Geography Optional - 2024

LAND FORM AND ROCKS

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Basic concepts

Despite the leveling influence of gravity, the Earth's surface is highly irregular and a great variety of surface features exists. Most regions contain a diverse assemblage of features that vary in age and origin.

Individual surface features of the Earth are referred to as **landforms**. A given landform may exist at almost any scale of magnitude, from a small mound to a major mountain range, but it should be recognizable as a distinct surface entity. Geographers have an interest both in the physical characteristics of landforms and in their surface distributions. The combination of landform characteristics and distributions within a region is referred to as the region's **topography**. Maps are usually employed when landforms are studied, and those displaying both the vertical dimensions of the landforms and the spatial relationships existing among them are termed topographic maps. A variety of methods exists for mapping the topography.

Geomorphology (from the Greek *geos* 'Earth', *morpe* 'form' and *logos* 'description') is the systematic study of landforms, including their origin, characteristics, and distribution. It is a subject shared by both physical geography and geology, and geomorphologists come from both of these disciplines.

Like climate and vegetation, the landforms of an area have multiple controls. A number of these controls are dynamic, causing the topography to change through time. Some changes occur rapidly and can be witnessed readily by human beings. Examples include changes in the course of a river during a flood, beach erosion as the result of a storm, and the deposition of ash or lava caused by the eruption of a volcano. Most changes occur very slowly, however, and centuries or millennia may pass before the landscape is altered significantly.

A region's topography, like its climate, vegetation, and soils, strongly influences the numbers, distribution, and economic characteristics of its human inhabitants. Lowlands, especially those near large rivers or the sea, often support large populations and contain few, if any, uninhabited areas. In contrast, rugged mountainous regions are typified by localized population clusters in favoured sites, separated by large areas with few, if any, inhabitants. The relative lack of flat or gently sloping land in such regions usually greatly restricts their agricultural potential, and the difficulties of movement into and out of such regions may hinder their economic development.

Until quite recently, the major terrestrial landform-producing controls were poorly understood. Well into the nineteenth century, geologists greatly underestimated the age of the Earth, believing it to be only a few thousand years old. This allowed a period of less than 6,000 years for all the geological events that have shaped our planet's surface. Scholars could easily see that such a restricted time span was insufficient to allow for the production of large landforms such as mountain ranges and river gorges at the very slow rates at which they were currently forming. As a result, they concluded that past cataclysmic events must have produced the Earth's major surface features. This concept has been referred to as the principle of **catastrophism**.

In the 1790s, the Scottish geologist James Hutton proposed that the Earth was actually far older than previously believed, and that its surface features had resulted simply from the long continued application of the same geological processes that were currently being observed. Nearly a century passed before this so-called principle of **uniformitarianism**, the basic tenet of which is 'the preset is the key to the past', was generally accepted by Earth scientists. It is now known that the individual geomorphic events that shape our planet's surface are mostly small in scope and often slow in their concurrence, but that the passage of vast amounts of time allows them to have a major cumulative effect.

In recent years, it has become increasingly apparent that strict uniformitarianism is too rigid a concept to be fully satisfactory as the guiding philosophical principle in geomorphology.

The Earth is believed to about 4.6 billion years old, but little detail is available about the geography of our planet's surface before the beginning of the Paleozoic era, about 600 million years ago. Some of the major geologic events that helped shape North America took place tens or even hundreds of millions of years ago. For example, the Appalachian Mountains began forming in the early to middle Paleozoic era, and the Rockies, in the late Mesozoic. Most contemporary individual landform features, however, are the comparatively recent products of events in the Quaternary period and are less than a million years old.

The geographic distribution of landforms is considerably more complex than the distributions of climate and natural vegetation. It will be recalled that these phenomena, despite their variations from place to place, display large-scale patterns that are repeated to some extent on the continents of both hemispheres. Zones of similar conditions tend to form on a latitudinal basis, with sequential changes occurring in equator ward or pole ward directions. Solar energy powers both systems, and its gradual reduction in intensity with latitude is ultimately responsible for the progression of changes that occur. The Sun is also a basic energy source for the production of landforms. Its influence results in a general latitudinal zonation of those landforms features resulting primarily from solar-powered processes.

A second group of geomorphic processes exists, however, powered not by solar energy but the atomic fission of radioactive elements in the interior of the Earth. These are the tectonic processes. No organized latitudinal zonation exists with regard to these forces and their resulting features. As a consequence, nearly all large regions contain an assemblage of landforms, some produced by solar-powered processes and others by internal Earth processes, while still others owe their existence to the interaction of both sets of processes.

Because surface features are generally slow to change, the existing assemblage of landforms within any area is the result of both present and past geomorphic processes. In some instances, the controlling processes have changed greatly, and the landscape is still dominated by relict features produced by environmental processes no longer active within the region. The glacial features produced during the Pleistocene epoch over much of northern North America and northwestern Europe are an important group of relict landforms. At any given time, however, the topography is actively evolving as it is modified by existing conditions. The tendency is for relict landforms to be removed gradually and to be replaced by others in equilibrium with the current environment. Large-scale landform changes occur so slowly, however, and environmental processes that can influence landforms vary so frequently, that topographic changes are occurring nearly everywhere on our planet's surface.

Landform classification

Physical geographers have long been confronted with a choice of two different conceptual approaches to the study of landforms. One approach is to categorize landforms on the basis of physical appearance. This is sometimes referred to as the '**descriptive approach'** to landform study. A shortcoming of this approach is that features of similar general appearance, such as mountain ranges, may have vastly different modes of origin. The alternative approach is to categorize landforms by their method of formation or, more precisely, by the geomorphic processes responsible for their production. This is sometimes referred to as the **'genetic approach**' to landform study. Difficulties are also inherent in this approach. First, virtually all landforms are polygenetic in origin; that is, they have been produced by the interaction of a number of processes. A second problem is that features that differ greatly in physical form may have been produced by the same geomorphic processes and therefore will be grouped together. The choice of which of these two approaches to use rests largely on the priorities that are given to the two basic landform attributes of form and process.

In recent years, most physical geographers have employed the genetic approach to study landforms. Before commencing a systematic treatment of landforms based on their processes of formation, however, it seems desirable to discuss briefly the major descriptive categories of landforms.

Descriptive approach to Landform study

When a region's topography is to be divided into categories based on physical characteristics, the chief factor taken into consideration generally is the extent of local differences in elevation, or the topographic **relief**. Subdivisions are then made according to the origin, distribution, or characteristics of the surface features. Some differences of opinion exist as to the number and identity of the major topographic categories, but a popular division recognize four: plains, hills, mountains, and plains with areas of high relief.

Plains

Plains are areas of limited local relief and have a predominance of flat to gently rolling surfaces. The maximum amount of allowable relief is somewhat arbitrary, but a figure of 60 meters (200 feet) is frequently used. Most plains occur at rather low elevations, but plains in large interior basins of the Andes and Himalayas have elevations as great as 3,650 meters (12,000 feet).

Plains cover extensive portions of the Earth's land surface. The combination of flat plains and rolling and irregular plains comprises about a third of the Earth's land area. Plains also contain more than 80 percent of the world's population, largely because their relatively level surfaces produce few impediments for human activities such as agriculture, transportation, and construction. Plains are produced by a variety of processes and typically comprise several different portions of any given continent. While some plains result from long-term erosional processes, others results from the accumulations of sediment in depositional environments. The most extensive plains are situated in the interiors of continents and are largely or entirely separated from the coasts by intervening ranges of hills and mountains. These **interior plai**ns, which normally have elevations of less than 300 meters (1,000 feet), result from the long-term stability of the Earth's crust in interior locations, including much of the central portion of the North American continent. **Coastal plains** have very low elevations and typically are flatter than interior plains. Most result from processes that have raised portions of the ocean floor above sea level in the geologically recent past. This is the case on most of the Atlantic and Gulf coastal plain of the United States.

Hills and Mountains

In contrast to the low relief and gentle slopes that characterize plains, surfaces classified as hilly or mountainous have moderate to high relief and a predominance of sloping land. Their elevations are also much higher on average than those of plains; mountainous regions contain the most elevated portions of the Earth's surface.

Hills and mountains, although normally classified separately, actually are variations on the same these and are discussed jointly here. Although it is agreed that hills are smaller than mountains, no generally accepted point of demarcation between the two exists. This sometimes gives rise to confusing or inconsistent terminology, since what are mountains to one group of people may be classified as hills by another. For our purposes, areas with a local relief of 60 to 300 meters (200 to 1,000 feet) are classified as hilly, and areas with a relief exceeding 300 meters (1,000 feet) as mountainous. Mountainous areas have been separated into areas with low mountains and high mountains. Together, hilly and mountainous lands comprise approximately a third of the Earth's surface.

Hills and mountains both result, directly or indirectly, from the uplift of the surface. They may be produced directly by internal Earth forces that thrust up individual peaks or ranges of hills or mountains.

They may also result from the uplift of an extensive surface area, followed by erosion that leaves hills or mountains as residual remnants. Both the amount of uplift and the nature and extent of subsequent erosion, which is partially the result of climatic conditions, are critical in determining the relief and ruggedness of the topography. The Earth's major mountain systems have all been uplifted in the geologically recent past; that is, within the last few tens of millions of years. Hilly regions may not have been uplifted as far, or, as in the case of the Appalachians, they may represent the erosional remnants of older mountain systems that were once much higher.

Plains with Areas of High Relief

In most regions where hills and mountains exist, they occupy a large enough proportion of the land that the majority of the surface is in slope. On plains, conversely, the majority of the surface is relatively level. Large portions of the Earth's surface, however, while predominantly level, contain localized areas of high relief. In these instances, the actions of at least two different groups of geomorphic processes are reflected in the landscape.

Plains with areas of high relief can be divided into two categories on the basis of their surface characteristics. The first category may be described as plains with scattered hills or mountains. In these areas, most of the surface exists near the low end of the elevation range, and the upland surfaces are limited in area. One of several processes may be responsible for the areas of high relief. If they are isolated, roughly conical hills or mountains, a volcanic origin is likely. If they are linear ranges, they probably were produced by folding or faulting, as in the Basin and Range region of Nevada and western Utah. If they are widely separated blocks of variable form with little linear organization, they probably represent the erosional remnants of a previously more extensive upland surface. Portions of the Piedmont of the eastern United States are an example.

The second category may be described as plateaus with canyons or marginal escarpment. A **plateau** is a relatively level upland surface that frequently is bounded on at least one side by an abrupt descent to lower elevations. In this case, most of the surface is at the high end of the range of elevations, and the low elevation surfaces are limited in area. Plateaus are most commonly created by the geologically recent uplift of a large area with an initial flat surface. One example is the Colorado Plateau, in the southwestern United States, whose level surface originally formed on the ocean floor. In some instances, however, plateaus are produced by outpourings of tremendous volumes of lava, as in the cases of the Columbia Plateau of the northwestern United States and the Deccan Plateau of India. The high elevations of plateaus cause streams draining them to have a large amount of gravitational energy, frequently enabling them to carve deep, steep-walled ***canyons*** or ***gorges*** into the plateau surfaces. The Grand Canyon, which has been eroded by the Colorado River into the rock surface of the Colorado Plateau to a mean depth of 1.6 kilometers (1 mile), is undoubtedly the world's best-known example.

Genetic Approach to Landform Study

The genetic approach to the study of landforms emphasizes the causal factors in the development of the topography rather than its physical attributes. Two basic groups of geomorphic forces exist. Each is powered by a different energy source; one influences the Earth's surface from below and the other from above.

The first group of forces, **tectonic forces**, originate within the Earth. They are powered primarily by the nuclear decay of unstable isotopes of the elements uranium and thorium. The general tendency of the tectonic forces is to increase the elevation and relief of the surface. Consequently, they are often described as being constructive forces in landform development. From a global standpoint, tectonic forces are largely responsible for raising land above sea level and for initially producing mountains and plateaus.

Landform producing forces

1. Tectonic forces

A. Diastrophism

1. Folding
2. Faulting

B. Volcanism

1. Intrusive
2. Extrusive

Tectonic forces are in turn, divided into two categories. **Diastrophism** involves solid-state movements of the Earth's crust. This displacement may occur either through the ***folding*** (bending) of the rock material or through ***faulting***, which involves rock fracturing followed by the movement of the two sides of the fracture relative to one another. **Volcanism** involves the transfer of molten rock material, either from one point to another beneath the surface or, more rarely but spectacularly, its expulsion onto the surface.

The second group of landform-producing forces – the **gradational forces** – originates above the Earth's surface. They are powered by solar energy and are given a downward directional component by gravity. The overall tendency of gradation is to lower the surface and to reduce topographic relief. The application of these forces is very uneven, however, so that a sequence of changing features is produced during the gradational process. The ultimate effect of gradation would be to reduce all land surfaces to smooth surfaces at or slightly below sea level.

Three different substances accomplish most of the actual gradational reduction of the surface. These are water, ice, and air (as wind), often collectively referred to as the 'three tools of gradation'. It is noteworthy that one is a liquid, one a solid, and one a gas. These substances accomplish their work by being heated, evaporated, or both, largely by solar energy. This causes them to expand, become more buoyant, and rise into the atmosphere. When the energy is later lost, gravity causes them to return to the surface in the forms of liquid or solid precipitation or win. Once on the surface, they tend to flow downhill or, in the case of air, to areas of lower pressure. Frictional drag exerted on the surface by this movement accomplishes the work of gradation. The force of gravity acting alone can also transport materials downhill in areas with loose or weak surface materials.

Examined in a temporal sequence, there are four steps in the gradational process, regardless of which tool is involved. The first step is **weathering**. Weathering actually is a preliminary process that makes gradation possible. It involves the breakup of solid rock or large rock fragments into pieces small enough to be moved by the three tools of gradation. This is necessary because the forces of gradation are not as powerful as the tectonic forces. For example, although a mountain range may be raised tectonically as a single unit, it must be carried off by water, ice, or wind piece by piece.

One weathering has prepared the surface, the weathered materials are in relatively quick succession picked up or **eroded**, transported, and finally deposited by one or more of the three tools of gradation. Because erosion involves the removal of material, it lowers the surface. Deposition, conversely, increases surface elevations. Erosion occurs where the tools of gradation have excess energy and are able to perform the work involved in picking up and transporting weathered material. Deposition usually occurs at relatively low elevations and in areas of low relief. It takes place where the gradation tools lack sufficient energy to continue to transport the materials they have been carrying. For the world as a whole, erosion must in the long run equal disposition, since everything that is picked up must eventually be put back down. The geographical distributions of sites in which erosion and deposition dominate differ greatly, though, because the environmental conditions that favour these sets of processes directly oppose one another. As a basic geographical generalization, erosion exceeds deposition on land areas, resulting in their net gradational reduction, while deposition exceeds erosion on the ocean floor.

Tectonic and gradational forces are in essence diametrically opposed to one another in terms of their effects on the surface and can be envisioned as being engaged in a constant struggle for a controlling influence on the topography. As soon as tectonic forces produce surface uplift, forming hills, mountains, and plateaus, gradational forces attack these uplands, carrying them bit by bit to lowlands or to the sea. Tectonic forces are much more powerful and fast acting than gradational forces; they are capable, for example, of thrusting up a volcanic peak in only a few years – an amount of time so short that the gradational effect is minimal. Tectonic forces, however, operate very sporadically, with periods of intense activity followed by long interludes of quiescence.

Each year, gradational forces erode some 1.0 and 1013 kilograms (11 billion tons) of material from the land and transport it to the oceans. If erosion proceeded unopposed at this rate, the continents would be reduced to sea level in a span of only 40 million years. A comparable mass of material, however, is lifted above the oceans annually by tectonic activity, so that the total mass of land tends to remain relatively constant.

Although the net gains and losses of mass from the Earth's land areas resulting from tectonic and gradational forces may be roughly equal, the geographical distribution of these opposing forces and the types of surface features they produce differ greatly. In a basic sense, the tectonic forces can be considered as primarily responsible for the large-scale patterns of surface features, such as the arrangements of the continents and ocean basins and the locations of the major mountain ranges. Gradational forces, on the other hand, can only operate where, and when, the tectonic forces have first created topographic features to erode.

The sizes, shapes, and locations of the continents, ocean basins, and mountain ranges are among the most basic and important aspects of our planet's physical geography. They form the largest units of the Earth's surface features. In addition, because of the complex interactions that exist among the various Earth surface phenomena, they exert a vital influence on the global patterns of climate, plant and animal distributions, and human activities.

Insofar as astronomers and geomorphologists are able to tell, the Earth's topography is unique among the planets and satellites of our solar system. Detailed surface observations of many of these astronomical bodies have been made in recent years, and none has been found to have a landform assemblage even remotely similar to that of the Earth's. The uniqueness of the Earth's topography results more from the gradational forces than from the tectonic forces. All the planets and larger satellites of the solar system apparently either currently have, or at one time had, tectonic forces roughly comparable to those of the Earth. (Some bodies, such as the Moon, seem at present to be tectonically inactive, apparently due to the depletion of their internal energy supplies). Not all these astronomical bodies, however, have gradational forces other than the force of gravity. The existence of these forces requires both an atmosphere and sufficient proximity to the Sun to supply an effective quantity of insolation. Those bodies without an atmosphere, such as the Moon, therefore have no way of erasing tectonic features of meteorite impact craters. They contain ancient landscapes that are nearly frozen in time. The Earth's surface, in contrast, is dynamic and is unique even when compared with the planets and satellites that have an atmosphere and a reasonable supply of solar energy. This is because the surface of the Earth contains an abundance of life-forms, is largely covered by water, and as an overlying atmosphere containing water vapour that is engaged in a constant exchange with the water at the surface. The presence of life forms makes possible a large number of biochemical reactions that greatly accelerate weathering processes, while the cycling of surface and atmospheric water permits the erosion of the surface by streams, ocean water, and ice. Without a hydrologic cycle, only the wind, the weakest of the three tools of gradation, would be available to erode the surface. This would greatly reduce both the speed of gradation and the variety of surface features produced.

If one looks at the working of the tectonic and gradational forces from a long-term global standpoint, a complex geological cycle can be discerned. The same sequence of activities occurs over and over again, and the same Earth materials are continually used and reused. The sequence can be envisioned as beginning with the tectonic uplift of a portion of the surface. The material forming the uplifted region is then subjected in turn to weathering, erosion, transport to the ocean floor or some other basin, and deposition. The deposited sediment is eventually buried, compacted by the weight of the overlying materials, and gradually reconstituted as rock. At some later time, this rock is once again uplifted by another episode of tectonic activity, and the sequence begins anew.

Rocks and minerals on the earth's crust

The solid surface of the Earth is composed almost exclusively of rock materials and their weathering products. Rocks in different regions vary greatly in origin, composition, appearance, and in both physical and chemical characteristics. Two consequences of this distribution that are of great practical importance to humanity are the global patterns of soil types and the patterns of mineral deposits. Rock types and structures are crucial in determining the characteristics of landforms. In general, high-standing portions of the surface either have been uplifted recently by tectonic forces or are composed of physically strong and chemically stable rock types that resist gradational forces. In contrast, lowlands frequently are underlain by rocks that are highly susceptible to weathering and erosion. A basic understanding the major categories of surface rock types is therefore an important prerequisite to the study of landforms.

The Earth's crust contains only a small number of chemical elements in abundance. Only eight, in fact, individually account for more than 1 percent of the weight of the crust. Oxygen and silicon are about three times as abundant as all the rest combined. These two elements usually occur in chemical combination with metals to form the **silicate minerals**, the dominant mineral group of the crust and mantle. A **mineral** is a naturally occurring, solid, inorganic compound. It has a specific chemical composition and usually exhibits a crystalline structure that results from a distinctive atomic arrangement of its constituent elements. The 2,000+ known minerals are divided into several major mineral groups dominated by the silicates, which comprise 92 percent of the Earth's crust.

Minerals can be considered the building blocks of rocks. A **rock** is simply a solid aggregate of minerals. Most rocks contain several different minerals, the individual crystals of which are sometimes readily visible. In most areas the solid surface rock, or **bedrock**, is overlain by comparatively thin layers of weathered rock and soil. Most of the continental crust is composed of rocks with a high content of silicon and aluminum. These rocks are normally low in density and light in colour. The oceanic crust, in contrast, consists almost entirely of denser, dark-coloured rock containing a greater abundance of iron, magnesium, and calcium. This rock is sometimes brought to the surface by volcanic eruptions or is exposed by the long-term erosion of a landmass.

Major categories of Rocks

From the standpoint of the Earth scientist, the most meaningful way of categorizing rocks is by their method of formation. Three basic rock categories are recognized: igneous, sedimentary, and metamorphic. Within each category, a large variety of individual rock type exists. Differences among rock types are determined by mineralogical makeup and mode of origin as well as the presence, size, and orientation of their constituent mineral crystals or rock particles.

Any rock type in any one of the three major rock categories can be converted by Earth processes to one of more types in either of the other two categories. These conversions occur because of changes in the environmental conditions that influence the rocks. A given rock type can form only in an environment where physical and chemical conditions favour its formation. If the rock-forming environment changes, or if the rock is transported to a different environmental setting, it is no longer in equilibrium with existing conditions. It therefore begins to change toward a condition of equilibrium with its new environment.

The continuous cycle of rock formation and transformation is known as the **rock cycle**. As in the hydrologic cycle, the same materials are used over and over again. The energy that powers the rock cycle is derived from both the Sun and the interior of the Earth. As long as these two energy sources continue to operate, the materials of the Earth's crust will continue to be involved in a constant cycle of change.

Igneous Rocks

Igneous rocks (from the Latin igneous, 'from fire') are formed directly from the solidification of molten rock and are produced by tectonic activity. If the Earth at one time existed in a molten state, as is believed to have been true during the period of planetary formation, it must have consisted entirely of igneous rock when it solidified. This means that the constituents of all rocks must originally have been derived from igneous rock. The great majority of the Earth, including all of the mantle and oceanic crust and even most of the continental crust, still consists of igneous rock. Only within a few kilometers of the surface are sedimentary and metamorphic rocks found.

Most igneous rocks, including many now at the surface, formed in the lower crust or upper mantle. Although both of these segments of the Earth's interior consist primarily of solid rock, localized **magma** (molten rock) pockets form in the vicinity of zones of weakness where pressures are not sufficiently high to keep the rock from expanding and melting. Such masses of magma may be injected into overlying rock layers before solidification occurs, forming bodies of **intrusive igneous rocks**. Where bodies of hot or molten igneous rock exist near the Earth's surface, they may heat large volumes of groundwater than can be withdrawn by humans for heating or electricity.

The most visible characteristic of intrusive igneous rocks is the large size of their constituent mineral crystals. These crystals, which have time to form because of the very slow rate of cooling and solidification of intrusive igneous rock bodies, normally are easily visible, and their sharp edges give the rock a rough, a granular texture. The best-know intrusive igneous rock type is **granite**, which is composed mostly of the minerals quartz, mica, and feldspar.

Intrusive igneous rock bodies (known as **plutons**) often serve as sites for the formation of veins of economically important metallic minerals. These veins form along fractures or other zones of weakness in the slowly cooling plutons. Mineral-bearing fluids enter and move along the fractures, depositing dissolved minerals because the reduction of pressure in these zones of weakness reduces the ability of the fluids to carry minerals in solution. Richly mineralized igneous rock bodies are the sources of much of the world's supplies of metals such as gold, silver, copper, and tin.

On occasion, magma makes its way to the Earth's surface, where it flows out as **lava** or is thrown out as **volcanic ejecta**. The solidification of this material forms what is termed **extrusive igneous rock** because it is extruded onto the surface while still molten. Because of the rapidity with which it cools, extrusive igneous rock generally has microscopic mineral crystals and, unless it contains air pockets, is relatively smooth. **Basalt**, a dense, black rock containing substantial quantities of iron and magnesium, is the best-known extrusive igneous rock type. The Hawaiian Islands and the Columbia Plateau of the northwestern United States consist largely of basalt. A less dense, lighter-colored extrusive igneous rock containing large quantities of silicon and aluminum is termed **rhyolite**, while a third common rock type, **andesite**, is intermediate in composition. Some igneous rock types, including **obsidian** and **pumice**, have cooled so rapidly that mineral crystallization did not occur at all, and they are glassy in texture.

Intrusive and extrusive igneous rocks together cover about one-third of the Earth's land surface, and that the intrusive rocks are the more common of the two groups. The distributional pattern of intrusive igneous rocks is complex, but the largest areas consist of the cores of ancient plutons, such as those in eastern Canada, Scandinavia, and Africa. Only the erosion of great thicknesses of overlying rock masses has allowed these ancient rocks, which originally formed a great depth, to exist at the surface.

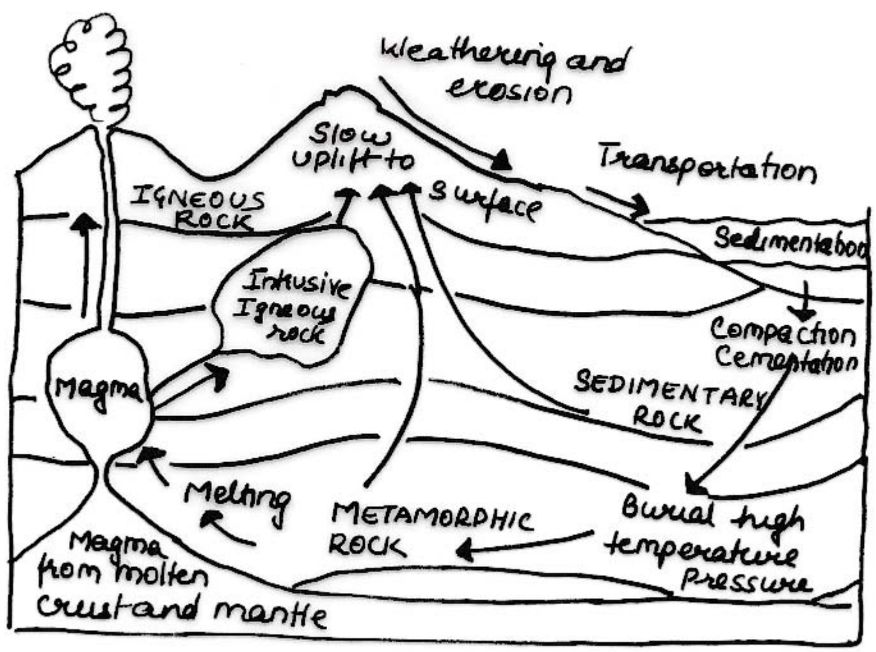
Extrusive igneous rocks are more commonly associated with oceanic crust than with continental crust. On land, they occur mostly within active volcanic zones located along the margins of the continents. They are quite common, for example, all along the borderlands of the Pacific. Because volcanic eruptions usually are rather localized phenomena, the resulting extrusive igneous rocks are scattered in numerous patches. In a few instances, though, large-scale fissure outpourings of lava have covered extensive areas.

Notable in this regard are the Columbia Plateau of the western United States, the Parana Plateau of southern Brazil, and the Deccan Plateau of India.

Sedimentary Rocks

Weathering processes frequently produce loose surface materials sufficiently small and light to be picked up and transported to other sites by gradational agents. Any such solid materials, of either organic or inorganic origin, that have been transported by water, ice, wind, or gravity are collectively termed **sediments**. Familiar examples include mud or gravel deposits left by streams, beach sand and shells washed ashore by the ocean, rock debris deposited by retreating glaciers, and windblown leaves and dust.

Sediments are deposited where the energy of the transporting agents is insufficient to carry them farther. Because water is by far the most effective gradational tool, most depositional sites are associated with bodies of slow-flowing or standing water. Examples include valley floors, lake bottoms, and especially the ocean floor. The ocean can be thought of as the ultimate sediment trap. Once sediments reach it, as they do in tremendous quantities, there is normally no way for them to be removed because most sediments are denser than water and sink to the seafloor. The great majority of land-derived sediments reach the ocean by way of rivers, so that the greatest rates of sediment accumulation occur along the continental margins, especially near the mouths of large rivers.



Where conditions remain favourable for the deposition of sediments over extended periods of time, they gradually accumulate to form horizontal layers termed **strata**. If accumulation is rapid, great thicknesses of material eventually collect, resulting in the deep burial of the lowermost sediments. This generates a large amount of pressure compacting these sediments. Frequently, water circulating through the compacted sediments precipitates chemicals that cement the deposits together. The processes of compaction and cementation, along with chemical changes in the sediments themselves, result in their gradual conversion to **sedimentary rock**.

The boundaries or **bedding planes** between adjacent strata mark periods in which local environmental conditions at the time of deposition changed, resulting in changes in the types of sediments being deposited. Thick sequences of sedimentary rocks containing many hundreds of individual strata occur in various parts of the world. Where deposition was continuous, these strata may provide information about past environmental conditions over a lengthy geological time span. They bear eloquent testimony to the great age of the Earth and to the inconstancy of surface environmental conditions.

Sedimentary rock types

Sedimentary rocks are categorized by their method of formation. Three basic categories are recognized: clastic, organic, and chemical – each containing a number of individual rock types.

Clastic sedimentary rocks are composed of particles of preexisting rocks. These particles were derived from the weathering of the parent rock and were subsequently transported, deposited, and **lithified**, or converted to rock. Clastic sedimentary rock types are differentiated on the basis of their sizes of their constituent particles. **Conglomerate** contains the largest particles, which must be at least gravel size. **Sandstone**, one of the most abundant sedimentary rock types, consists of sand-sized particles. Most sandstones contain quartz sand grains because the great chemical stability of this mineral allows it to remain in rock form long after other minerals have weathered away. **Siltstone** and **shale** are composed of silt-sized and clay-sized particles, respectively. These sediments were nearly always deposited on the bottom of a standing body of water such as a lake or ocean. Shale is the chief sedimentary rock produced on the deep seafloor and comprises approximately half of all sedimentary rock. Both siltstone and shale, although chemically stable, are physically weak and susceptible to erosion so that they are frequently associated with lowlands in areas where the topography is dominated by erosional processes.

Organic sedimentary rocks are produced from the remains of plants and animals. Most are composed of **carbonate minerals**, which contain a predominance of carbon and oxygen. **Limestone** ($CaCO3$) is by far the most abundant rock type within this category. It forms in clear, warm water as a result of the action of marine animals that synthesize calcium carbonate for their shells or exoskeletons. When these animals die, their remains accumulate on the seafloor and are buried, compacted, and lithified into limestone. Most atmospheric carbon dioxide is eventually dissolved into the ocean waters and ends up in limestone. Most of the Earth's near-surface supply of carbon is locked up in this rock.

While limestone is the chief organic sedimentary rock derived from animal remains, coal is the most common rock derived from the remains of plants. This rock type, composed largely of carbon, is formed from the burial, compaction, and gradual lithification of plant remains in shall standing water or on water-saturated ground. Most large coal deposits formed about 250 million years ago, when large portions of the Earth were covered by swampy, forested lowlands. Coal is our most abundant fossil fuel resource and is widely distributed around the Earth.

Chemical sedimentary rocks are formed by the precipitation of chemicals in water. For precipitation to occur, the water must become locally supersaturated in these substances. It already has been noted that chemical precipitates play an important role in the formation of the coarser clastic rocks, notably conglomerate and sandstone, by serving as the cementing agents holding the rock particles together. Under certain conditions, rocks are formed largely or entirely of these precipitates. The most common chemical precipitate is calcium carbonate (CaCO3), which can accumulate to form chemical limestone deposits. Most currently forming chemical limestones are on the floors of shallow areas in the tropics.

Distribution of sedimentary rocks

Sedimentary rocks are the most widely distributed of the three major rock categories at the Earth's surface. Although they comprise only about 5 percent of the volume of the continental crust, they form a relatively thin veneer over approximately two-thirds of the land surface and virtually all of the seafloor beneath the cover of marine sediments. The chief land areas not covered by these rocks are ancient plutonic rock areas and areas that have experienced recent volcanism. In addition, some sedimentary rock areas are overlain by thick unconsolidated glacial deposits.

The widespread presence of sedimentary rocks of marine origin is continental settings indicates that the land in these areas must have risen above sea level after the rocks were formed. Marine sedimentary rocks, for example, cover much of the midwestern United States and Canadian prairies. In most low-lying coastal regions where sedimentary rocks of recent origin are found, oceanic retreat apparently was accomplished by slight reduction in sea level or by surface uplift with little accompanying disturbance to the rock layers. The nearly horizontal sedimentary rocks of the Atlantic and Gulf coastal plain of the eastern United States serve as good examples. In other places, though, major tectonic upheavals have lifted sedimentary rock sequences great distances above sea level, often complexly deforming them while doing so. Most of the Earth's major mountain ranges, including the Rockies of northern North America, are composed chiefly of sedimentary rocks that formed on the ocean floor.

Metamorphic Rocks

Metamorphic rocks (from the Green *metamorphosis*, or 'transformation') are rocks altered from their original form by heat, pressure, and/or chemical activity, while remaining in the solid state. Metamorphic changes in rocks produce textures, structures, mineral compositions, and general appearances that differ from those of the original rocks. The consistent chemical elements remain the same, but they are rearranged into different mineral combinations. Metamorphism results from the high temperatures and pressures generated well beneath the surface by tectonic processes. Most metamorphic rocks are produced by large-scale or **regional metamorphism** that occurs during mountain-building activity.

All types of rock are subject to metamorphism with sufficient applications of heat and pressure; this includes igneous, sedimentary, and even metamorphic varieties. Each rock type has one or more metamorphic equivalents. Varying degrees of metamorphism exist, from slight alterations to complete recrystallization. The type of metamorphic rock produced at any given site depends on the original type of rock and on the nature, intensity, and duration of the metamorphic processes.

Metamorphic rocks are by far the least abundant of the three major surface rock categories. They are much more common deep within the crust where they have been produced by tectonic movements. Because great thicknesses of overlying materials must be eroded before rocks subjected to regional metamorphism appear at the surface, they are exposed mostly in ancient plutons. Most metamorphic rocks comprised the root zones of major mountain ranges that were thrust up by collisions between blocks of crustal material.