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.

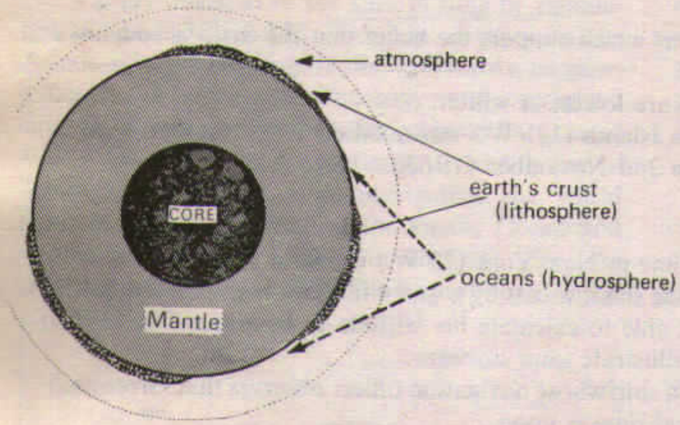


Fig. 15 A section showing the structure and composition of the earth

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

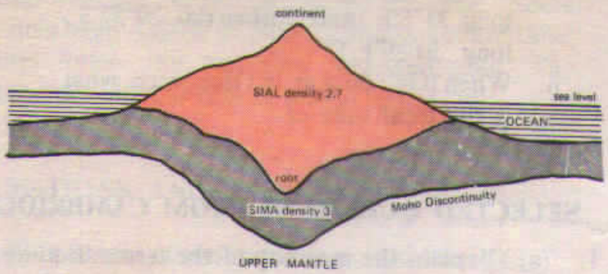


Fig. 16 A section showing how the continent (SIAL) floats on the denser SIMA

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

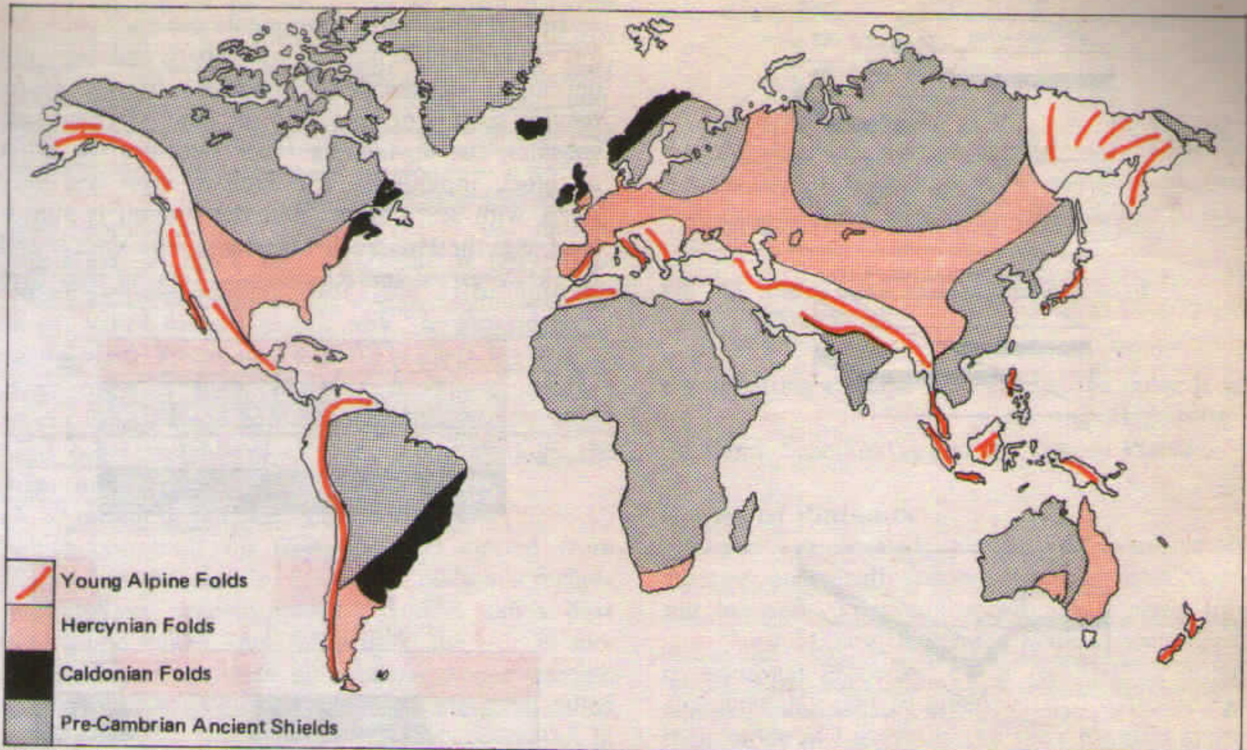


Fig. 17 Structural divisions of the earth

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 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 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.

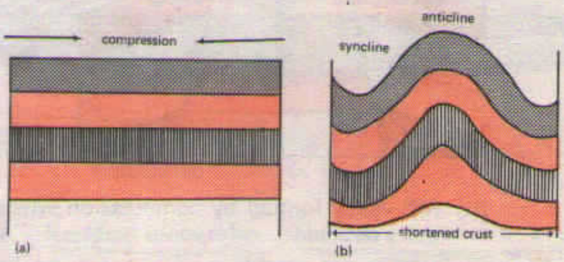


Fig. 18 (a) The horizontal strata of the earth's crust before folding
(b) Compression shortens the crust forming fold mountains

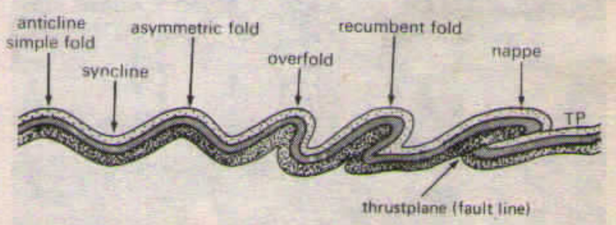


Fig. 19 Types of folding

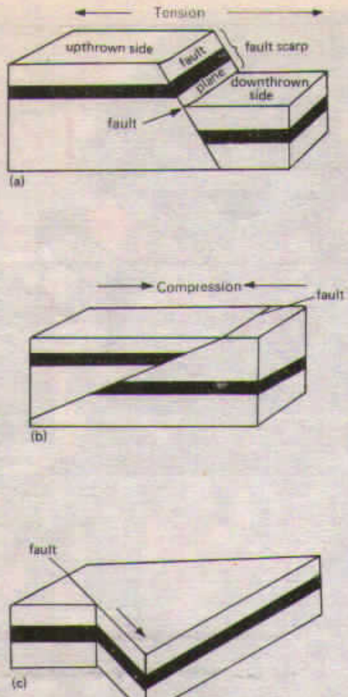


Fig. 20 Normal, reverse and transcurrent faults

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

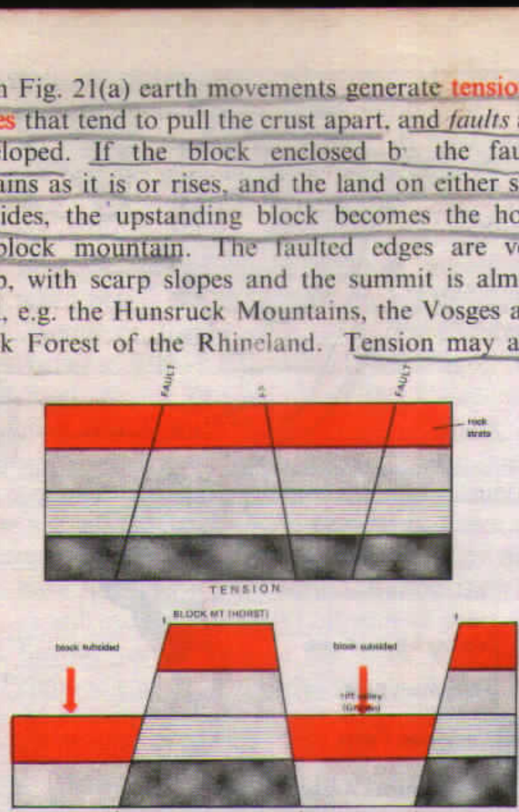
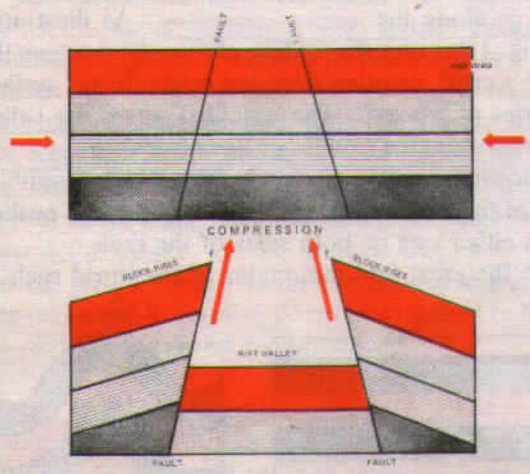
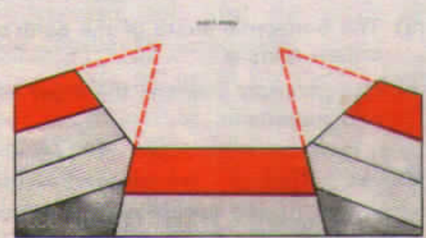


Fig. 21 (a) Block mountain (horst) formed by tension when faults develop



(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.

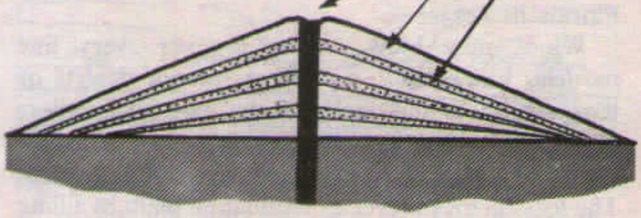


Fig 22 A volcano or 'mountain of accumulation' with successive layers of lava

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

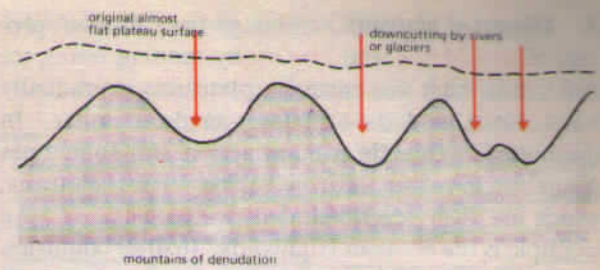


Fig. 23 Residual mountains or mountains of denudation.

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.

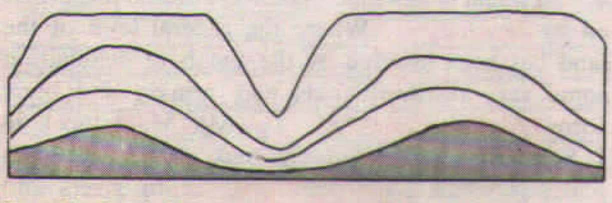


Fig. 24 Peneplain.
In the formation of a peneplain in humid conditions the hills are both lowered and worn back to give an undulating lowland

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).

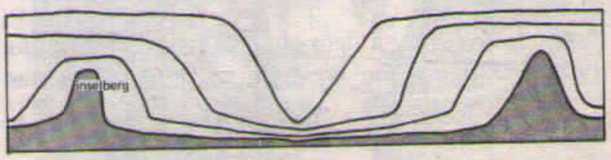


Fig. 25 Pediplain
In the formation of a pediplain in arid or semi-arid conditions the hills are worn back to form a gently sloping plain but some steep hills remain. These are called inselbergs

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.