount of material the wind is able to carry is greatest. This explains why telegraph poles in the deserts are protected by a covering of metal for a foot or two above the ground. A great variety of desert features are produced by abrasion.

3. **Attrition.** When wind-borne particles roll against one another in collision they wear each other away so that their sizes are greatly reduced and grains are rounded into millet seed sand. This process is called attrition.

Landforms of Wind Erosion in Deserts

In the combined processes of abrasion, deflation and attrition, a wealth of characteristic desert landforms emerge.

1. **Rock pedestals or mushroom rocks.** The sand-blasting effect of winds against any projecting rock masses wears back the softer layers so that an irregular edge is formed on the alternate bands of hard and soft rocks. Grooves and hollows are cut in the rock surfaces, carving them into fantastic and grotesque-looking pillars called rock pedestals (Fig. 56). Such rock pillars will be further eroded near their bases where the friction is greatest. This process of *undercutting* produces rocks of mushroom shape called mushroom rocks or gour in the Sahara.

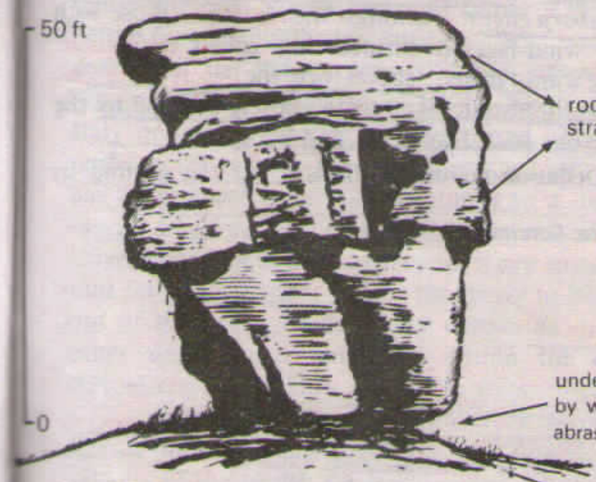


Fig. 56 Rock pedestals or gour

2. **Zeugen.** These are tabular masses which have a layer of soft rocks lying beneath a surface layer of more resistant rocks. The sculpting effects of wind abrasion wear them into a weird-looking *'ridge and furrow'* landscape. *Mechanical weathering* initiates their formation by opening up joints of the surface rocks. Wind *abrasion* further 'eats' into the underlying softer layer so that deep furrows are developed. The hard rocks then stand above the furrows as ridges or zeugen (Fig. 57), and many even overhang. Such tabular blocks of zeugen may stand 10 to 100 feet above the sunken furrows. Continuous abrasion by wind gradually lowers the zeugen and widens the furrows.

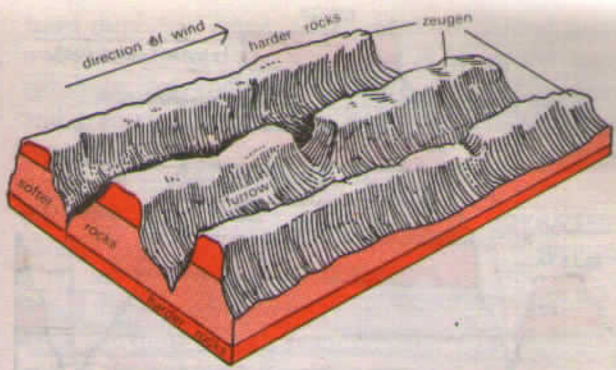


Fig. 57 Zeugen (with horizontal strata of hard and soft rocks)

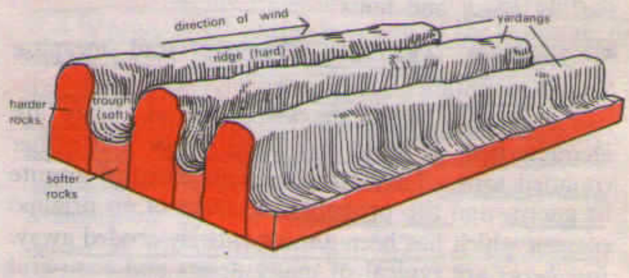


Fig. 58 Yardangs (with vertical bands of hard and soft rocks)

3. **Yardangs.** Quite similar to the 'ridge and furrow' landscape of zeugen are the steep-sided yardangs. Instead of lying in horizontal strata upon one another, the hard and soft rocks of yardangs are vertical bands and are aligned in the direction of the prevailing winds. Wind abrasion excavates the bands of softer rocks into long, narrow corridors, separating the steep-sided over-hanging ridges of hard rocks, called *yardangs* (Fig. 58). They are commonly found in the Atacama Desert, Chile, but the more spectacular ones with yardangs rising to 25–50 feet are best developed in the interior deserts of Central Asia where the name originated.

4. **Mesas and buttes.** Mesa is a Spanish word meaning 'table'. It is a flat, table-like land mass with a very resistant horizontal top layer, and very steep sides. The hard stratum on the surface resists denudation by both wind and water, and thus protects the underlying layers of rocks from being eroded away. Mesas may be formed in canyon regions e.g. Arizona, or on fault blocks e.g. the Table Mountain of Cape Town, South Africa. Continued denudation through the ages may reduce mesas in area so that they become isolated flat-topped hills called buttes. Many of them in arid countries are separated by deep gorges or canyons (Fig. 59).

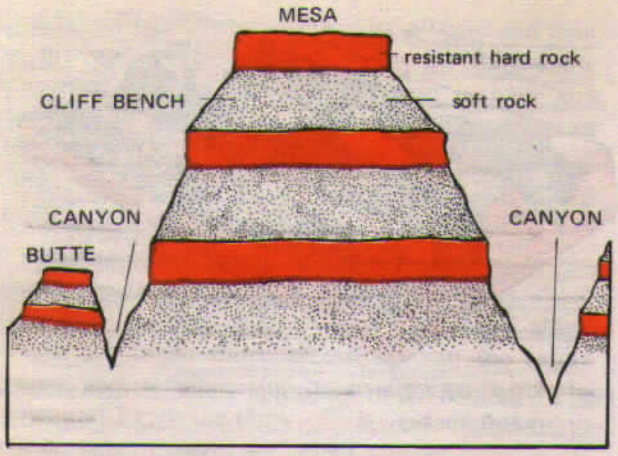


Fig. 59 Mesa and butte

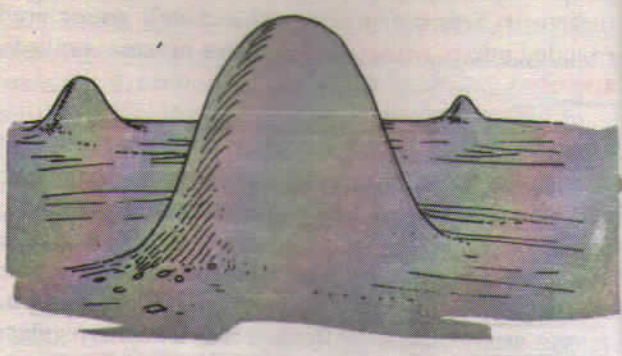


Fig. 60 Round-topped, steep-sided inselbergs

5. Inselberg. This is a German word meaning 'island-mountain'. They are isolated residual hills rising abruptly from the level ground. They are characterised by their very steep slopes and rather rounded tops. They are often composed of granite or gneiss, and are probably the relics of an original plateau which has been almost entirely eroded away. *Inselbergs* are typical of many desert and semi-arid landscapes in old age e.g. those of northern Nigeria, Western Australia and the Kalahari Desert (Fig. 60).

6. Ventifacts or dreikanter. These are pebbles faceted by sand-blasting. They are shaped and thoroughly polished by wind abrasion to shapes resembling Brazil nuts. Rock fragments, mechanically weathered from mountains and upstanding rocks, are moved by wind and smoothed on the windward side. If wind direction changes another facet is developed. Such rocks have characteristic *flat facets* with *sharp edges*. Amongst the ventifacts those with *three* wind-faceted surfaces are called dreikanter. These wind-faceted pebbles form the desert pavement, a smooth, mosaic-like region, closely covered by the numerous rock fragments and pebbles.

7. Deflation hollows. Winds lower the ground by

Ayers Rock, an inselberg in the Australian Desert *Australian Tourist Commission*

blowing away the unconsolidated materials, and small depressions may form. Similarly, minor *faulting* can also initiate depressions and the eddying action of on-coming winds will wear off the weaker rocks until the water table is reached. Water then seeps out forming oases or swamps, in the deflation hollows or depressions. The Faiyum Depression in Egypt lies 130 feet below the sea level. Large areas in the western U.S.A., stripped of their natural vegetation for farming, were completely *deflated* when strong winds, moved materials as dust-storms, laying waste crops and creating what is now known as the Great Dust Bowl. In a dust-storm, winds may lift dust hundreds of feet high and carry it thousands of miles away.

Landforms of Wind Deposition in Deserts

Materials eroded and transported by winds must come to rest somewhere. The finest dust travels enormous distances in the air, and may be moved completely out of the desert. It has been estimated that some dust grains travel as far as 2,300 miles before they are finally deposited on land or sea. The dust from the Sahara Desert is sometimes blown across the Mediterranean to fall as *'blood rains'* in Italy or on the glaciers of Switzerland. Dust that settles in the Hwang-Ho basin from the Gobi Desert has accumulated over past centuries to a depth of several hundred feet! As wind-borne materials are sifted according to their coarseness, it can be expected that the coarser sands will be too heavy to be blown out of the desert limits. They remain as dunes or other depositional landforms within the deserts themselves. Since they are *rarely static*, their migration pattern depends on a number of factors: the size of the particles they carry, the direction and velocity of the winds, the location and nature of the surfaces over which the particles are transported and the presence or absence of water and natural vegetation.

The following are some of the major features of wind deposition.

1. Dunes. Dunes are, in fact, *hills of sand* formed by the accumulation of sand and shaped by the movement of winds. They may be active or live dunes, constantly on the move, or inactive fixed dunes, rooted with vegetation. Dunes are most well represented in the erg desert where a sea of sand is being continuously moved, reshaped and redeposited into a variety of features. Because of their great contrast in shape, size and alignment, they have been given a long list of fanciful names, such as attached dune or head dune, tail dune, advanced dune, lateral dune, wake dune, star dune, pyramidal dune, sword dune, parabolic blow-out dune, hairpin dune, smoking dune and transverse dune. However, the following two types of common dunes, barchans and seifs, will be described in more detail.

(a) Barchan. These are crescentic or moon-shaped dunes which occur individually or in groups. They are live dunes which advance steadily before winds that come from a particular prevailing direction. They are most prevalent in the deserts of Turkestan and in the Sahara. Barchans are initiated probably by a chance accumulation of sand at an obstacle, such as a patch of grass or a heap of rocks. They occur transversely to the wind, so that their horns thin out and become lower in the direction of the wind due to the reduced frictional retardation of the winds around the edges. The *windward* side is *convex* and *gently-sloping* while the *leeward side*, being sheltered, is *concave and steep* (the slip-face) (Fig. 61). The crest of the sand dune moves forward as more sand is accumulated by the prevailing wind. The sand is *driven up* the windward side and, on reaching the crest, *slips down* the leeward side so that the dune advances. The rate of advancement varies from 25 feet a year for the high dunes measuring up to

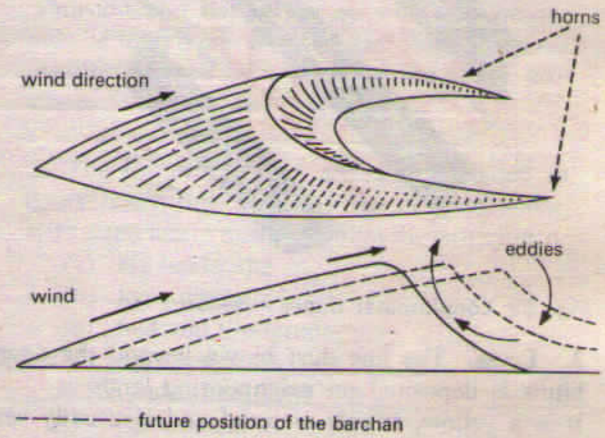


Fig. 61 Crescentic sand dune—barchan

100 feet high, to 50 feet a year, for the lower dunes which may be only a dozen feet high.

The *migration* of the barchans may be a threat to desert life for they may encroach on an oasis burying palm trees or houses. Long-rooted sand-holding trees and grasses are therefore planted to halt the advance of the dunes thus preventing areas of fertile land from being devastated. Under the action of winds, barchans take a chaotic changing pattern. Several barchans may coalesce into a line of irregular ridges, ever-changing with the direction of the winds. Ergs or sandy deserts are thus most difficult to cross.

(b) **Seifs or longitudinal dunes.** Seif is an Arabic word meaning 'sword'. They are long, narrow ridges of sand, often over a hundred miles long lying parallel to the direction of the *prevailing winds*. The high, serrated ridges may attain a height of over 200 feet. The crestline of the seif rises and falls in alternate peaks and saddles in regular successions like the teeth of a monstrous saw. The dominant winds blow straight along the corridor between the lines of dunes so that they are swept clear of sand and remain smooth. The eddies that are set up blow towards the sides of the corridor, and, having less power, drop the sand to form the dunes. In this manner, the prevailing winds increase the length of the dunes into tapering linear ridges while the occasional cross winds tend to increase their height and width. Extensive seif dunes are found in the Sahara Desert, south of the Qattara Depression; the Thar Desert and the West Australian Desert (Fig. 62).

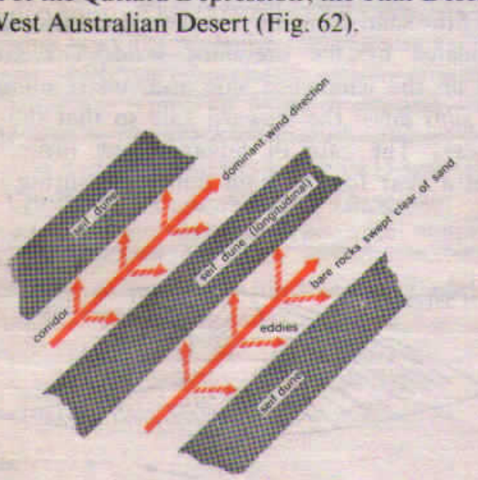


Fig. 62 Longitudinal dunes—seifs

2. **Loess.** The fine dust blown beyond the desert limits is deposited on neighbouring lands as loess. It is a yellow, friable material and is usually very fertile. Loess is in fact, fine loam, rich in lime, very coherent and extremely porous. Water sinks in readily so that the surface is always dry. Streams have cut deep valleys through the thick mantle of soft loess and badland topography may develop. It is so soft that roads constructed through a loess region soon sink and their walls rise steeply.

The most extensive deposit of loess is found in north-west China in the loess plateau of the Hwang-Ho basin. It is estimated to cover an area of 250,000 square miles, and the deposits have accumulated to a depth of 200 to 500 feet! In China, such yellowish wind-borne dust from the Gobi Desert is called *'Hwangtu' – the yellow earth!* But the original term *loess* actually comes from a village in Alsace, France, bearing that name, where such deposits occurred. Similar deposits also occur in some parts of Germany, France and Belgium, and are locally called limon. They are also wind-borne but were blown from material deposited at the edge of ice-sheets during the Ice Ages. In parts of the Mid-West, U.S.A. loess was derived from the ice sheets which covered northern North America and is termed adobe.

Landforms due to Water Action in Deserts

Few deserts in the world are entirely without rain or water. The annual precipitation may be small, 5 to 10 inches, and comes in irregular showers. But thunderstorms do occur and the rain falls in torrential downpours, producing devastating effects. A single rainstorm may bring several inches of rain within a few hours, drowning people who camp in dry desert streams and flooding mud-baked houses in the oases. As deserts have little vegetation to protect the surface soil, large quantities of rock wastes are transported in the sudden raging torrents, or flash-floods. Loose gravels, sand and fine dust are swept down the hill sides. They cut deep gullies and ravines forming *badland topography*. Subsequent downpours widen and deepen the gullies when they wash down more soft rocks from the surface. There is so much material in the flash floods that the flow becomes *liquid* mud. When the masses of debris are deposited at the foot of the hill or the mouth of the valley, an alluvial cone or fan or 'dry delta' is formed, over which the temporary stream discharges through several channels, depositing more material. The pasty alluvial deposits are subjected to rapid evaporation by the hot sun and downward percolation of water into the porous ground, and soon dry up leaving *mounds of debris*.

Apart from gullies there are many larger dry channels or valleys. These are deepened by vertical corrasion by raging torrents during the occasional cloudbursts. These are the wadis and are dry for most of the time. Some desert streams are fed by the melting snow of the distant mountains outside the deserts and rivers flow as exotic streams. The water carves out steep walls, which rise abruptly from the stream bed. In Algeria such gorges are termed chebka.

In arid and semi-arid areas the outflowing streams from the upland regions are both short and intermittent. They drain into the lower depressions so that

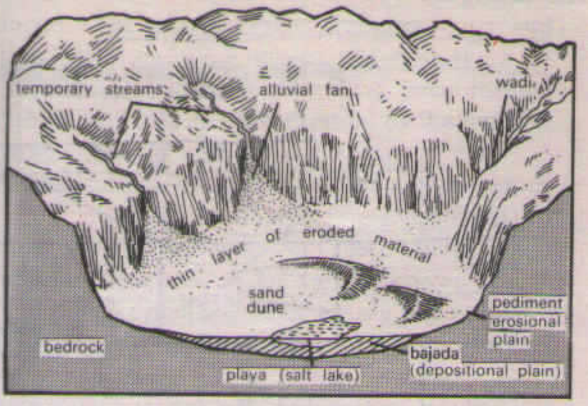


Fig. 63 Intermont desert basin

drainage is almost entirely internal. Sometimes water collected in a depression or a desert basin does not completely disappear by evaporation or seepage, and a temporary lake is formed. Such lakes contain a high percentage of salts, because of high evaporation, and are glistening white when they dry up. The lakes and the alluvial plains formed by them are called playas, salinas or salars in the United States and Mexico, and shotts in northern Africa (Fig. 63). The floor of the depression is made up of two features, the *bajada* and the *pediment*. The bajada is a depositional feature made up of *alluvial material* laid down by the intermittent streams. The pediment is an *erosional plain* formed at the base of the surrounding mountain scarps.

QUESTIONS AND EXERCISES

1. Draw annotated diagrams and explain very briefly any *three* of the following desert features.
   (a) yardangs
   (b) barchans
   (c) pediments
   (d) inselbergs
   (e) wadis

2. Attempt a simple classification of deserts. Justify your basis of classification by bringing out their distinct differences in appearance, formation and outstanding features.

3. With the aid of diagrams, explain the major differences between any *three* of the following pairs of desert landforms.
   (a) zeugen and yardangs
   (b) mesas and inselbergs
   (c) crescentic barchans and longitudinal seifs
   (d) bajadas and pediments
   (e) ventifacts and dreikanter

4. Explain concisely the processes of deflation, abrasion and deposition by winds. With the aid of diagrams explain *two* topographical features formed by any two of the above processes.

5. The following terms are closely related to desert landforms. For any *four* of them, define with reference to examples what the terms mean.
   (a) erg landscape
   (b) loess deposits
   (c) badland topography
   (d) rock pedestals
   (e) Great Dust Bowl
   (f) flash floods

Chapter 8 Limestone and Chalk Landform

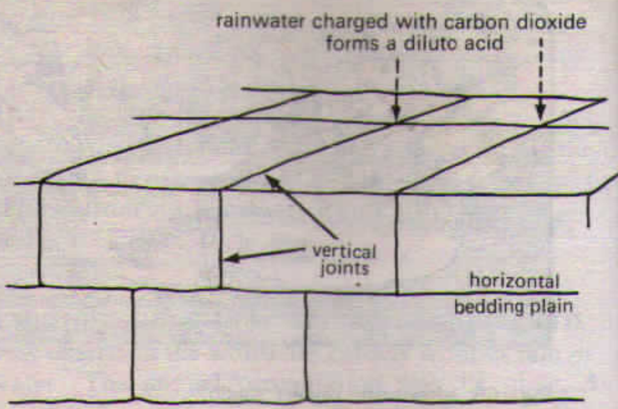
Limestone and Chalk

Limestone and chalk are *sedimentary rocks* of organic origin derived from the accumulation of corals and shells in the sea. In its pure state, limestone is made up of *calcite* or **calcium carbonate**, but where magnesium is also present it is termed **dolomite**. Chalk is a very pure form of limestone, white, and rather soft. Limestone is **soluble** in rain-water, which, with carbon dioxide from the air, forms a weak acid. A region with a large stretch of limestone therefore possesses a very distinct type of topography. It is then termed a **karst** *region*, a name derived from the Karst district of Yugoslavia where such topography is particularly well developed.

Characteristic Features of a Karst Region

Generally speaking, karst regions have a bleak landscape, occasionally broken by precipitous slopes. There is a general **absence of surface drainage** as most of the surface water has gone underground. Streams rising on other rocks only flow over limestone for a short distance and then disappear underground. For the greater part of their course, they cut their way along the joints and fissures of the rock wearing out a system of underground channels. The surface valleys are therefore dry. When the water penetrates to the base of the limestone and meets non-porous rocks it re-emerges onto the surface as a spring or **resurgence**.

Limestones are **well jointed** and it is through these joints and cracks that rain-water finds its way into the underlying rock. Progressive widening by



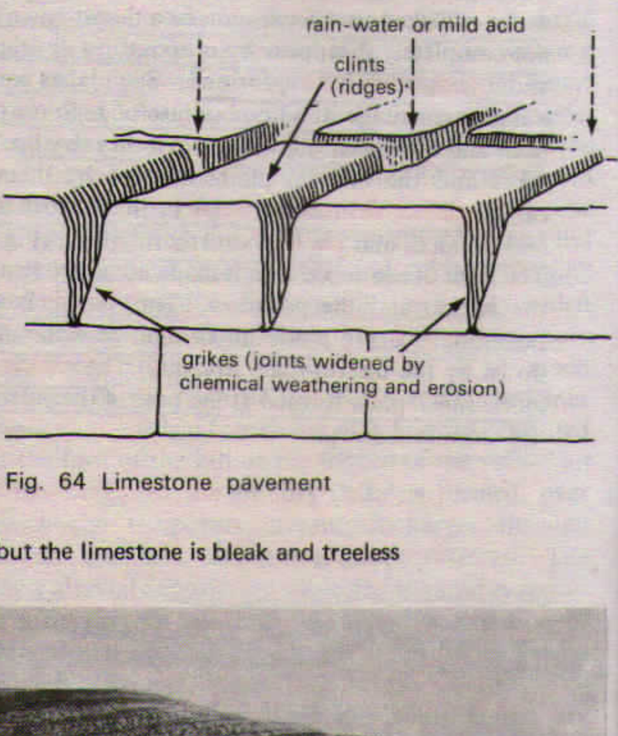


Fig. 64 Limestone pavement

A limestone escarpment. Notice that the valley is cultivated but the limestone is bleak and treeless
Institute of Geological Science

solution enlarges these cracks into trenches and a most intriguing feature called limestone pavement is developed. The enlarged joints are called grikes and the isolated, rectangular blocks are termed clints. The limestone pavements may have been formed beneath the soil and are now exposed by the removal of the soil cover (Fig. 64).

On the surface of the limestone are numerous swallow holes, which are small depressions carved out by solution where rain-water sinks into the limestone at a point of weakness. They are also known as sink holes. Gaping Ghyll in Yorkshire is a fine example. These holes grow in size through continuous solvent action.

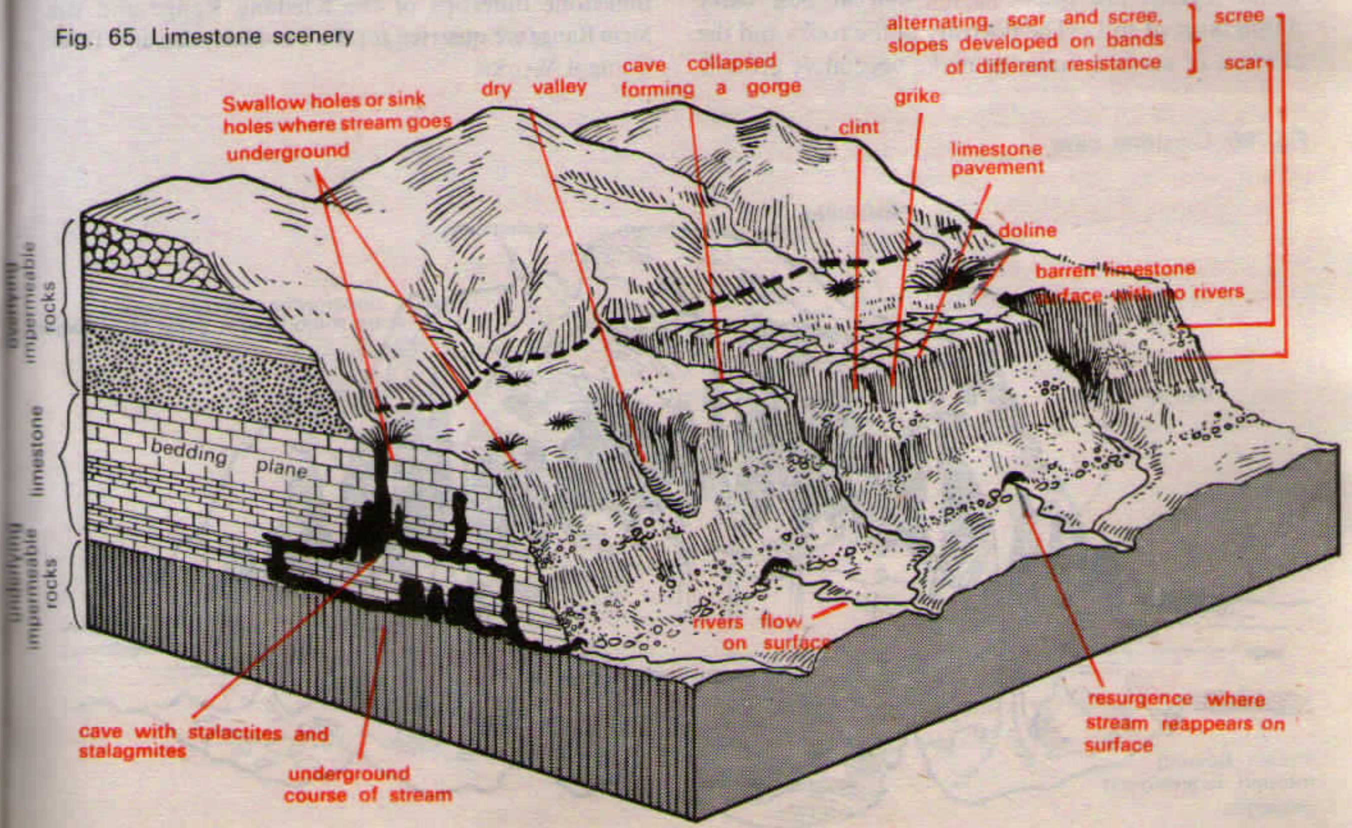
Once water has sunk into the limestone it etches out caverns and passages along joints or bedding planes. When the roof of an underground tunnel collapses, a precipitous limestone gorge such as the Cheddar Gorge is formed. Where a number of swallow holes coalesce a larger hollow is formed and is called a doline (Fig. 65). Several dolina may merge as a result of subsidence to form a larger depression called an uvala. Some of them are a mile across, containing much clayey soil from the limestones, weathered after their subsidence.

In Yugoslavia, some very large depressions called polje may be as large as a hundred square miles but these are partly due to faulting. During the rainy season, parts of the floor which are at or near the water table may become temporary lakes, but the drier areas are fertile and may support large villages.

Where subterranean streams descend through swallow holes to underground passages, the region may be honeycombed with caves and *caverns*, some containing ponds and lakes. The most spectacular underground features that adorn the limestone caves are stalactites, stalagmites and pillars. Stalactites

A limestone pavement

Fig. 65 Limestone scenery



are the sharp, slender, downward-growing pinnacles that hang from the cave-roofs. The water carries calcium in solution and when this lime-charged water evaporates, it leaves behind the solidified crystalline calcium carbonate. As moisture drips from the roof it trickles down the stalactite and drops to the floor where calcium is deposited to form **stalagmites**. They are shorter, fatter and more rounded. Over a long period, the stalactite hanging from the roof is eventually joined to the stalagmite growing from the floor to form a **pillar** (Fig. 66). Such features are commonly seen in any well-developed limestone caves e.g. Batu Caves, Kuala Lumpur; Mammoth Caves, Kentucky and Carlsbad Cave, New Mexico, in U.S.A. and Postojna Caves, Yugoslavia.

The Major Limestone Regions of the World

The most characteristic stretch of limestone occurs in north-west Yugoslavia. Other regions include: the Causses district of southern France, the Pennines of Britain, Yorkshire and Derbyshire in particular, the Kentucky region of the United States, the Yucatan Peninsula of Mexico, the Cockpit Country of Jamacia, and the limestone hills of Perlis.

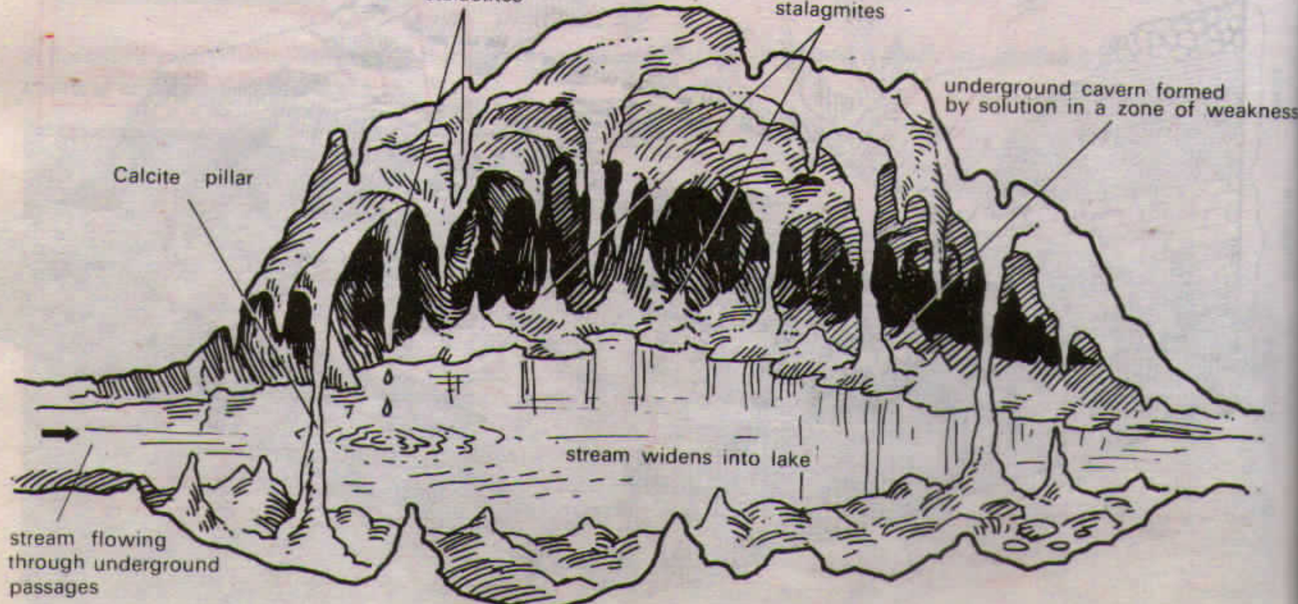
Human Activities of Karst Regions

Karst regions are often **barren** and at best carry a thin layer of soil. The porosity of the rocks and the absence of surface drainage make vegetative growth

A dry valley in the chalk region of southern England

difficult, so that limestone can usually support only poor grass and short turf; some sheep grazing is possible. Limestone vegetation in tropical regions, however, is luxuriant because of the heavy rainfall all the year round. Settlements are scattered and the population is often sparse. The only mineral of importance is **lead** which occurs in veins in association with limestone. Besides this, good quality limestones are often used as **building** materials or quarried for the **cement** industry. In West Malaysia, the limestone outcrops of the Kledang Range and the Main Range are quarried for the Pan-Malaysian and Tasek Cement Works.

Fig. 66 Limstone cave



Chalk

The landforms of chalk are rather different from those of other limestones. There is little or no surface drainage and valleys which once contained rivers are now dry. These are often called coombes. The chalk forms low rounded hills in southern and south-eastern England, where they are called downs and in northern France. The chalk is covered with short turf, and in places with woodland, and is used for pasture and sometimes for arable farming. Because of the friable nature of the rock, swallow-holes and underground cave networks do not generally develop.

QUESTIONS AND EXERCISES

1. Choose *three* outstanding features of a karst region. With the aid of diagrams describe their appearance and explain how they have been formed.

2. The following features are associated with karst topography.
   (a) Clints and grikes
   (b) Dolines and uvalas
   (c) Stalactites and stalagmites
   For any *two* of them, with the aid of annotated diagrams, explain their origin and locate an actual example of each.

3. Explain why:
   (a) Karst regions have very little surface drainage.
   (b) Subterranean streams produce a magnificent underground scenery.
   (c) Limestone areas have little agriculture and are sparsely peopled.

4. With the aid of labelled diagrams, describe and account for the development of physical features which result from the action of *water* in:
   (a) limestone regions
   (b) arid deserts
   (c) granite uplands

5. Draw a large diagram of a karst region and indicate the following: swallow holes, limestone gorge, dry valleys, limestone pavement with clints and grikes. Describe briefly how any *two* of them have been formed.

Chapter 9 Lakes

L. Titicaca – highest
Caspian Sea – Largest] – Tectonic] Lakes formed by Earth movements
L. Tanganyika – deepest
Dead Sea – Lowest] – Rift valley

General

Lakes are amongst the most varied features of the earth's surface. They occupy the hollows of the land surface in which water accumulates. They vary tremendously in size, shape, depth and mode of formation. The tiny ones are no bigger than ponds or pools, but the large ones are so extensive that they merit the name of seas, e.g. the Caspian Sea which is 760 miles long, as much as 3,215 feet deep, with a total area of 143,550 square miles, and is bigger than the whole of Malaysia!

Lakes may exist *temporarily* filling up the small depressions of undulating ground after a heavy shower. But those which are deep and carry more water than could ever be evaporated remain *permanent*. Most of the lakes in the world are *fresh-water lakes* fed by rivers and with out-flowing streams e.g. Lake Geneva, Lake Poyang and the Great Lakes of North America. In regions of low precipitation and intense evaporation where there are few rivers strong enough to reach the sea, streams drain into a lake forming a basin of *inland drainage*. Because of the intense evaporation these lakes are saline. For example the Dead Sea has a salinity (salt content) of 250 parts per thousand, and the Great Salt Lake of Utah, U.S.A. has a salinity of 220 parts per thousand. But, the Black Sea, into which drain many large rivers, has a salinity of less than 17 parts per thousand! *Playas* or salt lakes, are a common feature of deserts.

It must be pointed out that lakes are only temporary features of the earth's crust; they will eventually be eliminated by the double process of draining and silting up. In regions of unreliable rainfall, lakes dry up completely during the dry season. In the hot deserts lakes disappear altogether by the combined processes of evaporation, percolation and outflow. Though the process of lake elimination may not be completed within our span of life, it takes place relatively quickly in terms of geological time.

The Formation and Origin of Lakes

The following are the various ways in which lakes can be formed. Each of them is placed in a specific category, though in a few cases the lakes could have been formed by more than one single factor.

1. Lakes Formed by Earth Movement

(a) Tectonic lakes. Due to the warping, sagging, bending and fracturing of the earth's crust, tectonic depressions occur. Such depressions give rise to lakes of immense sizes and depths. They include Lake Titicaca, occupying a huge depression in the intermont plateau of the Andes, 12,500 feet above sea level the highest lake in the world; and the Caspian Sea, 143,550 square miles, the largest lake, almost 5 times larger than its nearest rival, Lake Superior.

(b) Rift valley lakes. Due to faulting, a rift valley is formed by the sinking of land between two parallel faults, deep, narrow and elongated in character. Water collects in these troughs and their floors are often below sea level. The best known example is the East African Rift Valley which runs through Zambia, Malawi, Tanzania, Kenya and Ethiopia, and extends along the Red Sea to Israel and Jordan over a total distance of 3,000 miles. It includes such lakes as Lakes Tanganyika (4,700 feet deep, the world's deepest lake), Malawi, Rudolf, Edward, Albert, as well as the Dead Sea 1,286 feet below mean sea level, the world's lowest lake (Fig. 67).

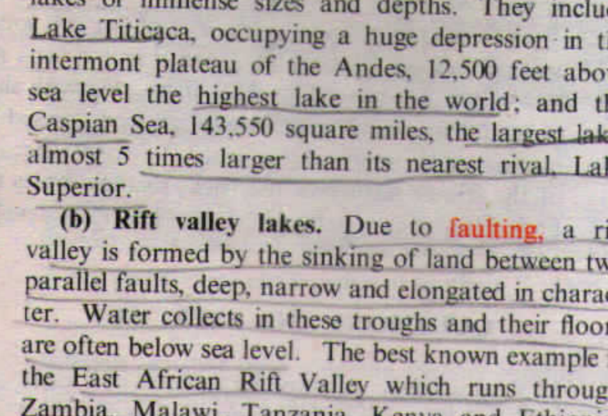
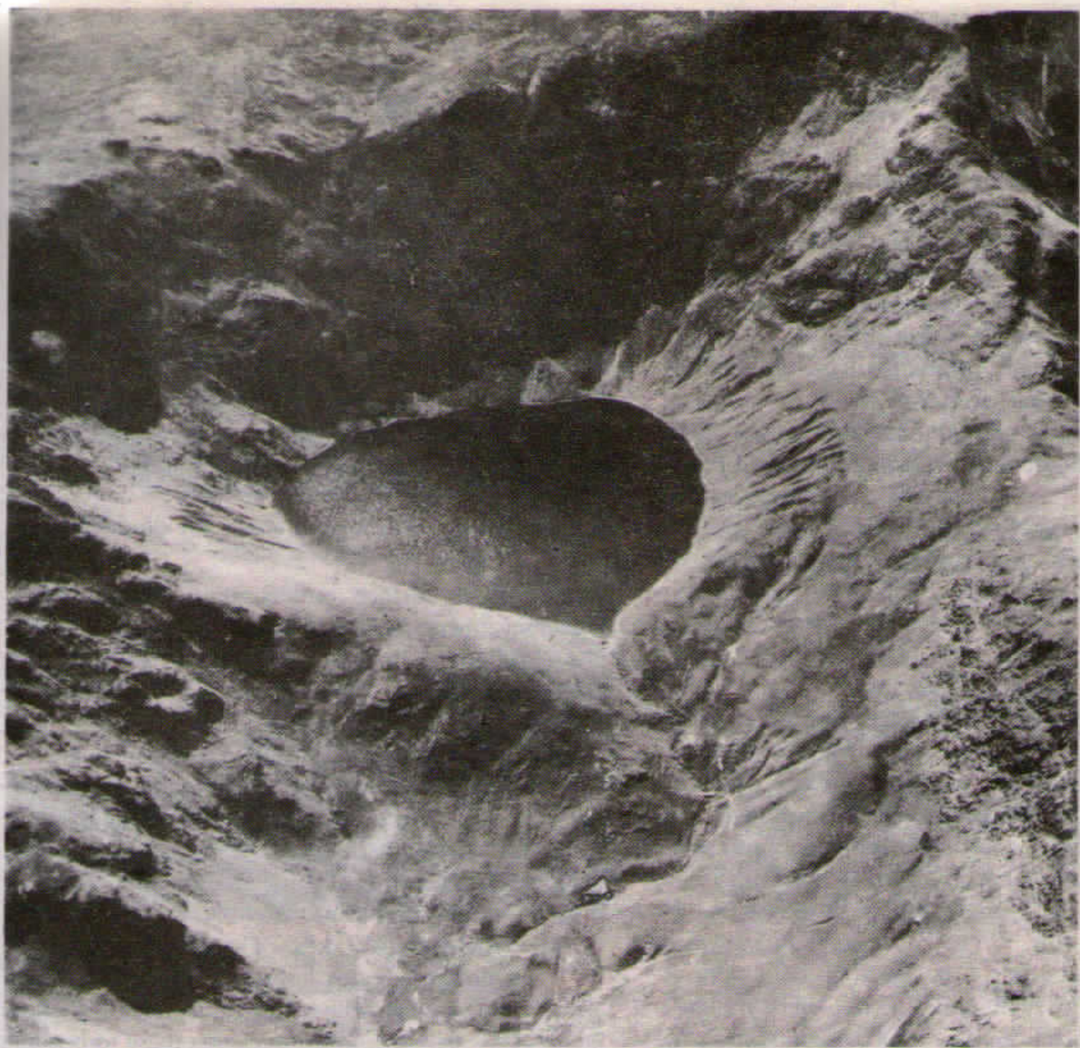


Fig. 67 Earth movement

2. Lakes Formed by Glaciation

(a) Cirque lakes or tarns. A glacier on its way down the valley leaves behind circular hollows in the heads of the valleys up in the mountains. Such hollows are the arm-chair-shaped cirques or corries. Their over-deepened floors may be filled with water to become cirque lakes e.g. Red Tarn in the English Lake District (Fig. 68). Those that occupy glacial troughs are long and deep and are termed ribbon lakes, e.g. Lake Ullswater.

(b) Kettle lakes. These are depressions in the



Blea Water in Westmorland, England, a typical corrie lake
J.K. St. Joseph

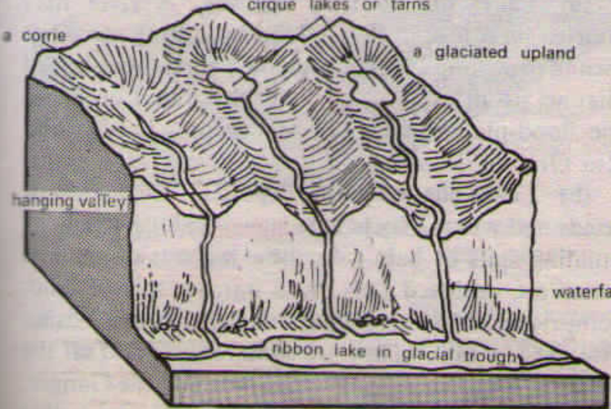


Fig. 68 Glaciation

outwash plain left by the melting of masses of stagnant ice. They are irregular because of the uneven morainic surface and are never of any great size or depth e.g. the meres of Shropshire in England, and the kettle-lakes of Orkney in Scotland.

(c) Rock-hollow lakes. These are formed by ice-scouring when valley glaciers or ice sheets scoop out hollows on the surface. Such lakes of glacial origin are abundant in Finland, indeed the Finns call their country *Suomi* — the Land of Lakes. It is said that there are over 35,000 glacial lakes in Finland!

(d) Lakes due to morainic damming of valleys. Valley glaciers often deposit morainic debris across a valley so that lakes are formed when water accumulates behind the barrier. Both lateral and terminal moraines are capable of damming valleys e.g. Lake Windermere of the Lake District, England.

(e) Lakes due to the deposition of glacial drifts. In glaciated lowlands with a predominant drumlin landscape, where drainage is poor, there are intervening depressions. These depressions are often water-logged, forming small lakes like those of County Down in Northern Ireland.

3. Lakes Formed by Volcanic Activity

(a) Crater and caldera lakes. During a volcanic explosion the top of the cone may be blown off leaving behind a natural hollow called a *crater*. This may be enlarged by subsidence into a *caldera*. These depressions are normally dry, bounded by steep cliffs and roughly circular in shape. In dormant or extinct volcanoes, rain falls straight into the crater or caldera which has no superficial outlet and forms a crater or caldera lake. The outstanding ones are the Crater Lake in Oregon, U.S.A. which in fact occupies a caldera; Lake Toba in northern Sumatra and Lake Avernus near Naples (Fig. 69).

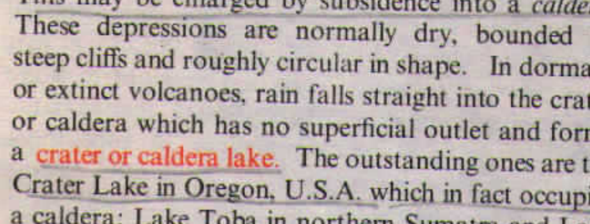


Fig. 69 Volcanic activity

(b) Lava-blocked lakes. In volcanic regions a stream of lava may flow across a valley, become solidified and thus dam the river forming a lake, e.g. a lava flow blocks the Jordan valley forming the Sea of Galilee which is an inland lake, rather elongated in shape.

(c) Lakes due to subsidence of a volcanic land surface. The crust of a hollow lava flow may collapse The subsidence leaves behind a wide and shallow depression in which a lake may form, e.g. Myvatn of Iceland.

4. Lakes Formed by Erosion

(a) Karst lakes. The solvent action of rain-water on limestone carves out solution hollows. When these become clogged with debris lakes may form in them. The collapse of limestone roofs of underground caverns may result in the exposure of long, narrow lakes that were once underground e.g. the Lac de Chaillexon in the Jura Mountains.

The large depressions called poljes, which normally

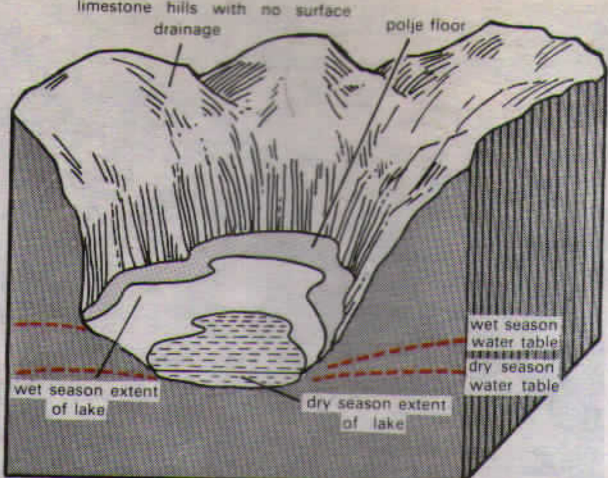


Fig. 70 A karst lake formed above the ground water table in a limestone region.

do not have surface outlets, may contain lakes. During wet periods these may cover most of the polje floor but they shrink during dry periods due to seepage (Fig. 70). An example is Lake Scutari in Yugoslavia.

Solution is important in other rocks such as rock salt. Local subsidence may occur when the underlying beds of rock-salt are gradually removed in solution. Many of the meres of Cheshire, England, were probably caused by this, and are also the result of salt-mining operations.

(b) Wind-deflated lakes. The deflating action of winds in deserts creates hollows. These may reach ground water which seeps out forming small, shallow lakes. Excessive evaporation causes these to become salt lakes and playas. These are found in the Qattara Depression in Egypt, and the Great Basin of Utah, U.S.A.

5. Lakes Formed by Deposition

(a) Lakes due to river deposits. A river may shorten its course during a flood by cutting across its meandering loops, leaving behind a horseshoe-shaped channel as an ox-bow lake, e.g. those that occur on the flood-plains of Lower Mississippi, U.S.A. and Rio Grande, Mexico.

(b) Lakes due to Marine deposits. The action of winds and waves may isolate lagoons along coasts by building spits or bars. As these lagoons of shallow water are enclosed only by a narrow spit of land, comprising mud, sand and shingle, they may drain away at low tide. They are commonly found off the deltas of large rivers such as the Nile and the Ganges. In East Germany and Poland, lagoons are called haffs. Strong on-shore winds are capable of pushing *coastal sand dunes* landwards, and these may enclose marshy lagoons. This type of lagoon is well developed in the Landes of south-west France.

(c) Lakes due to landslides, screes and avalanches. Lakes formed by these processes are also known as barrier lakes. Landslides or screes may block valleys so that rivers are dammed. Such lakes are short-lived, because the loose fragments that pile across the valleys will soon give way under the pressure of water. When they suddenly give way, the dammed water rushes down, causing floods. Examples of lakes of this type are, Lake Gormire in Yorkshire, blocked by landslides; Ffynnon Frech on Snowdon blocked by screes (Fig. 71).

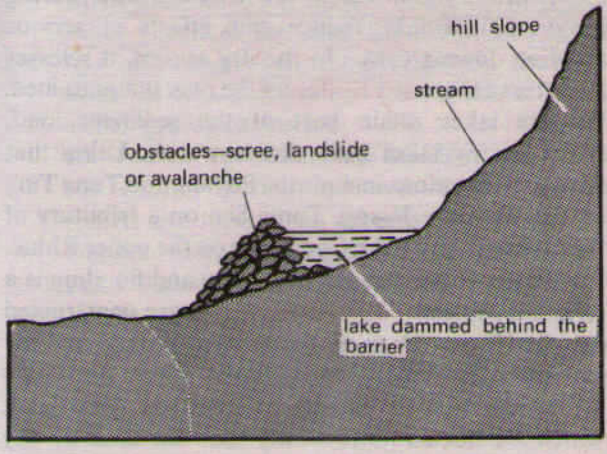


Fig. 71 Deposition (a barrier lake formed by the deposition of an obstacle)

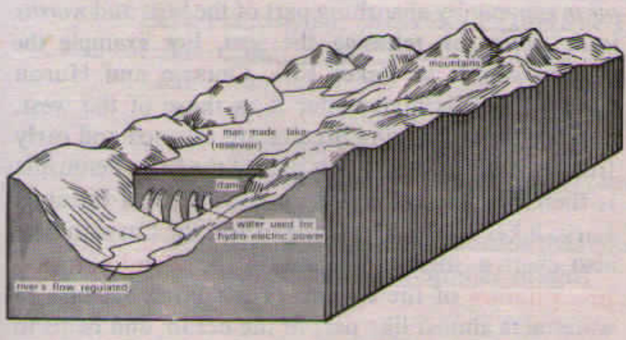


Fig. 72 Human activities (a lake made by constructing a concrete dam across a river valley)

6. Lakes Formed by Human and Biological Activities

(a) Man-made lakes. Besides the natural lakes, man has now created artificial lakes by erecting a *concrete dam* across a river valley so that the river water can be kept back to form reservoirs (Fig. 72). Amongst such man-made lakes, the most imposing is Lake Mead above the Hoover Dam on the Colorado River, U.S.A.

(b) Lakes made by animals. Animals like beavers are particularly interesting. They live in communities and construct dams across the rivers with timber. Such beaver dams are quite permanent and are found in North America, e.g. Beaver Lake in Yellowstone National Park, U.S.A.

(c) Other types of lakes. These include ornamental lakes, especially made to attract tourists, e.g. Lake Gardens, Kuala Lumpur, Taiping Lakes. Man's mining activities, e.g. tin mining in West Malaysia, have created numerous lakes. Inland fish culture has necessitated the creation of many *fishing-lakes*.

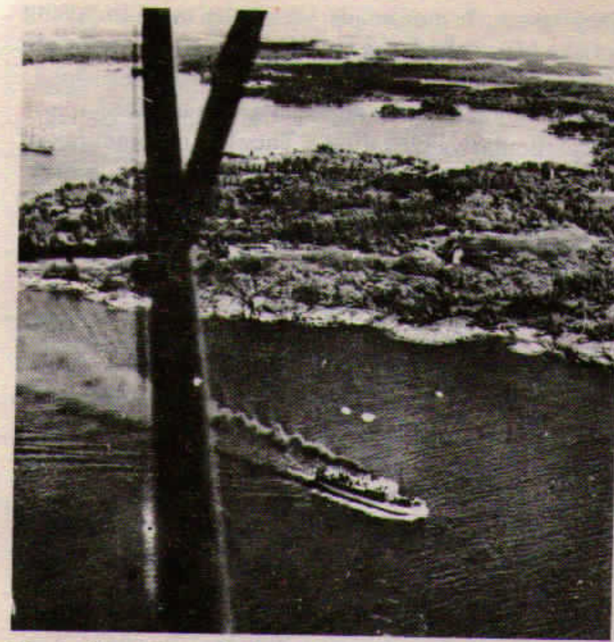
Lakes and Man

A careful examination of the lakes of the world will reveal their immense human significance. In countries where they are found in abundance, such as Finland, Canada, U.S.A., Sweden and the East African states, lakes, together with other inland waterways, have played a dominant role in the human, economic, social and cultural life of the people. The pattern of settlement, commerce and communication is very closely related to the distribution of the water features.

The following are the major uses of lakes and their associated human activities.

1. Means of communication. Large lakes like the Great Lakes of North America provide a cheap and convenient form of transport for heavy and bulky goods such as coal, iron, machinery, grains and timber. The Great Lakes-St. Lawrence waterways penetrate more than 1,700 miles into the interior. They are thus used as the chief arteries of commerce. It is estimated that the annual tonnage passing through the Sault-Ste. Marie Canal, or the Soo Canal, between Lake Huron and Lake Superior is greater than the combined annual tonnage of the Suez and Panama Canals.

2. Economic and industrial development. Early settlements and town sites were very much influenced by the presence of lakes. Lakes are an even more decisive factor when they are drained by large rivers with outlets to the sea. The Great Lakes-St. Lawrence waterways were responsible for the development of the interior wheat farms and lakeside industries. Raw materials, minerals and fuels were economically handled and assembled in the *'HOMES'* district (Lakes *H*uron, *O*ntario, *M*ichigan, *E*rie and *S*uperior), which has since become one of the greatest industrial districts of the world. Similarly, Lakes Poyang, Tung Ting and other lakes of the central



Some of the lakes of Finland scoured out by ice action
Camera Press

Yang-tze basin have greatly assisted in the commercial and industrial development of *Wuhan* (*Wu*chang, *Han*yang and *Han*kow).

3. Water storage. Lakes of either natural or artificial origin are vital sources of *domestic* water supply to surrounding towns and industrial cities. For example in Britain Lake Thirlmere supplies water to Manchester, Loch Katrine to Glasgow, Lake Vyrnwy (in Wales) to Liverpool. The Okhla Reservoir supplies Delhi and the Vetarna, Vihar and Tulsi lakes supply Bombay.

4. Hydro-electric power generation. In mountainous districts, lakes or man-made reservoirs are used to furnish *a good* head of water to generate hydro-electric power. Natural lakes are preferred to artificial reservoirs because the volume of water that flows from them varies very little throughout the year. For instance, the Niagara River flowing from Lake Erie to Lake Ontario has a very regular supply of water for its power stations, whereas the Catawba River in the Carolinas which does not flow from a lake, has very little water during the dry season. Cotton mills have been forced to close down during the period of drought due to insufficient power supplies to run the mills. The Aswan Dam on the Nile in Egypt and the Lloyd Barrage on the Indus at Sukkur suffer from similar defects. The Abu Bakar Dam of the Cameron Highlands supplies much hydro-electricity for central West Malaysia.

5. Agricultural purposes. As mentioned earlier most lakes will eventually be eliminated, and when they dry up, their former beds are covered with thick layers of fertile alluvium. They make excellent agricultural land like the fertile Vale of Pickering in Yorkshire, or the rich Red River Valley of Canada which was in fact the former site of Lake Agassiz.

Modern multi-purpose dams, besides generating hydro-electric power also supply water for irrigation e.g. the Sennar Dam on the Blue Nile in Sudan, the Burrinjuck Dam on the Murrumbidgee in Australia, and the Hirakud Dam (Madhya Pradesh) on the Mahanadi in India.

6. Regulating river flows. A river with large lakes in its basin seldom experiences serious floods or lack of water. By absorbing the excess water during heavy rain, a lake reduces the effects of serious flooding downstream. In the dry season, it releases its water so that a steady flow of the river is maintained. Because lakes retain part of the sediment load, rivers leaving lakes have clearer water. Lakes that have such functions include the Poyang and Tung Ting on the Yang-tze Kiang, Tonle Sap on a tributary of the Mekong, and Lake Constance on the upper Rhine. Where such lakes are not available, and flooding is a serious problem, artificial reservoirs are constructed e.g. the Hoover Dam on the River Colorado and the Bhakra and Nangal Dams on the Sutlej in India.

7. Moderation of climate. Large and deep lakes which are heated more slowly than the land by day and cooled more slowly than the land by night, exercise an appreciable effect in moderating the climate of a region in the same way as oceans affect adjoining land masses. Water in the lakes *cools the air in summer* by absorbing part of the heat and *warms it in winter* by releasing the heat. For example the eastern shores of Lakes Erie, Ontario and Huron have a much milder winter than those of the west, because the on-coming breezes are warmed and early frosts are minimised. This part of the Lake Peninsula is therefore important for grapes and fruit farming. Large lakes like Lake Michigan and the Caspian Sea, also exert a slight influence on the cloudiness and precipitation of the region. Their large expanse of water acts almost like part of the ocean, and helps to precipitate atmospheric moisture into rain. The leeward side of Lake Michigan records a little more precipitation than the windward side, though the actual amount is often not easily noticeable. Small lakes have practically no effect at all on either temperature or rainfall.

8. Source of food. Many large lakes have important supplies of protein food in the form of freshwater fish. Sturgeon is commercially caught in the Caspian Sea, salmon and sea trout in the Great Lakes, and in Tonle Sap in Cambodia, fishing is a leading occupation. Amateur fishermen have found fishing in lakes and rivers a most rewarding pastime. In many countries, artificial lakes have been created for inland fish breeding. This is particularly important in China and Japan.

9. Source of minerals. Salt lakes provide valuable rock salts. In the Dead Sea, the highly saline water is being evaporated and produces common salt, almost indispensable for human well-being. Borax is mined in the salt lakes of the Mojave Desert.

Gypsum is mined in Cheshire, and Stassfurt, a small distance from Berlin, is so rich in potash and other chemical deposits, that they have given rise to a wide range of chemical industires. In both these areas the salts are obtained from deposits formed in a earlier geological period.

10. Tourist attraction and health resorts. Some of the world's best frequented holiday and health resorts are located on lakesides for example, Lake Geneva, Lake Lucerne, Lake Lugano, Lake Como, Lake Placid (New York), Lake Vaner and Lake Vatter, (Sweden), the English Lake District and Taiping Lakes. The glacier-formed lakes of the Alps have made the tourist industry a national occupation of the Swiss.

QUESTIONS AND EXERCISES

1. Locate any *three* of the following lakes. Lake Tanganyika, Great Salt Lake, Lake Toba, Lake Como, Lake Victoria, Lake Scutari, Lake Mead
   (a) With the aid of sketch maps, explain their mode of formation
   (b) State their specific value to the countries they serve
   (c) Name another lake outside that country which has fairly similar origins

2. Explain how each of the following types of lakes are formed. Quote an example of each and locate them in clear sketch maps.
   (a) ox-bow lake
   (b) kettle lake
   (c) crater lake
   (d) karst lake

3. (a) With the help of large, labelled diagrams, explain how lakes may be formed by any *three* of the following.
   i. glaciation
   ii. earth movement
   iii. volcanic activity
   iv. erosion
   v. deposition
   (b) Quote three actual examples of each
   (c) State three uses of man-made lakes

4. Rivers may be dammed for
   (a) generating hydro-electricity
   (b) controlling floods
   (c) irrigating crops
   (d) supplying drinking water
   (e) assisting inland water transport

   For any *four* of them, locate a dam and a river in which the damming has taken place. Explain briefly how each of the above purposes has been successfully achieved.

5. Each of the following terms are in one way or another connected with lake formation and uses. For any *five* of them give a concise explanation of their implications and give a good example of each.
   (a) basin of inland drainage
   (b) tectonic lakes
   (c) haffs
   (d) beaver dams
   (e) playas
   (f) barrier lakes
   (g) tarns

Chapter 10 Coastal Landforms

The Action of Waves, Tides and Currents

The coastline, under the constant action of the waves, tides and currents, is undergoing changes from day to day. On calm days, when winds are slight, waves do little damage to the shoreline and may instead help to build up beaches and other depositional features. It is in storms that the ravages of the waves reach their greatest magnitude. The average pressure of Atlantic waves on adjacent coasts is about 600 lb. per square foot in the summer and treble that in winter. During storms, the pressure exerted is more than 6,000 lb. or 3 tons per square foot! Movements of such intensity will wear down not only the cliffs but also sea walls and buildings. *Tides and currents*, on contact with the shores, make very little direct attack on the coastline. Tides affect marine erosion mainly by extending a *line* of erosion into a zone of erosion. This zone corresponds to the area between the low water level and the high water level. Currents help to move eroded debris and deposit it as silt, sand and gravel along the coasts.

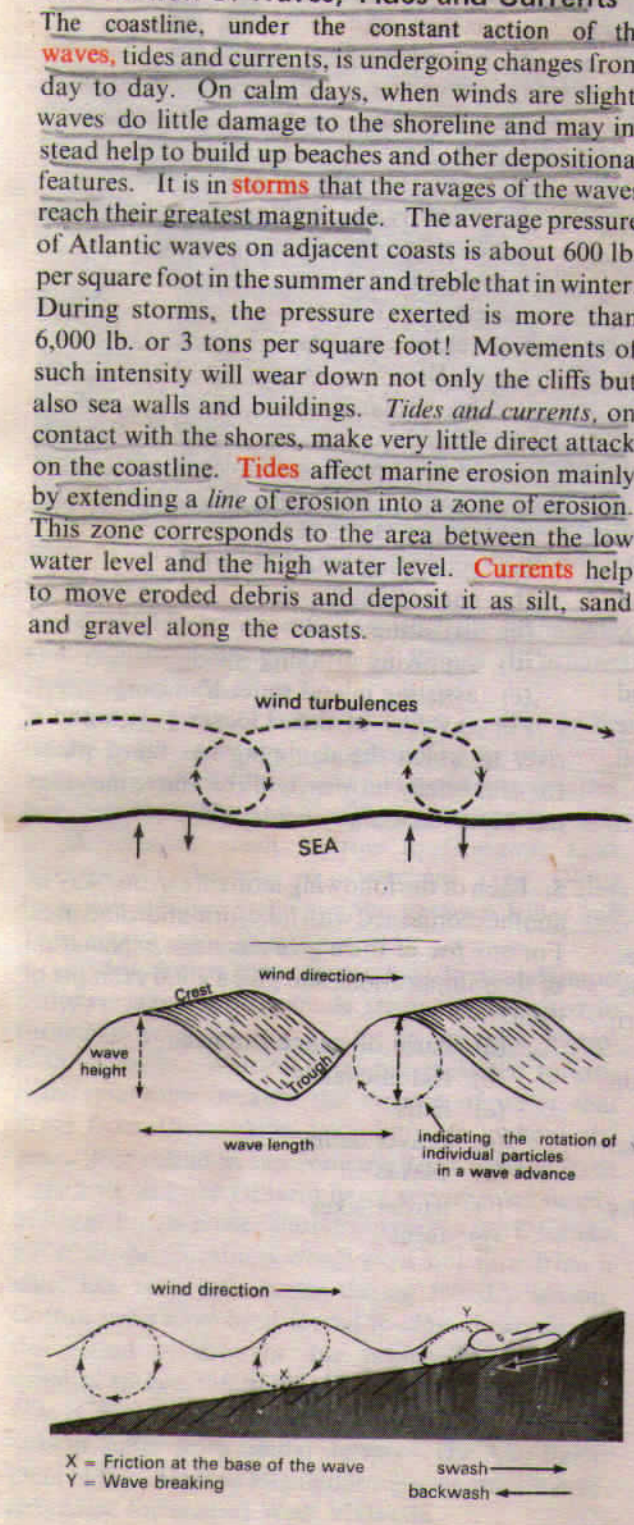


Fig. 73 The mechanism of wave motion

The Mechanism of Marine Erosion

The most powerful agents of marine erosion are waves. Their origin is due to the sweeping of winds over the water surface, which sets a series of undulating swells surging forward. These become higher and swifter. A normal wave in an open ocean may measure 20 feet high (the vertical height between the crest and the trough) and 400 feet long (the wave-length or the horizontal distance between one crest and another). During storms this is greatly increased, depending on the speed and duration of the winds. On approaching shallow water near the shores, their speed is reduced and the waves are curved or refracted against the alignment of the coast. Shallow water, when it is less than the height of the waves, checks their forward movement, the crests curl over and break into the shores in a mass of foam as breakers. The water that finally rushes up the beach and hurls rock debris against the land is termed swash. The water is sucked back and retreats as backwash. Another element in offshore drift is the undertow, which flows near the bottom away from the shore. This current exerts a pulling effect which can be dangerous to sea-bathers (Fig. 73).

Marine agents of erosion operate in the following ways to transform the coastal landscape.

1. Corrasion. Waves armed with rock debris of all sizes and shapes charge against the base of the cliffs, and wear them back by corrasion. On-coming currents and tides complete the work by sweeping the eroded material into the sea.

2. Attrition. The constantly moving waves that transport beach materials such as boulders, pebbles, shingle and fine sand also hurl these fragments against one another, until they are broken down by attrition into very small pieces. The grinding and polishing of such fragmental materials against cliff faces and against each other is largely responsible for the fine sand which forms the beaches that are so typical of the seaside resorts.

3. Hydraulic action. In their forward surge, waves splashing against the coast may enter joints and crevices in the rocks. The air imprisoned inside is immediately compressed. When the waves retreat, the compressed air expands with explosive violence. Such action repeated again and again soon enlarges the cracks and rock fragments are prised apart.

4. Solvent action. On limestone coasts, the solvent action of sea water on calcium carbonate sets up chemical changes in the rocks and disintegration takes place. This process is limited to limestone coasts.

The rate of marine erosion depends on the nature of the rocks, the amount of rock exposed to the sea, the effects of tides and currents, and human interference in coast protection. Other effects such as vulcanicity, glaciation, earth movement and organic accumulations have also to be considered.

Coastal Features of Erosion

1. Capes and bays. On exposed coasts, the continual action of waves on rocks of varying resistance causes the coastline to be eroded irregularly. This is particularly pronounced where hard rocks, e.g. granites and limestones, occur in alternate bands with softer rocks e.g. sand and clay. The softer rocks are worn back into inlets, coves or bays and the harder ones persist as headlands, promontories or capes (Fig. 74). Along the Dorset coast of southern England, Swanage Bay and Durlston Head are examples. Even where the coast is of one rock type irregularities will be caused by variation within the rock. Thus Penang Island, made of granite, has many bays and headlands. Very large indentations such as the Persian Gulf or the Bay of Bengal are due to other causes such as submergence or earth movement.

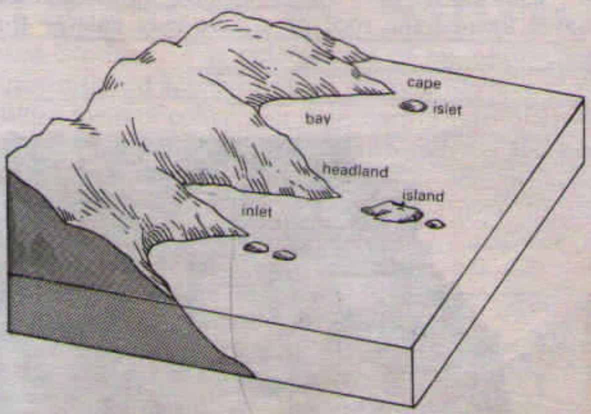


Fig. 74 Coastal features of differential erosion

2. Cliffs and wave-cut platforms. Generally any very steep rock face adjoining the coast forms a cliff. The rate of recession will depend on its geological structure, that is the stratification and jointing of the rocks and their resistance to wave attack. If the beds dip seawards, large blocks of rock will be dislodged and fall into the sea. The cliff will rise in a series of 'steps' as shown in Fig. 75. On the contrary, if the beds dip landwards as illustrated in Fig. 76, the cliff will be more resistant to wave erosion. Some of the best known cliffs are the chalk cliffs of the English Channel and include Beachy Head which is 500 feet high, the Seven Sisters near the mouth of the Cuckmere and the 'White Cliffs' of Dover.

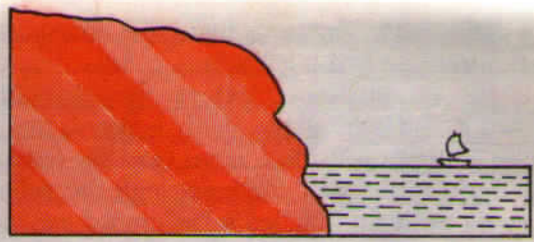


Fig. 75 Cliff beds dipping seawards

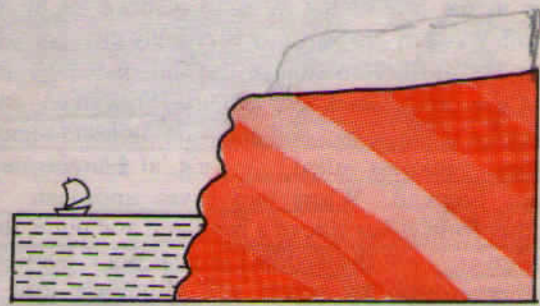


Fig. 76 Cliff beds dipping landwards

At the base of the cliff the sea cuts a notch, which gradually undermines the cliff so that it collapses.

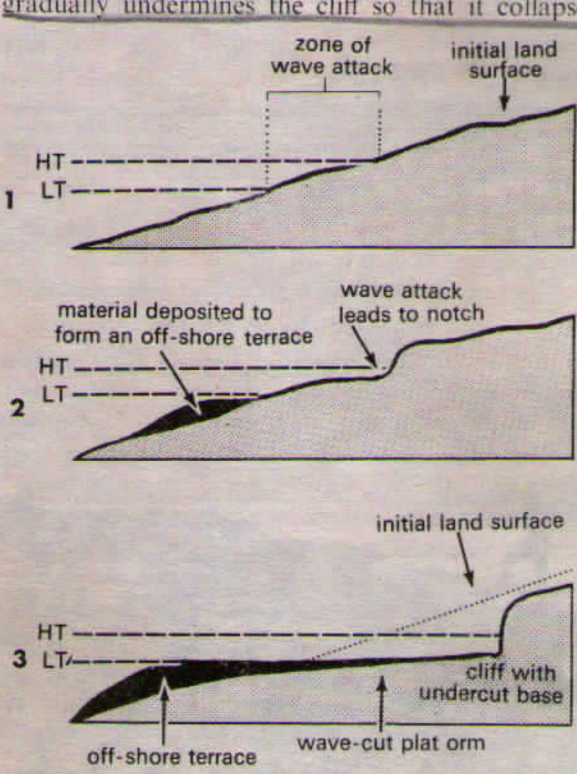


Fig. 77 The development of shore profile

As a cliff recedes landwards under the pounding of waves, an eroded base is left behind, called a **wave-cut platform**. The platform, the upper part of which is exposed at low tide, slopes gently seawards and its surface is strewn with rock debris from the receding cliff. Further abrasion continues until the pebbles are swept away into the sea. The eroded materials are deposited on the **off-shore terrace** (Fig. 77). When the platform attains a greater width (e.g. 30 miles in the case of the wave-cut platform of Strandflat off Western Norway), it is entirely covered with water and further erosion of the cliffs is negligible.

3. Cave, arch, stack and stump. Prolonged wave attack on the base of a cliff excavates holes in regions of local weakness called **caves** e.g. at Flamborough Head, England. When two caves approach one another from either side of a headland and unite, they form an **arch**, e.g. the Neddle Eye near Wick, Scotland. Further erosion by waves will ultimately lead to the total collapse of the arch. The seaward portion of the headland will remain as a pillar of rock known as a **stack**. One of the finest examples of a stack is the Old Man of Hoy in the Orkneys which is of Old Red Sandstone and is 450 feet high. Equally outstanding are the Needles, Isle of Wight, which are a group of stacks cut in chalk and diminishing in size seawards. In the course of time, these 'stubborn' stacks will gradually be removed. The vertical rock pillars are eroded, leaving behind only the **stumps** which are only just visible above the sea level, e.g. those of the St. Kilda group, off the Outer Hebrides, Scotland (Fig. 78).

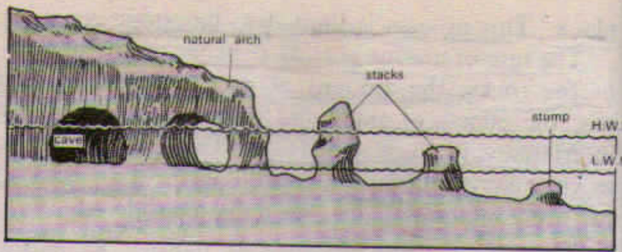
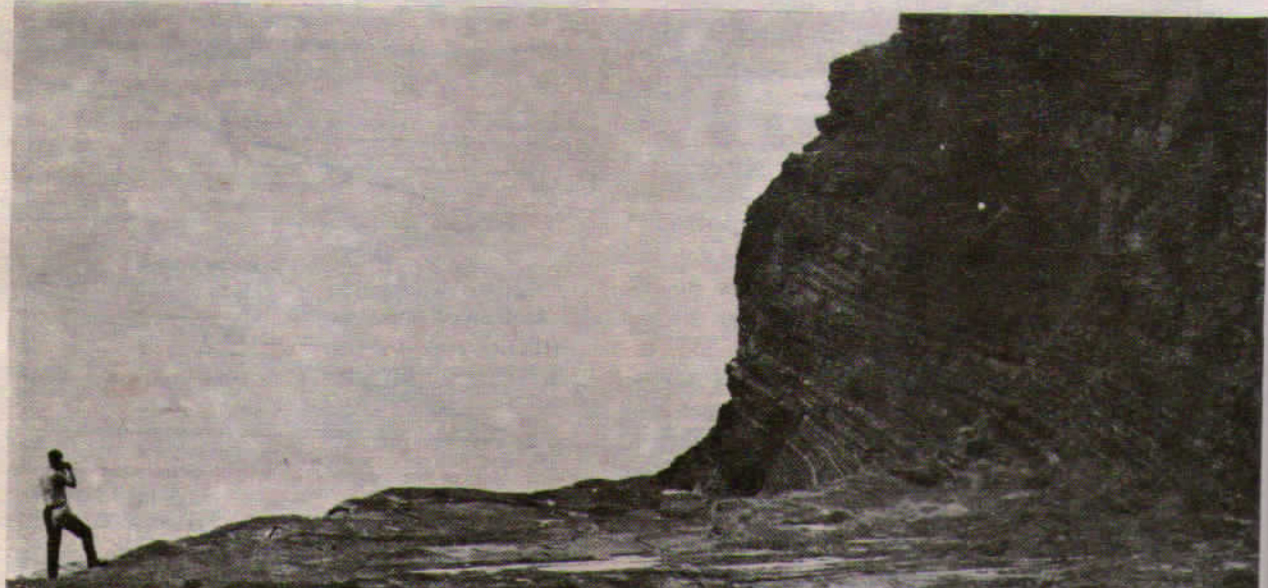


Fig. 78 Arch, stacks and stumps. Where two caves are eroded on either side of a headland they may eventually join to form a natural arch. If the top of the arch collapses stacks are formed. These are gradually worn down until they become stumps exposed only at low tide

4. Geos and gloups. The occasional splashing of the waves against the roof of a cave may enlarge the

A wave-cut platform on the Hong Kong coast *S.T. Fok*



joints when compressed air is trapped inside. A natural shaft is thus formed which may eventually pierce through to the surface. Waves breaking into the cave may force water or spray or just air out of this hole. Such a shaft is termed a gloup (from the noise made by the water gurgling inside) or blow-hole (Fig. 79). An example is at Holborn Head in Caithness Scotland.

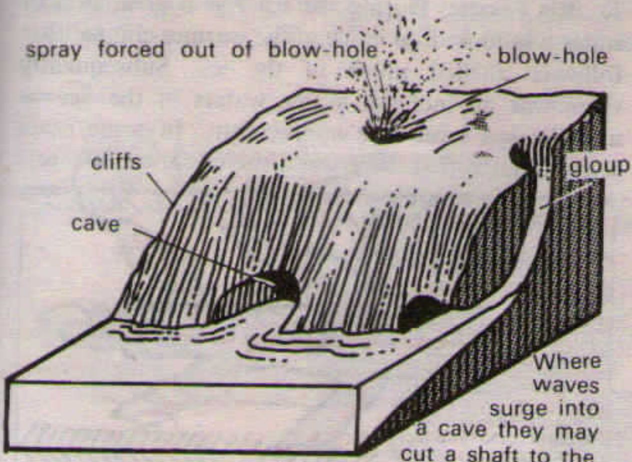


Fig. 79 Gloup

The enlargement of blow-holes and the continued action of waves weakens the cave roof. When the roof collapses a long, narrow inlet or creek develops. Such deep clefts, which may be 100 feet deep and equally long, are called geos, e.g. the Wife Geo, near Duncansby Head, Scotland (Fig. 80).

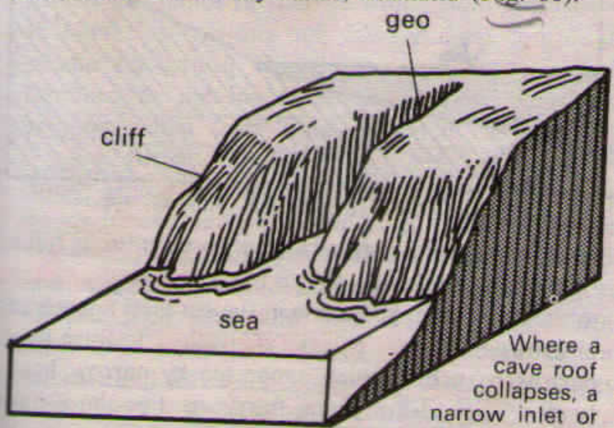


Fig. 80 Geo

Coastal Features of Deposition

1. **Beaches.** Sands and gravels loosened from the land are moved by waves to be deposited along the shore as beaches. This is the most dominant form of the constructive work of the sea. The eroded material is transported along the shore in several distinct ways. The longshore drift which comes obliquely to the coast carries the material along the shore in the direction of the dominant wind (Fig. 81). At the same time, the backwash removes part of the material seawards along the bed of the sea, and deposits it on the off-shore terrace and even beyond. Finer materials such as silt and mud are deposited in the shallow waters of a sheltered coast.

A natural arch

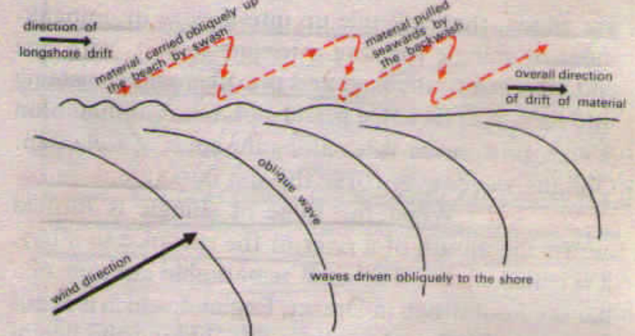


Fig. 81 Longshore drift

The constant action of the waves automatically sorts out the shoreline deposits in a graded manner. The coarser materials (cobbles and boulders) are dropped by the waves at the top of the beach. The finer materials (pebbles and sand grains) which are carried down the beach by the backwash are dropped closer to the sea. On smooth lowlands, beaches may continue for miles, like those of the east coast of West Malaysia, but in upland regions where the land descends abruptly into the sea, such as the Chilean coast, long beaches are absent.

2. **Spits and bars.** The debris eroded by waves is continually moved by longshore drift and where there is an indentation in the coast, such as the mouth of a river or a bay, material may continue to be deposited across the inlet. As more materials

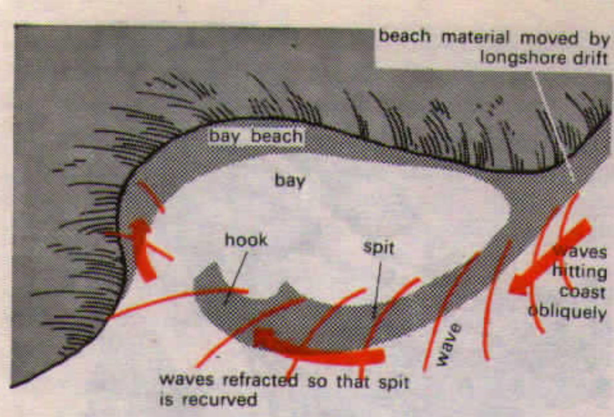


Fig. 82 Development of spit

are added, they will pile up into a ridge or embankment of shingle forming a tongue or spit, with one end attached to the land and the other end projecting into the sea (Fig. 82), e.g. Calshot Spit, Southampton Water, England or those along the coast of Kelantan. Oblique waves may curve the spit into a hook or recurved spit. When the ridge of shingle is formed across the mouth of a river or the entrance to a bay, it is called a bar. The most remarkable example of a bar is Chesil Beach in Dorset, England, which extends for over 16 miles along the coast, linking the Isle of Portland with mainland, and enclosing a lagoon called the Fleet. Such a connecting bar that joins two land masses is better known as tombolo. On the Baltic coast of Poland and Germany, large bodies of water are almost completely enclosed by long bars, locally termed nehrungs, to form marshy lagoons or haffs.

3. Marine dunes and dune Belts. With the force of on-shore winds, a large amount of coastal sand is driven landwards forming extensive marine dunes that stretch into dune belts. Their advance inland may engulf farms, roads and even entire villages. The dunes of the Landes, south-west France, cover 6,000 square miles; the crests of the dunes are over 130 feet high. Dunes are common in the coastlands of Belgium, Denmark and the Netherlands. To arrest the migration of the dunes, sand-binding species of grass and shrubs, such as marram grass, and pines are planted.

Types of Coasts

Despite a great variety of coastal features coastlines may be divided into two basic types.

1. Coastlines of submergence. These are due to the sinking of the land or the rise of the sea, including such coasts as ria coasts, fiord coasts, estuarine coasts and Dalmatian or longitudinal coasts.

2. Coastlines of emergence. These are due to the uplift of the land or a fall in the sea level. They are less common and are represented by the uplifted lowland coast and the emergent upland coast.

Coastlines of Submergence

1. Ria coasts. During the Ice Age a great deal of water was locked up in ice. The warmer climate that followed melted much of the ice. Subsequently there was an increase in the waters of the oceans and the sea level rose appreciably. In some cases it is estimated that there was a rise of almost 300 feet!

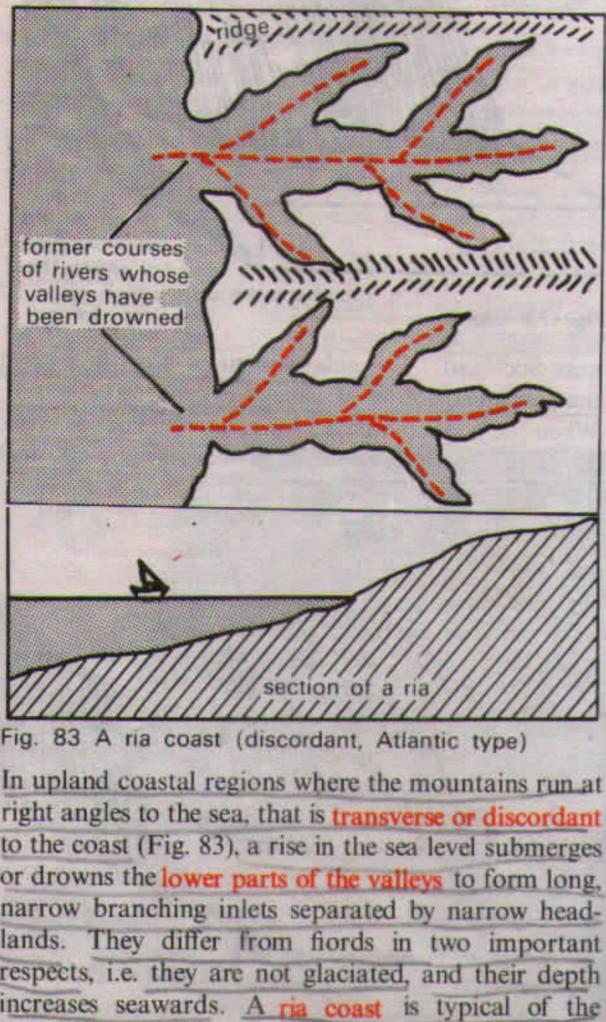


Fig. 83 A ria coast (discordant, Atlantic type)

In upland coastal regions where the mountains run at right angles to the sea, that is transverse or discordant to the coast (Fig. 83), a rise in the sea level submerges or drowns the lower parts of the valleys to form long, narrow branching inlets separated by narrow headlands. They differ from fiords in two important respects, i.e. they are not glaciated, and their depth increases seawards. A ria coast is typical of the Atlantic type of coast like those of north-west France, north-west Spain, south-west Ireland, Devon and Cornwall. As rias are generally backed by highland, they support few large commercial ports though they have deep water and offer sheltered anchorage. They have been extensively used for siting fishing ports and naval bases such as Plymouth and Brest.

2. Fiord coasts. Fiords are *submerged U-shaped* glacial troughs. They mark the paths of glaciers that plunged down from the highlands. They have **steep walls,** often rising straight from the sea, with tributary branches joining the main inlet at right angles. Due to the greater intensity of ice erosion fiords are deep for great distances inland but there is a shallow section at the seaward end formed by a ridge of rock and called the **threshold** (Fig. 84). Off the fiord coast are

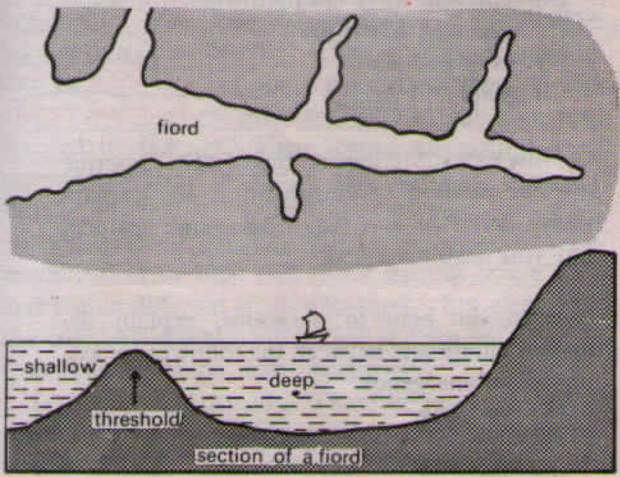


Fig. 84 A fiord coast (submergent and glaciated)

numerous islands or skerries which, with the shallow thresholds, sometimes only 200 feet deep, complicate coastal navigation. Fiord coasts are almost entirely confined to the higher latitudes of the temperate regions which were once glaciated e.g. Norway, Alaska, British Columbia, southern Chile and the South Island of New Zealand. Some of the large fiords are extremely long and deep. For example the **Sogne Fiord** of Norway is 110 miles long, 4 miles wide and almost 4,000 feet deep in its mid-channel. Despite their deep and sheltered water, few large ports are located in fiords. Their mountainous background with poor accessibility inland, attract few settlements. Agriculture is confined to the **deltaic fans,** built up where streams flow down to the fiords. The few towns that exist either as fishing or market centres e.g. Trondheim, are only of local importance.

3. Dalmatian coast. This is the longitudinal coast where mountains run **parallel or concordant** to the coast. The name is taken from the coast of Dalmatia, Yugoslavia, along the Adriatic Sea, where the submergence of the coastline produces long, narrow inlets with a chain of islands parallel to the coast. The

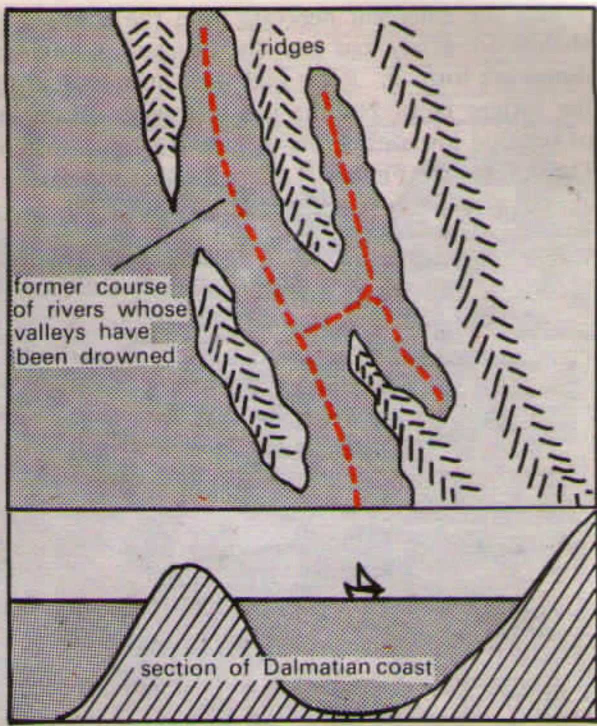


Fig. 85 A Dalmatian coast (concordant, Pacific type)

elongated islands are the crests of former ranges and the narrow **sounds** were the former longitudinal valleys (Fig. 85). The Dalmatian type of coast is also typical of the Pacific coast where the ranges are parallel to the coast e.g. western coasts of North and South America but there the coastline is more regular. Like the ria and fiord coasts, the mountainous nature of the Dalmatian coastline hinders communication inland. It has deep, sheltered harbours but no distinguished ports. On the Pacific coast, however, there are some important ports such as San Francisco.

4. Estuarine coasts. In submerged lowlands, the mouths of rivers are drowned so that funnel-shaped **estuaries** are formed. If their entrances are not silted by moving sand-banks, they make excellent sites for ports, e.g. the estuaries of the Thames, Elbe and Plate are the sites of such great seaports as London, Hamburg and Buenos Aires. Tidal effects further enhance the value of the ports and even when there is a little silting, modern dredges help to keep the ports open all the time.

Coastlines of Emergence

1. Uplifted lowland coast. The uplift of part of the continental shelf produces a smooth, *gently sloping coastal lowland* (Fig. 86). The offshore waters are shallow with **lagoons, salt-marshes and mud-flats.**

Where the emergent deposits from the continental shelves are sandy and gravelly, beaches and marine dunes are formed. Ports that were once located on the former coast become inland towns. Examples of uplifted lowland coasts include the south-eastern U.S.A., western Finland, eastern Sweden and parts of coastal Argentina south of the Rio de la Plata.

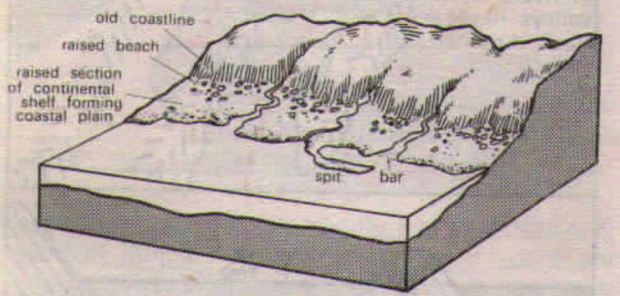


Fig. 86 Lowland coastline of emergence

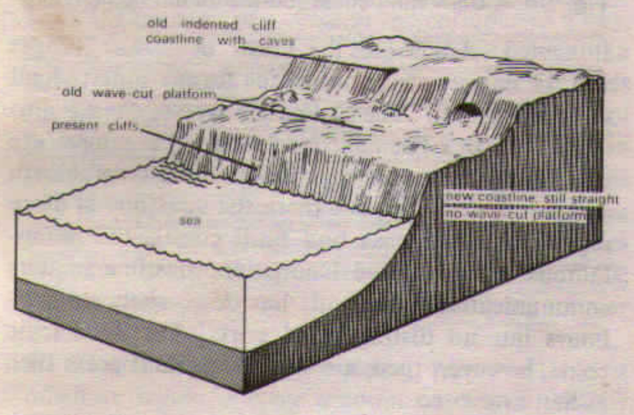


Fig. 87 Upland emergent coastline

2. Emergent upland coast. Faulting and earth movement may thrust up coastal plateaux so that the whole region is raised, with consequent emergent features. A raised beach is the most prominent. The raised beach is beyond the reach of the waves, though it may still possess arches, stacks and other coastal features. The emergent upland coast is quite straight with steep cliffs and deeper off-shore water, for the waves have not yet eroded lines of weakness or carved a wave-cut platform (Fig. 87). It has little potential for good port sites. Examples of emergent upland coasts are found in Scotland, the western coast of the Deccan, India and the western Arabian coast facing the Red Sea.

QUESTIONS AND EXERCISES

1. By reference to specific examples describe some of the major coastal features resulting from the constructive and destructive work of the sea.

2. With the aid of annotated diagrams, describe the appearance and formation of any *three* of the following pairs of features of coastal landforms.
   (a) cliff and wave-cut platform
   (b) geo and blowhole
   (c) arch and stack
   (d) spits and bars

3. How can shorelines be classified? Describe any *one* method of classification and explain briefly some of the major shoreline features that you have classified.

4. With the help of diagrams, explain the distinct differences between the following coastlines of submergence.
   (a) ria coast
   (b) fiord coast
   (c) Dalmatian coast
   (d) estuarine coast

5. Choose any *three* of the following terms connected with marine landscape. Explain the meaning of each and state its role in transforming the coastline.
   (a) longshore drift
   (b) undertow
   (c) concordant coast
   (d) raised beach
   (e) tombolo

Chapter 11 Islands and Coral Reefs

An island is a piece of land surrounded on all sides by water. It may occur individually or in a group, in open oceans or seas. Smaller ones of only local significance are found even in lakes and rivers. Generally speaking all islands may be grouped under the following types.

1. Continental islands. These islands were formerly part of the mainland and are now detached from the continent. They may be separated by a shallow lagoon or a deep channel. Their separation could be due to subsidence of some part of the land or to a rise in sea level, so that the lowland links are submerged by the sea. Their former connection with the neighbouring mainland can be traced from the similar physical structure, flora and fauna that exist on both sides of the channel. In the course of time, modification by men and other natural forces may give rise to different surface features. But even then, the basic structural features will remain the same. Continental islands may appear as:

(a) Individual islands. These lie just outside the continent, very much associated with the characteristic features of the mainland of which they were once part. Some of the outstanding examples are Newfoundland, separated from the mainland by the Strait of Belle Isle; Madagascar, by the Mozambique Channel; Ceylon by the Palk Strait; Tasmania by the Bass Strait and Formosa by the Formosa Strait.

(b) Archipelagoes or island groups. These comprise groups of islands of varying sizes and shapes, e.g. the British Isles, the Balearic Islands of the Mediterranean and also those of the Aegean Sea.

(c) Festoons or island arcs. The islands form an archipelago in the shape of a loop around the edge or the mainland, marking the continuation of mountain ranges which can be traced on the continent, e.g. the East Indies, the Aleutian Islands, Ryukyu Islands, Kurile Islands and other island arcs of the Pacific coasts.

2. Oceanic islands. These islands are normally small and are located in the midst of oceans. They have no connection with the mainland which may be hundreds or thousands of miles away. They have a flora and fauna unrelated to those of the continents. The Galapagos Islands have many unique species of animals. Due to their remoteness from the major trading centres of the world, most of the oceanic islands are very sparsely populated. Some of them provide useful stops for aeroplanes and ocean

Rarotonga in the Cook Islands, a rugged volcanic island in the Pacific *N.Z. High Commission Malaysia*

steamers that ply between continents across vast stretches of water. Generally speaking, oceanic islands fall into one of the following groups.

(a) Volcanic islands. Many of the islands in the oceans are in fact the topmost parts of the cones of volcanoes that rise from the ocean bed. Most of them are extinct, but there are also some active ones. The best known volcanic peak of the Pacific Ocean is Mauna Loa in Hawaii, which is 13,680 feet above sea level. Tracing downwards, Mauna Loa is found to have been built up from the ocean floor at a depth 18,000 feet below the water surface! Other volcanic islands have emerged from the submarine ridges of the oceans.

The volcanic islands are scattered in most of the earth's oceans. In the Pacific Ocean, they occur in several groups such as Hawaii, the Galapagos Islands and the South Sea islands. In the Atlantic are the Azores, Ascension, St. Helena, Madeira and the Canary Islands. Those of the Indian Ocean are Mauritius and Reunion. In the Antarctic Ocean are the South Sandwich Islands, Bouvet Island and many others.

(b) Coral islands. Unlike the volcanic islands, the coral islands are very much lower and emerge just above the water surface. These islands, built up by coral animals of various species, are found both near the shores of the mainland and in the midst of oceans. Coral islands include the Marshall Islands, Gilbert and Ellice Islands of the Pacific; Bermuda in the Atlantic and the Laccadives and Maldives of the Indian Ocean.

Coral Reefs

In tropical seas many kinds of coral animals and marine organisms such as coral polyps, calcareous algae, shell-forming creatures and lime-secreting plants live in large colonies. Though they are very tiny creatures, their ability to secrete **calcium carbonate** within their tiny cells has given rise to a peculiar type of marine landform. They exist in numerous species of many forms, colours and shapes. Under favourable conditions, they grow in great profusion just below the water level. Taking coral animals as a whole, the **polyps** are the most abundant and also the most important. Each polyp resides in a tiny cup of coral and helps to form **coral reefs**. When they die, their limy skeletons are cemented into coralline limestone. There are also non-reef-building species such as the 'precious corals' of the Pacific Ocean and the 'red coral' of the Mediterranean which may survive in the colder and even the deeper waters. As a rule they thrive well only in the warmer tropical seas.

The reef-building corals survive best under the following conditions.

1. The **water temperature** must not fall below 68°F. (20°C.). This virtually limits the areal distribution of corals to the **tropical, and sub-tropical zones**. Again they will *not flourish* where there are *cold currents* because of the upwelling of the cold water from the depths that cools the warm surface water. This explains why coral reefs are generally absent on the western coasts of continents. On the other hand the warming effect of the **warm currents**, e.g. the Gulf Stream, means that corals are found far to the north of the West Indies in the Atlantic Ocean. The Pacific and the Indian Oceans, however, have the most numerous coral reefs.

2. The **depth of the water** should not exceed 30 fathoms or 180 feet, because beyond this depth **sunlight** is too faint for photosynthesis to take place. This is essential for the survival of the microscopic **algae**, on which the coral polyps depend. Shallow water of less than 100 feet is ideal. But there should always be plenty of water as polyps cannot survive for too long out of water.

Atafu atoll in the Tokelau island group *N.Z. High Commission Malaysia*

3. The water should be saltish and free from sediment. Corals therefore survive best in the moving ocean water well away from the silty coasts or muddy mouths of streams. The corals are best developed on the seaward side of the reef, where constantly moving waves, tides and currents maintain an abundant supply of clear, *oxygenated water*. They also bring an adequate supply of food in the form of microscopic organisms.

A fringing reef on the Hong Kong coast

Types of Coral Reefs

There are three main types of coral reefs.

1. **Fringing reefs.** A fringing reef is a coralline platform lying close to the shore extending outwards from the mainland. It is sometimes separated from the shore by a shallow lagoon. It is widest when fringing a protruding headland but completely absent when facing the mouth of a stream. The outer edge grows rapidly because of the splashing waves that continuously renew the supply of fresh food. The reefs may be about a mile wide, lying just above the

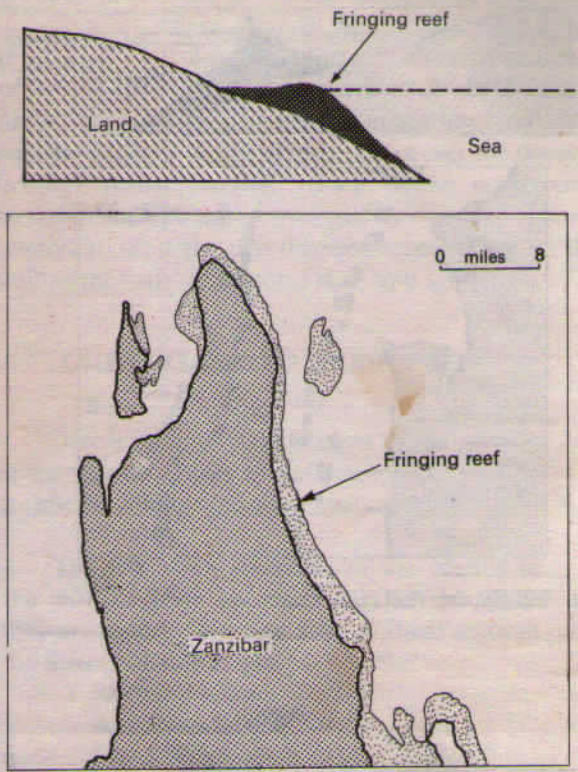


Fig. 88 Fringing reef

level of low water and sloping steeply downwards on the seaward side to a depth of about 100 feet (Fig. 88).

2. **Barrier reefs.** A barrier reef is separated from the coast by a much wider and deeper channel or lagoon (Fig. 89). The reef is partially submerged. Where it lies above the water level and sand can accumulate on it, a little vegetation is possible. The barrier reefs have narrow gaps at several places to allow the water from the enclosed lagoon to return to the open ocean. Such gaps are very useful for shipping and provide the only entrances for ships to enter or leave the lagoon. The best known barrier reef is the Great Barrier Reef off the coast of Queensland, Australia. It is 1,200 miles long, separated from the coast by a channel 100 miles wide in places and over 200 feet deep.

3. **Atolls.** Atolls are similar to barrier reefs except that they are circular in shape, enclosing a shallow lagoon without any land in the centre. The encircling ring is usually broken in a few places to allow the free flow of water (Fig. 90). On the inside of the reefs, sand and limestone debris collect and palm trees like coconuts may grow. Such palm trees

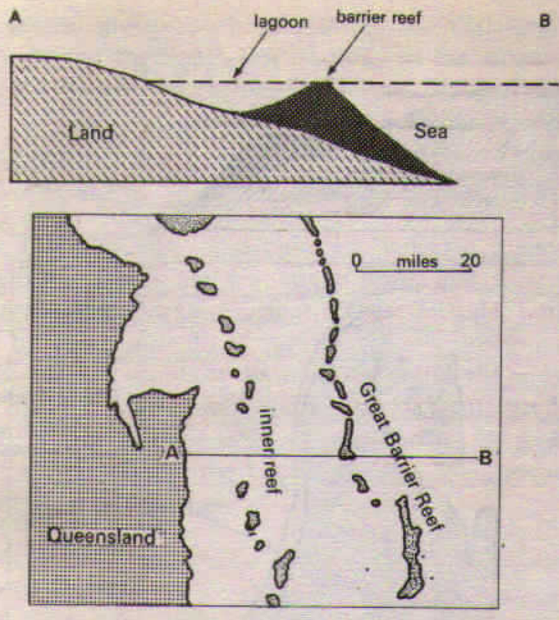


Fig. 89 Barrier reef

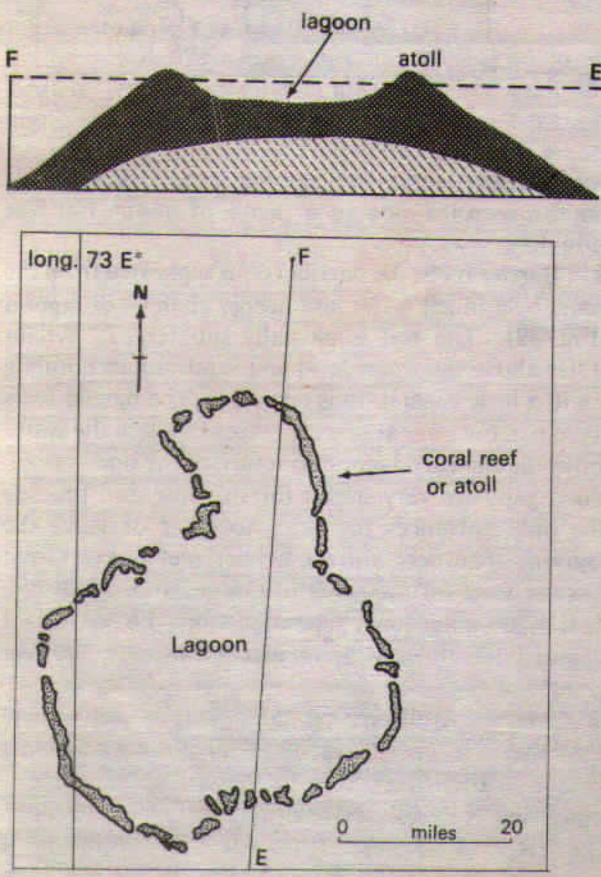


Fig. 90 Atoll

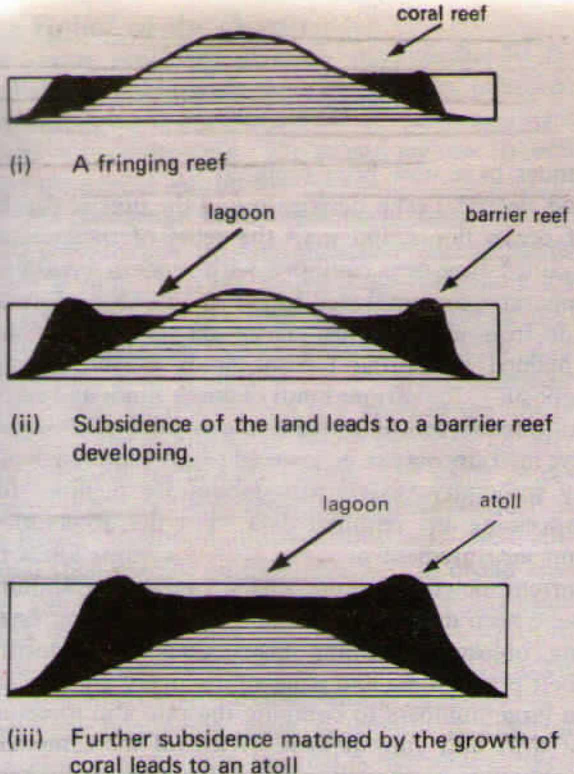
thrive well in the brackish water of the lagoon. The nuts fall into the water and are distributed widely by floating from one coral island to another. The calm waters are useful for fishing and canoeing. Some of the large atolls, e.g. Suvadiva in the Maldives, west of Ceylon, have a lagoon over 40 miles across. A number of them provide essential air bases for trans-Pacific aircraft.

The Probable Origin of Coral Reefs

The subject of the origin of coral reefs has been studied and debated for over one and half centuries. Several theories have been suggested but none is universally accepted.

The most widely accepted theory is that put forward by the great scientist Charles Darwin, after his voyage to the Pacific islands in 1842. It is known as the subsidence theory. Darwin assumed that all coral reefs began as fringing reefs around an island or the topmost portions of extinct volcanoes that stood above the ocean bed. Due to a general downwarping of the earth's crust, the islands gradually subsided. The corals continued to grow upwards to keep pace with the subsidence. The growth was more vigorous at the outward edge than the landward edge because of the more favourable living conditions for corals, so the encircling reef widened. It then formed a barrier reef with a lagoon between the island and the reef. Eventually, when the land completely submerged, only the outer rims of the reefs were seen, forming an atoll. The submerged island was covered by a layer of sediment so that the characteristic circular lagoon is generally shallow. Thus atolls mark the position of the former islands (Fig 91a). More recent researches by oceanographers have revealed that the ocean floor has, in fact, been subjected to subsidence especially in the Pacific. Darwin's explanation was therefore generally correct.

Amongst the other theories, perhaps the American geographer, R.A. Daly's glacial control theory put forward in 1910 is worth consideration. During his visit to Mauna Kea in Hawaii, he noticed the close relationship between glaciation and the development of coral reefs. He believed that during the height of the Ice Ages, the water was too cold for any coral growth to take place. With the absence of a coral barrier, marine erosion was able to attack and lower the islands. With the return of the warmer climate, the water that was locked up in the ice sheets melted. Consequently, there was a rise in the sea level which in some cases submerged these lower islands. On these wave-planed platforms, corals

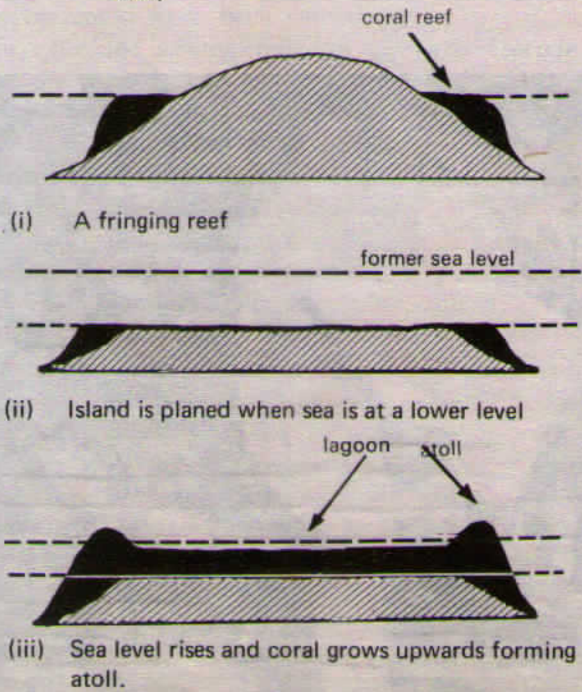


(i) A fringing reef

(ii) Subsidence of the land leads to a barrier reef developing.

(iii) Further subsidence matched by the growth of coral leads to an atoll

Fig. 91 (a) Darwin's theory of subsidence (coral reef growing upwards and outwards to keep pace with subsiding island, passing from fringing reef, to barrier reef and eventually atoll)



(i) A fringing reef

(ii) Island is planed when sea is at a lower level

(iii) Sea level rises and coral grows upwards forming atoll.

Fig. 91 (b) Daly's Glacial Control Theory

began to grow upwards at the rate of a foot in a decade to keep pace with the rising water level (Fig 91b). Coral reefs, where islands still project above sea level, and atolls were thus formed. Recent evidence of boring through coral formations seems to favour Daly's explanation of a change in sea level and consequent erosion of the islands. However the deepest borings reveal basaltic rocks. These correspond to the subsided islands envisaged by Darwin. Thus a combination of the two theories accounts for all the important features of coral reefs and atolls.

QUESTIONS AND EXERCISES

1. Give a concise classification of the islands of the world. Quote actual examples of islands to justify your proposed classification.

2. The following are some of the islands of the world. State in which part of the globe they are found. For any *three* of them account for their probable origin.
   - Sakhalin Island
   - Andaman Islands
   - Maldive Islands
   - St. Helena
   - Hawaiian Islands
   - Crete

3. What are the three general types of coral reefs formed by coral animals. Point out the distinct differences between them.

4. Explain clearly how coral reefs are formed. Under what conditions do corals thrive best?

5. With the aid of examples and diagrams, explain any *three* of the following terms connected with islands and coral reefs.
   - (a) continental islands
   - (b) archipelagoes
   - (c) oceanic islands
   - (d) coral polyps
   - (e) fringing reefs
   - (f) atolls

Chapter 12 The Oceans

Exploring the Oceans

The oceans, comprising more than 70 per cent or 140 million square miles of the earth's surface, have tremendous potential waiting to be developed. Besides being a source of food—fish, mammals, reptiles, salt and other marine foodstuffs—the tides can be harnessed to provide power. Formal oceanographic investigation began only with the British expedition of the *Challenger* (1873–1876), the first successful world-wide deep-sea expedition.

Oceanography, the science of the oceans, has become such an important subject in recent years that researches into the deep seas have been conducted by many institutions, universities, government ministries and other international organizations. The most famous international oceanographic research centre is the International Council for the Exploration of the Sea with its headquarters in Copenhagen. Ocean exploration for the observation and recording of oceanographic data is a very expensive matter. It involves the operation and maintenance of specially equipped vessels in mid-ocean for long periods, and large-scale oceanographic researches are thus best undertaken by international bodies. The older echo-sounding techniques have now been replaced by radar sounding and electrical echo devices to find the precise depths of ocean floors and map the relief of the oceans. Trained frog-men equipped with modern breathing apparatus are employed to gather valuable information from great depths. Deep sea core samplesare obtained by boring for the study of the oceanic deposits—the various kinds of oozes, muds and clays. Automatic-recording thermometers and other sensitive instruments can be lowered to any required depth by stationary vessels with laboratory facilities for processing any required data. For the observation and measurement of current flow,various kinds of current meters using propellers, vanes or pendulums have been designed. Sealed bottles and other floating objects containing instructions for reporting their precise time and place of discovery are released in large numbers to compute the rate and direction of drift and current flow. With all these modern techniques at the disposal of the oceanographers, our knowledge of the mysteries of the oceans is greatly increased. But there is still much to be discovered.

Piston covers, such as this, are used to sample the sediment on the ocean floors *Mohammad Ayob*

The Relief of the Ocean

The ocean basins are in many ways similar to the land surface. There are submarine ridges, plateaux, canyons, plains and trenches. A section drawn across an ocean (Fig. 92) illustrates the typical submarine relief features.

1. The continental shelf. This is, in fact, the seaward extension of the continent from the shoreline to the continental edge marked, approximately, by the 100 fathom (600 feet) *isobath* (isobaths are contours marking depths below sea level). The continental shelf is thus a shallow platform whose width varies greatly, from a few miles in the North Pacific off the continent of North America, to over 100 miles off north-west Europe. In some places where the coasts are extremely mountainous, such as the Rocky Mountain and Andean coasts, the continental shelf may be entirely absent. Off broad lowland coasts like those of Arctic Siberia, a maximum width of 750 miles has been recorded! A width of 20 to 100 miles is generally encountered. The angle of the slope is also variable, and is normally least where the continental shelf is widest. A gradient of 1 in 500 is common to most continental shelves.

Many regard the continental shelf as part of the continent submerged due to a rise in sea level, e.g. at the close of the Ice Age, when the ice in the temperate latitudes melted and raised the sea level by several hundred feet. Some smaller continental shelves could have been caused by wave erosion where the land is being eroded by the sea as shown in Fig. 93. Conversely such shelves might have been formed by the deposition of land-derived or river-borne materials on the off-shore terrace as in Fig. 94.

The continental shelves are of great geographical significance for the following reasons.

(a) Their *shallowness* enables sunlight to penetrate through the water, which encourages the growth of minute plants and other microscopic organisms. They are thus rich in plankton on which millions of surface and bottom-feeding fishes thrive. The continental shelves are therefore the richest fishing grounds in the world, e.g. the Grand Banks off Newfoundland, the North Sea and the Sunda Shelf.

(b) Their limited depth and gentle slope keep out cold under-currents and increase the height of tides. This sometimes hinders shipping and other marine activities since ships can only enter and leave port on the tide. Most of the world's greatest seaports including Southampton, London, Hamburg, Rotterdam, Hong Kong and Singapore are located on continental shelves.

2. The continental slope. At the edge of the continental shelf, there is an abrupt change of gradient to about 1 in 20, forming the continental slope.

3. The deep-sea plain. This is the undulating plain lying two to three miles below sea level, and covering two-thirds of the ocean floor, generally termed the abyssal plain. It was once thought to be featureless, but modern sounding devices reveal that the abyssal plain is far from being level. It has extensive submarine plateaux, ridges, trenches, basins, and oceanic islands that rise above sea level in the midst of oceans, e.g. the Azores, Ascension Island.

4. The ocean deeps. These are the long, narrow

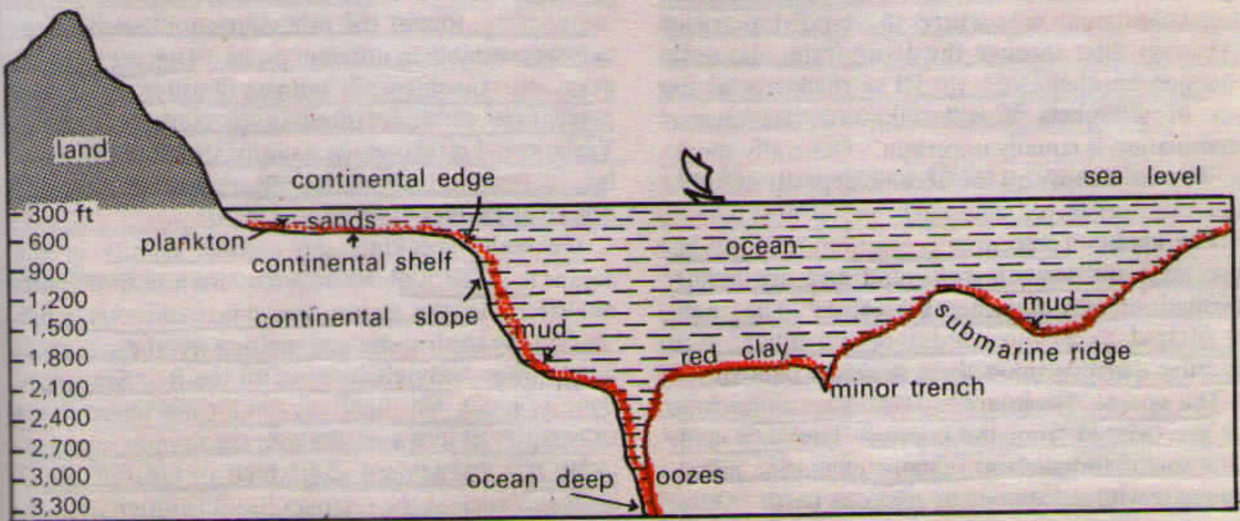


Fig. 92 The relief of the ocean basin (a typical section) with oceanic deposits—mud, clay and oozes.

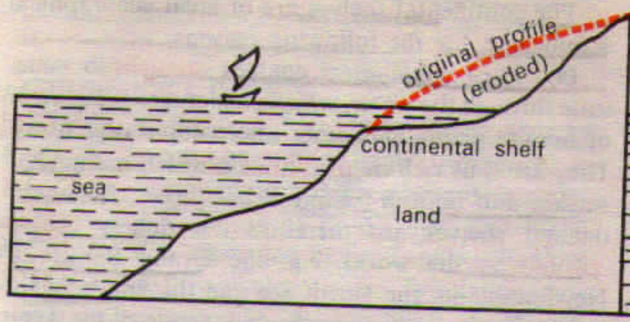


Fig. 93 Continental shelf formed by processes of erosion

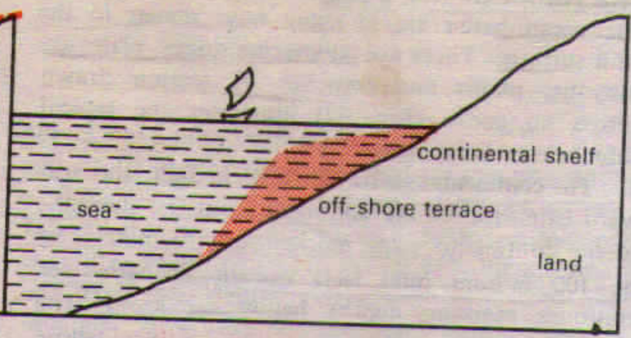


Fig. 94 Continental shelf formed by processes of deposition

trenches that plunge as great ocean deeps to a depth of 5,000 fathoms or 30,000 feet! Contrary to our expectations, most of the deepest trenches are not located in the midst of oceans. They are more often found close to the continents, particularly in the Pacific Ocean, where several deep trenches have been sounded. The greatest known ocean deep is the Mariana Trench near Guam Island, which is more than 36,000 feet deep. We can see from this that ocean trenches are greater in magnitude than the highest mountains on land, for the highest peak Mt. Everest is only 29,028 feet. Other notable ocean deeps include the Mindanao Deep (35,000 feet), the Tonga Trench (31,000 feet) and the Japanese Trench (28,000 feet), all in the Pacific Ocean.

The Oceanic Deposits of the Ocean Floor

Materials eroded from the earth which are not deposited by rivers or at the coast are eventually dropped on the ocean floor. The dominant process is slow sedimentation where the eroded particles very slowly filter through the ocean water and settle upon one another in layers. The thickness of the layer of sediments is still unknown. Its rate of accumulation is equally uncertain. Generally speaking, we may classify all the oceanic deposits as either muds, oozes or clays.

1. **The muds.** These are terrigenous deposits because they are derived from land and are mainly deposited on the continental shelves. The muds are referred to as blue, green or red muds; their colouring depends upon their chemical content.

2. **The oozes.** These are pelagic deposits because they are derived from the oceans. They are made of the shelly and skeletal remains of marine micro-organisms with calcareous or siliceous parts. Oozes have a very fine, flour-like texture and either occur as accumulated deposits or float about in suspension.

3. **The clays.** These occur mainly as red clays in the deeper parts of the ocean basins, and are particularly abundant in the Pacific Ocean. Red clay is believed to be an accumulation of volcanic dust blown out from volcanoes during volcanic eruptions.

Salinity of the Ocean

Almost every known chemical element can be found in varying proportions in the oceans whose most characteristic feature is their salinity, in contrast to the fresh water of lakes and streams. All sea water contains large amounts of dissolved mineral matter of which sodium chloride or common salt alone constitutes more than 77 per cent. The other more important compounds include magnesium, calcium and potassium, while the rest are distinguishable only in traces of very minute quantities. Due to the free movement of ocean water, the proportions of different salts, remain remarkably constant in all oceans and even to great depths. But the degree of concentration of the salt solution in oceans does vary appreciably in different areas. This is expressed as salinity the degree of saltness of water, either as a percentage or more often in parts per thousand. Variations are shown in salinity distribution maps by isohalines, lines joining places having an equal degree of salinity.

Generally speaking, the average salinity of the oceans is 35.2 ‰, about 35 parts of salt in 1,000 parts of water. In the Baltic Sea, where there is much dilution by fresh water and melting ice, the salinity is much lower, only about 7 ‰. In the Red Sea where there is much surface evaporation and fewer rivers to bring in fresh water, the average salinity increases to 39 ‰. In enclosed seas, which are areas of inland drainage, such as the Caspian Sea, the salinity is very high, 180 ‰, and in the Dead Sea of Palestine, a salinity of 250 ‰ has been recorded. The highest salinity is perhaps, that of Lake Van, in Asia Minor, with 330 ‰. It is a salt lake, and salts are collected from its shores. The density of the water is so high that in Lake Van or the Dead Sea, it is almost impossible to sink. Beginner-swimmers will find it much easier to float here than anywhere else! The variation of salinity in the various seas and oceans is affected by the following factors.

1. The rate of evaporation. The waters fringing the High Pressure Belts of the Trade Wind Deserts, between 20° and 30°N. and S., have high salinity because of the high rate of evaporation caused by high temperature and low humidity. The temperate oceans have lower salinity due to the lower temperature and a lower rate of evaporation.

2. The amount of fresh water added by precipitation, streams and icebergs. Salinity is lower than the average 35 ‰ in equatorial waters because of the heavy daily rainfall and high relative humidity. Oceans into which huge rivers like the Amazon, Congo, Ganges, Irrawaddy and Mekong drain, have much of their saltness diluted and have a lower salinity. The Baltic, Arctic and Antarctic waters have a salinity of less than 32 ‰ because of the colder climate with little evaporation and because much fresh water is added from the melting of icebergs, as well as by several large poleward-bound rivers, e.g. Ob, Lena, Yenisey, and Mackenzie.

3. The degree of water mixing by currents. In wholly or partially enclosed seas such as the Caspian Sea, Mediterranean Sea, Red Sea and Persian Gulf, the waters do not mix freely with the ocean water and they are not penetrated by ocean currents. Salinity is high, often over 37 ‰. In areas of inland drainage without links with the oceans, continuous evaporation under an almost cloudless sky causes the accumulation of salts around the shores. In the open oceans where currents freely flow, salinity tends to be near the average 35 ‰ or even a little lower. The range of salinity is negligible where there is free mixing of water by surface and sub-surface currents.

The Temperature of Ocean Water

Like land masses, ocean water varies in temperature from place to place both at the surface and at great depths. Since water warms up and cools down much more slowly than the land, the annual range of temperature in any part of the ocean is very much smaller. It is less than 10°F. for most of the open seas. Generally, the mean annual temperature of the surface ocean water decreases from about 70°F. in equatorial areas to 55°F. at latitudes 45°N. and S., and drops almost to freezing-point at the poles. The reduction of temperature with latitude is however never constant, because of the interference by warm and cold currents, winds and air masses. Unlike the solid earth, ocean water is mobile and variations in the temperature between different parts of the oceans can be expected. Water flowing out from the Arctic and Antarctic as cold currents, such as the Labrador Current off north-east Canada, tends to reduce the surface-water temperature. Ports of eastern Canada even at 45°N. are thus icebound for almost half the year. In the same way, coasts warmed by warm currents, such as the North Atlantic Drift, have their surface temperature raised. The Norwegian coast, even at latitudes 60° to 70°N. is ice-free throughout the year!

The highest water temperatures are found in enclosed seas in the tropics, e.g. the Red Sea which records a temperature of 85° to 100°F. The Arctic and Antarctic waters are so cold that their surface is permanently frozen as pack-ice down to a depth of several feet. In the warmer summer, parts of the ice break off as icebergs that both dilute the water and lower the surface temperature of surrounding ice-free seas.

The temperature of the oceans also varies vertically with increasing depth. It decreases rapidly for the first 200 fathoms, at the rate of 1°F. for every 10 fathoms, and then more slowly until a depth of 500 fathoms is reached. Beyond this, the drop is scarcely noticeable, less than 1°F. for every 100 fathoms. In the ocean deeps below 2,000 fathoms (12,000 feet), the water is uniformly cold, just a little above freezing-point. It is interesting to note that even in the deepest ocean trenches, more than 6 miles below the surface, the water never freezes. It is estimated that over 80 per cent of all ocean waters have a temperature between 35° and 40°F.

The Movements of Ocean Currents

Ocean currents are large masses of surface water that circulate in regular patterns around the oceans, as shown in the world map in Fig. 95. Those that flow from equatorial regions polewards have a higher surface temperature and are warm currents. Those that flow from polar regions equatorwards have a lower surface temperature and are cold currents. Their direction of movement is indicated by the arrows. But why should they follow such a pattern? Some of the underlying factors are explained below.

1. The planetary winds. Between the equator and the tropics blow the Trade Winds which move equatorial waters polewards and westwards and warm the eastern coasts of continents. For example the North-East Trade Winds move the North Equatorial Current and its derivatives, the Florida Current and the Gulf Stream Drift to warm the southern and eastern coasts of U.S.A. Similarly, the South-East Trade Winds drive the South Equatorial Current which warms the eastern coast of Brazil as the warm Brazilian Current.

In the temperate latitudes blow the Westerlies. Though they are less reliable than the Trade Winds, they result in a north-easterly flow of water in the northern hemisphere, so that the warm Gulf Stream is driven to the western coast of Europe as the North Atlantic Drift. In a similar manner, the Westerlies of the southern hemisphere, drive the West Wind Drift equatorwards as the Peruvian Current off South America and the Benguela Current off southern Africa. The planetary winds are probably the dominant influence on the flow of ocean currents. The strongest evidence of prevailing winds on current flows is seen in the North Indian Ocean. Here the direction of the currents changes completely with the direction of the monsoon winds which come from the north-east in winter and south-west in summer.

2. Temperatures. There is much difference in the temperature of ocean waters at the equator and at the poles. As warm water is lighter and rises, and cold water is denser and sinks, warm equatorial waters move slowly along the surface polewards, while the heavier cold waters of the polar regions creep slowly along the bottom of the sea equatorwards.

3. Salinity. The salinity of ocean water varies from place to place. Waters of high salinity are denser than waters of low salinity. Hence waters of low salinity flow on the surface of waters of high salinity while waters of high salinity flow at the bottom towards waters of low salinity. For example in the Mediterranean region, there is great difference in salinity between the waters of the open Atlantic and those of the partially enclosed Mediterranean Sea. The less saline water of the Atlantic flows on the surface into the Mediterranean, and this is compensated for by an outflow of denser bottom water from the Mediterranean.

4. The earth's rotation. The earth's rotation deflects freely moving objects, including ocean currents, to the right. In the northern hemisphere this is a clockwise direction (e.g. the circulation of the Gulf Stream Drift and the Canaries Current). In the southern hemisphere it is an anti-clockwise direction (e.g. the Brazilian Current and the West Wind Drift).

5. Land. A land mass always obstructs and diverts a current. For instance, the tip of southern Chile diverts part of the West Wind Drift northwards as the Peruvian Current. Similarly the 'shoulder' of Brazil at Cape Sao Roque, divides the west-flowing equatorial currents into the Cayenne Current which flows north-westwards and the Brazilian Current which flows south-westwards.

The Circulation of the Atlantic Ocean

Let us now study more closely the circulation of ocean currents in the Atlantic Ocean. We shall begin with the North and South Equatorial Current at the equator. The steady Trade Winds constantly drift two streams of water from east to west. At the 'shoulder' of north-east Brazil, the protruding land mass splits the South Equatorial Current into the Cayenne Current which flows along the Guiana coast, and the Brazilian Current which flows southwards along the east coast of Brazil.

In the North Atlantic Ocean, the Cayenne Current is joined and reinforced by the North Equatorial Current and heads north-westwards as a large mass of equatorial water into the Caribbean Sea. Part of the current enters the Gulf of Mexico and emerges from the Florida Strait between Florida and Cuba as the Florida Current. The rest of the equatorial water flows northwards east of the Antilles to join the Gulf Stream off the south-eastern U.S.A. The Gulf Stream Drift is one of the strongest ocean currents, 35 to 100 miles wide, 2,000 feet deep and with a velocity of three miles an hour. The current hugs the coast of America as far as Cape Hatteras (latitude 35°N.), where it is *deflected eastwards* under the combined influence of the *Westerlies* and the *rotation* of the earth. It reaches Europe as the North Atlantic Drift. This current, flowing at 10 miles per day, carries the warm equatorial water for over a thousand miles to the coasts of Europe. From the North Atlantic, it fans out in three directions, eastwards to Britain, northwards to the Arctic and southwards along the Iberian coast, as the cool Canaries Current. Oceanographic researches show that almost two-thirds of the water brought by the Gulf Stream to the Arctic regions is returned annually to the tropical latitudes by dense, cold polar water that creeps southwards in the ocean depths. The Canaries Current flowing southwards eventually merges with the North Equatorial Current, completing the clockwise circuit in the North Atlantic Ocean.

Within this ring of currents, an area in the middle of the Atlantic has no perceptible current. A large

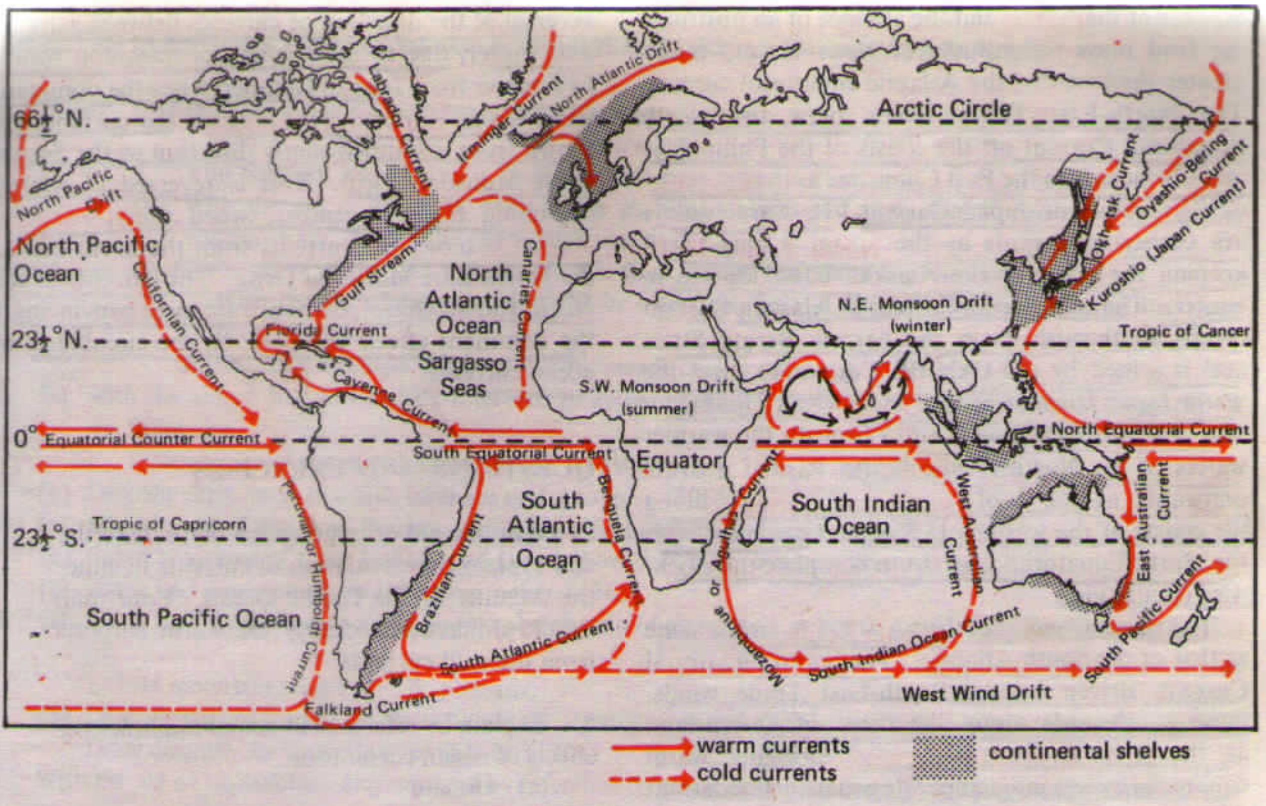


Fig. 95 Oceans currents of the world

amount of floating sea-weed gathers and the area is called the Sargasso Sea.

Apart from the clockwise circulation of the currents, there are also currents that enter the North Atlantic from the Arctic regions. These cold waters are blown south by the out-flowing polar winds. The Irminger Current or East Greenland Current flows between Iceland and Greenland and cools the North Atlantic Drift at the point of convergence. The cold Labrador Current drifts south-eastwards between West Greenland and Baffin Island to meet the warm Gulf Stream off Newfoundland, as far south as 50°N. where the icebergs carried south by the Labrador Current melt.

The South Atlantic Ocean follows the same pattern of circulation as the North Atlantic Ocean. The major differences are that the circuit is anti-clockwise and the collection of sea-weed in the still waters of the mid-South Atlantic is not so distinctive.

Where the South Equatorial Current is split at Cape Sao Roque, one branch turns south as the warm Brazilian Current. Its deep blue waters are easily distinguishable from the yellow, muddy waters carried hundreds of miles out to sea by the Amazon further north. At about 40°S. the influence of the prevailing Westerlies and the rotation of the earth propel the current eastwards to merge with the cold West Wind Drift as the South Atlantic Current. On reaching the west coast of Africa the current is diverted northwards as the cold Benguela Current (the counterpart of the Canaries Current). It brings the cold polar waters of the West Wind Drift into tropical latitudes. Driven by the regular South-East Trade Winds, the Benguela Current surges equatorwards in a north-westerly direction to join the South Equatorial Current. This completes the circulation of the currents in the South Atlantic. Between the North and South Equatorial Currents is the east-flowing Equatorial Counter Current.

The Circulation of the Pacific Ocean

The pattern of circulation in the Pacific is similar to that of the Atlantic except in modifications which can be expected from the greater size and the more open nature of the Pacific. The circulation can be easily followed in Fig. 95. Try to correlate it with the currents in the Atlantic.

The North Equatorial Current flows westwards with a compensating Equatorial Counter Current running in the opposite direction. Due to the greater expanse of the Pacific and the absence of an obstructing land mass the volume of water is very much greater than that of the Atlantic equatorial current. The North-East Trade Winds blow the North Equatorial Current off the coasts of the Philippines and Formosa into the East China Sea as the Kuroshio or Kuro Siwo or Japan Current. Its warm waters are carried polewards as the North Pacific Drift, keeping the ports of the Alaskan coast ice-free in winter. The cold Bering Current or Alaskan Current creeps southwards from the narrow Bering Strait and is joined by the Okhotsk Current to meet the warm Japan Current as the Oyashio, off Hokkaido. The cold water eventually sinks beneath the warmer waters of the North Pacific Drift. Part of it drifts eastwards as the cool Californian Current along the coasts of the western U.S.A. and coalesces with the North Equatorial Current to complete the clockwise circulation.

The current system of the South Pacific is the same as that of the South Atlantic. The South Equatorial Current, driven by the South-East Trade winds, flows southwards along the coast of Queensland as the East Australian Current, bringing warm equatorial waters into temperate waters. The current turns eastwards towards New Zealand under the full force of the Westerlies in the Tasman Sea and merges with part of the cold West Wind Drift as the South Pacific Current. Obstructed by the tip of southern Chile, the current turns northwards along the western coast of South America as the cold Humboldt or Peruvian Current. The cold water chills any wind that blows on-shore so that the Chilean and Peruvian coasts are practically rainless. The region is rich in microscopic marine plants and animals that attract huge shoals of fish. Consequently, millions of sea-birds gather here to feed on the fish. Their droppings completely whiten the coastal cliffs and islands, forming thick deposits of *guano*, a valuable source of fertilizer. The Peruvian Current eventually links up with the South Equatorial Current and completes the cycle of currents in the South Pacific.

The Indian Ocean Circulation

As in the other oceans as illustrated in Fig. 95, the currents of the South Indian Ocean form a circuit. The Equatorial Current, turning southwards past Madagascar as the Agulhas or Mozambique Current merges with the West Wind Drift, flowing eastwards and turns equatorwards as the West Australian Current.

In the North Indian Ocean, there is a complete reversal of the direction of currents between summer and winter, due to the changes of monsoon winds. In summer from June to October, when the dominant wind is the South-West Monsoon, the currents are blown from a south-westerly direction as the South-West Monsoon Drift. This is reversed in winter, beginning from December, when the North-East Monsoon blows the currents from the north-east as the North-East Monsoon Drift. The currents of the North Indian Ocean, demonstrate most convincingly the dominant effects of winds on the circulation of ocean currents.

QUESTIONS AND EXERCISES

1. With the aid of large sketch maps, describe and explain the circulation of currents in either the Atlantic or the Pacific Ocean. Your map should differentiate clearly the warm currents from the cold currents.

2. Explain by reference to actual examples the effects of ocean currents on:
   (a) climate
   (b) navigation
   (c) economic activities

3. What is meant by the relief of the oceans? In what ways are the structure and composition of the relief different from those of the land surface?

4. Give a reasoned explanation of any *three* of the following.
   (a) The richest fishing grounds are located on continental shelves.
   (b) The average salinity of the Baltic Sea is only 7 °/₀₀ whereas that of the Dead Sea is 240 °/₀₀.
   (c) The temperature of the ocean water varies both horizontally and vertically.
   (d) The dominant influence on the circulation of ocean currents is wind.

5. Write brief notes on any *three* of the following terms associated with the oceans.
   (a) deep sea core samples
   (b) Mariana Trench
   (c) isohalines
   (d) Gulf Stream Drift
   (e) Sargasso Sea

SELECTED QUESTIONS FROM CAMBRIDGE OVERSEAS SCHOOL CERTIFICATE PAPERS

1. *Either* (a) In each of *two* continents name i. a volcano.
   ii. a rift valley.
   You need not select i. and ii. from the same continent.
   (b) With the aid of diagrams, describe the physical features and method of formation of *one* of the volcanoes and *one* of the rift valleys you have named in (a).
   Or Choose *three* of the following landforms: fjord, barrier reef, delta, lagoon. For each:
   i. With the aid of diagrams, describe its main features and suggest how the landforms may have been formed.
   ii. Name an example and locate it by means of a sketch map. (1967)
2. (a) With the aid of diagrams and by reference to actual examples, explain how lakes are caused by any *two* of the following:
   i. movement of the earth's crust. ii. glaciation. iii. the action of man.
   (b) Describe *three* ways in which lakes are useful to man. (1966)
3. (a) With the aid of diagrams, describe the physical features of a limestone region.
   (b) Select any *three* of these features and explain how they may have been formed.
   (c) Name and locate *one* large limestone region. (1965)
4. (a) Using the World Map as a guide, draw a sketch map of *either* Asia *or* South America to show the distribution of:
   i. fold mountain ranges ii. plateaux.
   (b) Describe typical features of these two types of mountains and explain how *one* type may have been formed. Draw diagrams to illustrate your answer. (1964)
5. With the aid of explanatory diagrams and by reference to actual examples, describe the physical features of:
   (a) a coastline which includes fjords *or* rias.
   (b) a coastline which includes sandbars *or* spits, and lagoons. (1964)
6. *Either* Choose *two* of the following features: sand dune, canyon, delta. For each of the two:
   (a) With the aid of diagrams, describe its appearance and explain its formation.
   (b) Locate an area where an example can be found.
   Or Write an account of the glaciation of a mountain region. (1962)
7. (a) Briefly describe an active volcano.
   (b) What is an earthquake, and how it is caused?
   (c) Say why earthquakes and volcanoes are often associated with the same areas of the world, and locate *two* such areas. (1961)
8. Choose *two* of the coastal features–fjords, stacks, sand spits, rias. For each you choose:
   (a) With the aid of diagrams:
   i. describe its appearance
   ii. explain its formation.
   (b) Locate an area where an example could be found. (1960)
9. (a) Say what you understand by the term 'ocean currents'. State briefly how ocean currents are caused and why they are important.
   (b) For *either* the North Atlantic Ocean
   or the North Pacific Ocean draw a simple sketch map to show the positions and names of the principal currents and indicate whether they are warm or cold. (1962)
10. *Either:* Select *three* of the following, and explain with the aid of diagrams or maps how a lake may have been formed:
   (i) by a river in its lower course (ii) by glaciation in highland areas
   (iii) by volcanic action (iv) in a rift valley
   Or: With the aid of diagrams, describe *three* of the following and explain how they have been formed: spit, beach, coral reef, delta (1970)