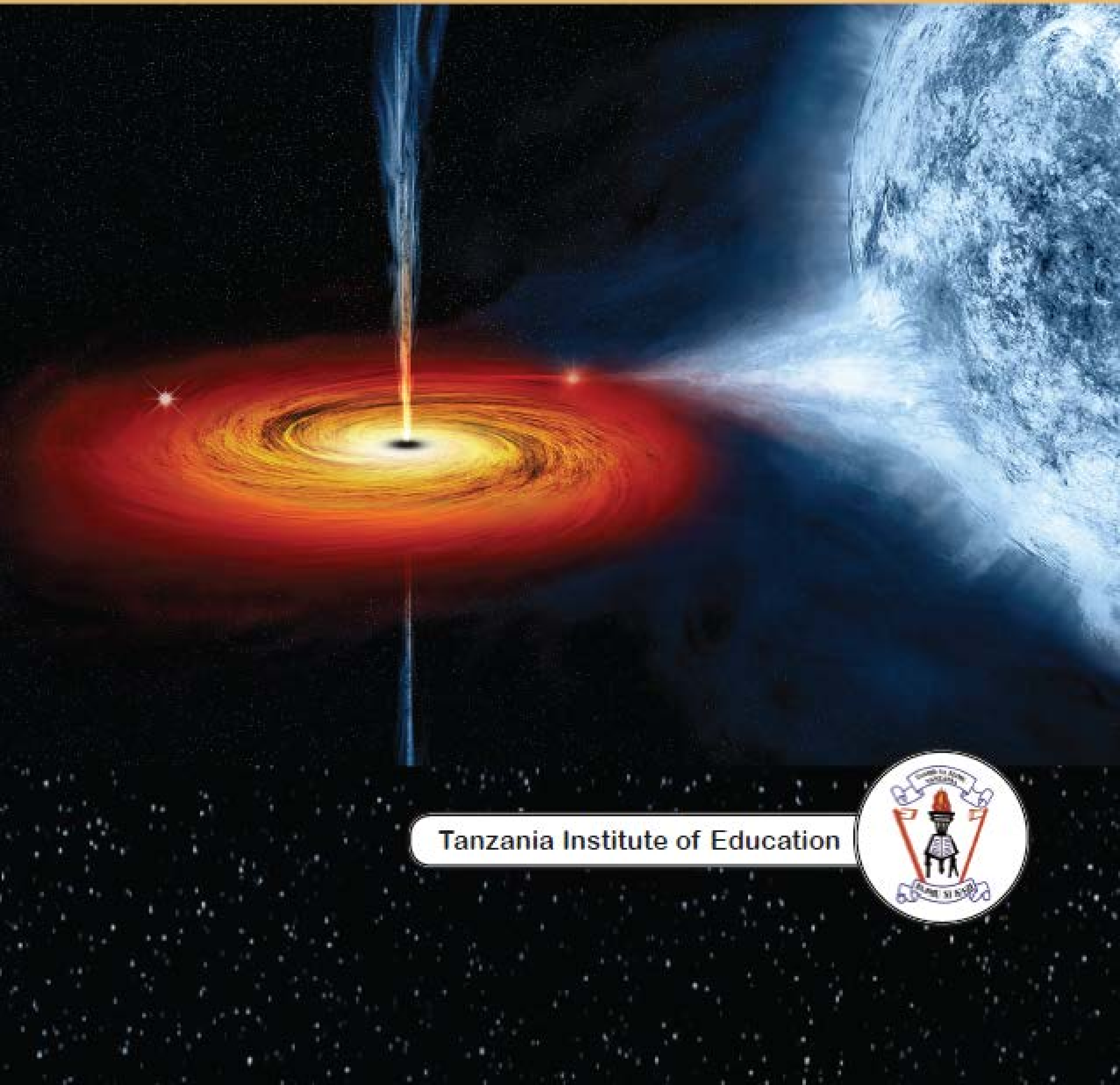
Physical Geography

for Secondary Schools

Student's Book

Form Five and Six



Tanzania Institute of Education

Physical Geography
for Advanced Secondary Schools

Student's Book
Form Five and Six

THE UNITED REPUBLIC OF TANZANIA
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Dr Lyabwene M. Mtahabwa
Commissioner for Education

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Dr Aneth A. Komba
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Preface

This textbook, Physical Geography for Advanced Secondary Schools, is written specifically for Form Five and Six students in the United Republic of Tanzania. The book is prepared in accordance with the 2023 Geography Syllabus for Advanced Secondary Education, Form V–VI, issued by the Ministry of Education, Science and Technology (MoEST). It is a revised edition of Physical Geography for Advanced Secondary Schools Student's Book for Form Five and Six that was published in 2022 in accordance with the 2010 syllabus issued by the then Ministry of Education and Vocational Training (MoEVT).

The textbook consists of six (6) chapters, namely Theories of landforms formation, Earth system, Endogenic processes of the Earth, Exogenic processes of the Earth, Rocks and Hydrology. In addition, each chapter contains activities, scenarios, illustrations, projects, and exercises. You are encouraged to do all the activities, projects, tasks and questions. You are also required to prepare a portfolio for keeping records of activities performed in different lessons. This will enhance your understanding and development of the intended competences for this level.

Additional learning resources are available in the TIE e-Library at https://ol.tie.go.tz or ol.tie.go.tz

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Chapter One: Theories of landforms formation

Introduction

The Earth has diverse range of landforms, from expansive mountain ranges to rolling hills, from deep oceanic trenches to meandering rivers. The formation of these landforms and the processes that create and shape them are of great significance in the field of physical geography. In this chapter you will learn about theories of landforms formation such as continental drift,seafloor spreading, plate tectonics, and isostasy and how they aid in explaining existing landforms. The competences developed will enable you to demonstrate an advanced understanding of the concept and theories explaining the structure of the Earth and interaction of the earth's system. It will also enable you to appreciate theoretical linkages between the earth's processes and formation of landforms.

Think about

The existence of continents and other landforms on the Earth

Theories guiding formation of landforms of the Earth

Activity 1.1

Search from online sources or library about theories explaining the formation of landforms. Write a summary on the key observations and evidence that support each of the theory you have studied.

The Earth has various landforms such as hills, mountains, plateaus, plains, and valleys which are created and shaped by one or a combination of processes. Understanding how different landforms come into existence is complex. However, theories such as continental drift, plate tectonics, and isostasy provide crucial insights into landform formation.

Continental drift theory

Continental drift theory was initially developed in 1908 by Frank Bursley Taylor who postulated about the concept of horizontal displacement of the continents to explain the distribution of the fold mountains. In 1912 the theory was proposed by Alfred Wegener who explained about how the continents have moved from their original position on the earth's surface. Wegener explained that the earth's continents were once united forming a single super-continent land mass called *Pangaea* (a Greek word meaning all lands together) which was surrounded by a huge water-mass (ocean) called *Panthalassa* about 280 million years ago. Later on about 200 million years Pangaea broke up to form two land masses, the northern continent which was known as *Laurasia* and the southern continent called *Gondwanaland*. These continents were separated by a long narrow sea called *Tethys*. About 150 million years later, between the Mid-Permian and the cretaceous periods, Laurasia broke up into three continents, that is Europe, North America and Asia while Gondwanaland broke up and formed Africa, South America, Australia, New Zealand, Antarctica, and Indian Sub-continent as shown in Figure 1.1

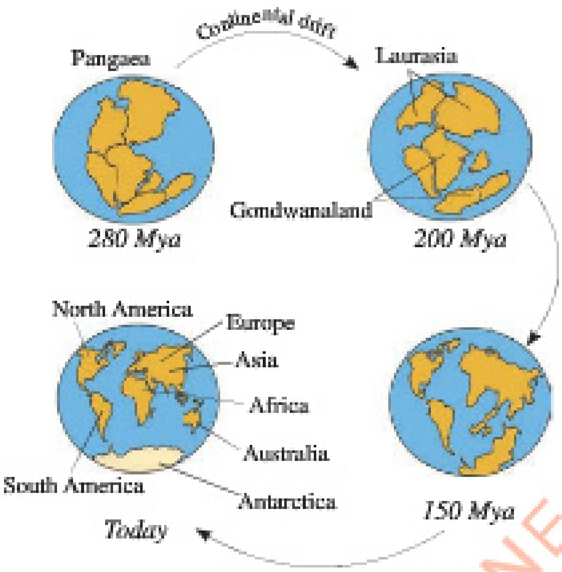


Figure 1.1: *Continental drift*

Wegener and other scientists such as Arthur Holmes and Frank Bursley Taylor proposed three main causes of continental drifting which are centrifugal force, tidal attraction and convection transfer of heat.

Centrifugal force: The rotation of the Earth created a centrifugal force towards the Equator. Wegener believed that Pangaea originated near the South Pole and that the centrifugal force of the planet caused the proto continent to break up and resulted into continents drifting towards the equator. He called this action the *pole-fleeing force*. According to him after breaking away from the Pangaea, the continents moved in two directions namely equatorward and west-ward movements. The equatorward movement of sialic blocks was caused by gravitational force and force of buoyancy. Wegener explained that the lightweight sialic materials were floating without friction on relatively denser (SIMA) materials. Equator-ward movement depended on the relation between the centre of gravity and centre of buoyancy of the floating continental mass.

Tidal attraction: Wegener presumed that tidal influence of the Sun and moon gave the continent westward motion, a counter movement of the revolution of the Earth. Wegener complemented Taylor's proposal that the main driving force possible for displacement of the continent was tidal force. According to Wegener the attraction force resulted from the Sun and the moon which attained its maximum level when the moon was nearest to the Earth, thus dragged the outer sialic crust (continental blocks) over the interior of the earth towards the West.

Convection and heat transfer: In 1929, Arthur Holmes elaborated one of the Wegener's hypotheses about the idea that the mantle undergoes thermal convection. This idea is based on the fact that, when a substance is heated its density decreases causing it to rise to the surface and when it cools down it sinks again. The repeated heating and cooling results in a current which may be sufficient to cause that substance to slightly move. This is associated with the movement of continents.

Evidence of continental drift

Ever since Wegener and other scholars put forward the continental drift theory, various evidence have been provided to support the idea of continental drift. The following are some of the available evidence to support the theory.

Jig-saw fit: According to Wegener there is a geographical similarity among various coasts of different continents. It was observed that some coastlines of different continents could fit into one another along the margin if brought together. For example, the east coast of South America could fit into the west coast of Africa (Figure 1.2). This is known as Jig-saw fit. The Jig-saw fit implies that all continents were formed from a single landmass.

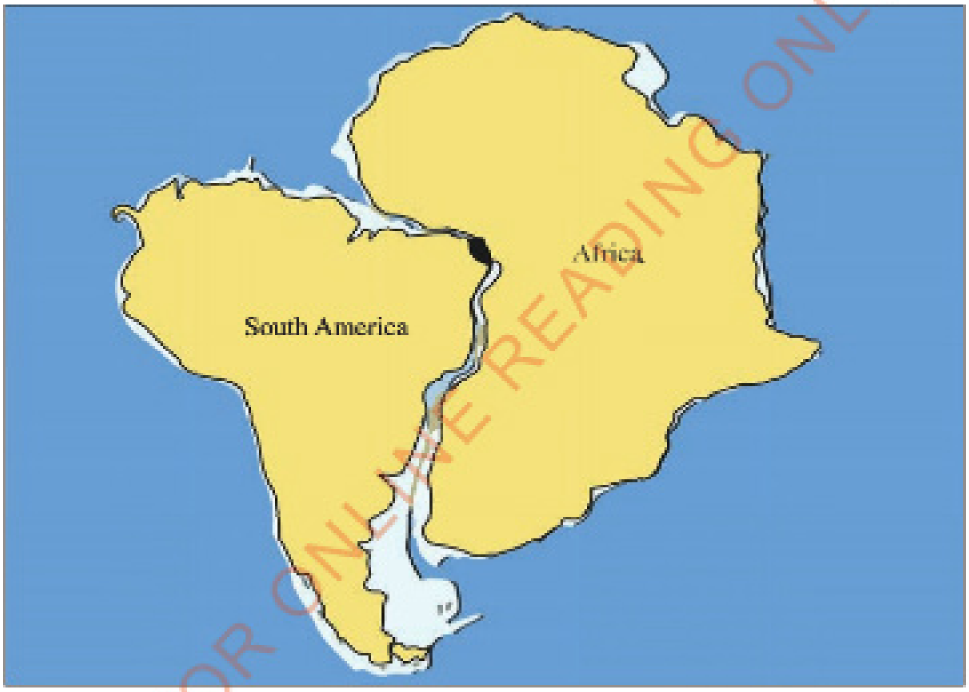


Figure 1.2: *Jig-saw fit of the continents*

Activity 1.2

Use internet sources for searching models or simulations that demonstrate the concept of continental drift. Based on the simulation observed, write short notes on the arguments of continental drift theory and its evidence.

Paleontological evidence: This is a biological evidence which explain the similarity of plants and animals' fossils in rocks with similar age which are found on the shores of the different continents and which suggests that the continents were once connected. For example, fossils of *Mosasaurs*, a freshwater reptile, have been found both in Brazil and Western Africa and fossils of the land reptile *Lystrosaurus* have been found in rocks of the same age in Africa, India and Antarctica (Figure 1.3). Moreover, the distribution of *glossopteris* flora in India, South Africa, Australia, Antarctica and Falkland island proves the fact that all landmasses were previously united.

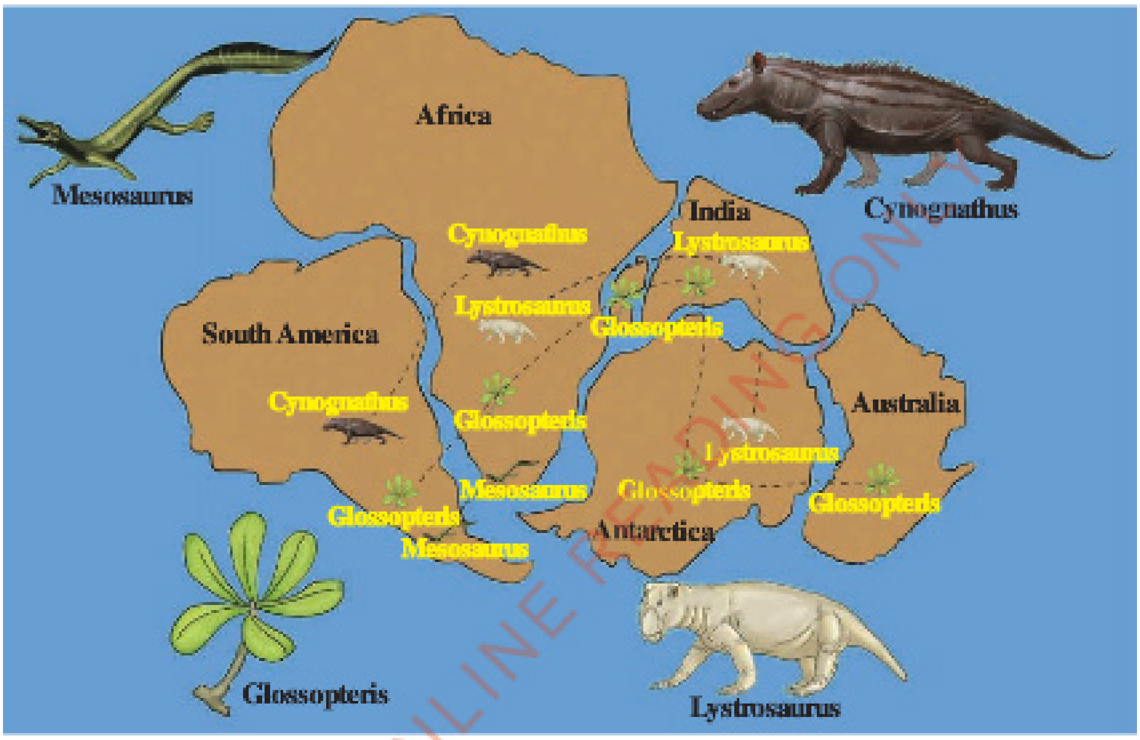


Figure 1.3: *Paleontological evidence of the continental drift*

Geological similarities: These refers to the similarities in the large scale geological features found in different continents. This evidence uses identical rocks in terms of types, structures and ages which are found on both sides of Atlantic Ocean. For example, rocks on the coastlines of South America and West Africa seem to match up. The familiar rock strata of the Karoo system of South Africa match correctly with the Santa Catarina system in Brazil. Moreover, the mountain ranges with the same rock types, structure and age are now found on the opposite sides of the Atlantic Ocean. For example, the Appalachian Mountains in Eastern North America are linked with the Eastern Greenland mountain ranges.

Evidence from glaciations: During the later part of the paregoric era (about 300 million years ago), glaciations occurred throughout the large part of the continent in the Southern hemispheres. The deposits left by these ancient glaciers are recognized by striations and grooves on the underlying rocks showing the direction in which the ice moved. The presence of glacial deposited in the Congo basin where the climate is warm, is used as the evidence that the continents drifted from regions which were cold to currently warm regions. For instance, Africa shifted northwards from the South.

Paleomagnetism: Paleomagnetism also supports the theory that continents changed position over time. When the rocks cooled, they were magnetized in the same direction the magnetic field (magnetic north) is found. The paleo magnetic dating shows that rocks older than 200000 years from different parts of the Earth have shifted their relative position, which indicates the shifting of continents. The shifting of continents is detected by using a sensitive instrument called magnetometer which is capable of determining the direction of magnetic poles at a given geographical period.

The formation of rift valley: The presence of rift valleys like the Great East African rift valley is another major indication of continental drift. This rift valley was formed due to the movement of plates beneath the continents. The tensional force of the moving plates forms cracks which finally formed a rift valley (Figure 1.4).

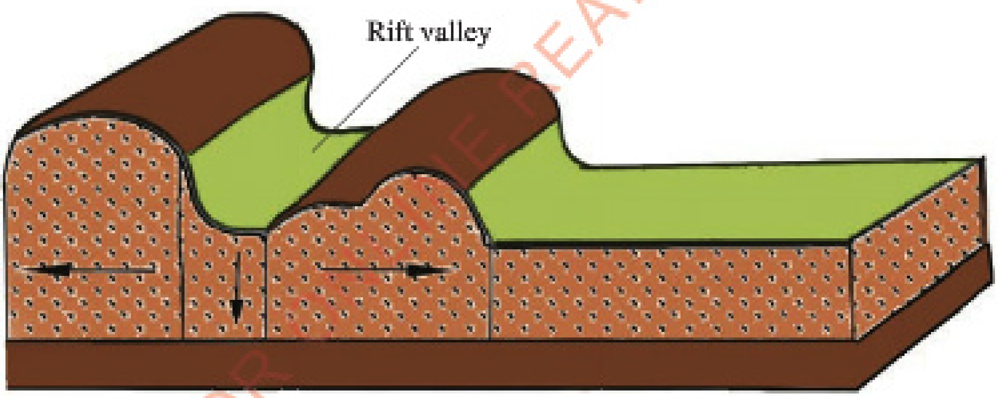


Figure 1.4: *Formation of a rift valley*

The red sea evidence: This began as a rift valley 20 million years ago and it is now over 300 km wide. It was formed by the divergence between African continent (plate) and Arabian plate (Figure 1.5).

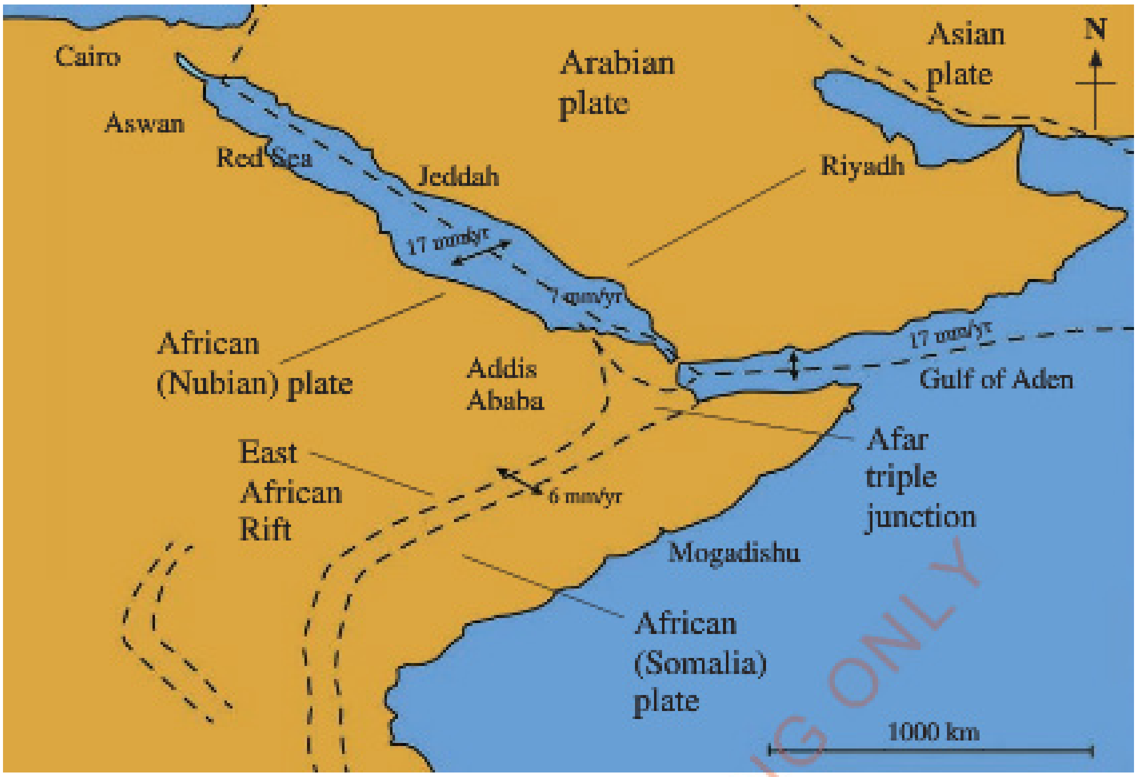


Figure 1.5: *Red sea evidence*

Coral reefs in the north pole: Recent expedition to the cold north water especially Arctic have revealed giant deep sea coral reefs. Normally, coral reefs develop in the warm water regions. The presence of coral reefs in the cold north water (Arctic) is an evidence that Laurasia was once located along the tropics.

Geomorphological evidence: This was based on the nature, age, structure and chain of Atlas mountain range in Africa and Alps mountain range in Europe that seem to be similar in age, structure and alignment. It is believed that possibly the mountains were formed when the African plate moved northward due to tectonic movement which resulted into collision with European plate and create the mountain ranges we see today.

The consequences of continental drift

The consequences of continental drift are highlighted based on the formation of physical features, climate change, changes in patterns of ocean currents, evolution of animals and speciation and crustal deformation.

Formation of physical features: Drifting of continents led to the formation of various features such as mountains, oceans, seas and the rift valleys. Taylor (1910) hypothesises that fold mountains were formed as a result of movement of landmass. He further argues that, the wrinkling of crust is due to the drifting of continents. The drifting of continents is believed to be causing the natural catastrophes such as earthquakes, volcanic eruption and tsunamis. Drifting up of the landmass resulted in the formation of oceans and seas. For example, westward movement of landmass opened the Atlantic Ocean while Red Sea was formed after a divergence between the African plate and the Arabian plate.

Climate change: Climate change is a long-term shift in weather conditions identified by changes in temperature, precipitation, winds, and other indicators. Climate change can involve both changes in average conditions and changes in variability, including, extreme weather events. It is commonly known as net pole-ward movement resulting to same continents shifting to the polar areas where they are assumed that there was very low temperature contrary to those positioned at the Equator where the temperature is high like the African continent.

Change in patterns of ocean currents: The ocean currents in some parts of the world were also affected in terms of temperature. For example, the waters around New Zealand's South Island cooled from 20°C at the beginning of Eocene period about 56-53 million years ago to 17°C during 30-14 million years ago and then cooling to the present temperature of 12°C.

Evolution of animals and speciation: The rearrangement and displacement of landmasses helped to create the diversity of animals which we see today. Without the continental drift, the Earth today would have been very different in terms of the diversity of animals available in different parts of the world. Continental drift promoted allopatric speciation as when the united landmass separated, regions that were once connected became geographically isolated. Each separate region became an evolutionary arena with plants and animals diverging from those in other continents. For example, the distribution of the flightless running birds or ratites in South America, Africa and Australia is a result of the break up of the Pangaea.

Crustal deformation: The drifting of continents is believed to be causing the natural catastrophes such as earthquakes, volcanic eruption and tsunamis. When the landmasses move they cause crustal deformation when the applied force exceeds the internal strength of the contracted rock. The force creates physical changes and causes fold, fracture and faults. When energy is released brittle deformation causes an earthquake.

Change of economic activities: The change in geographical position caused some changes in human activities in accordance to the nature of the position of that region. For example, if Africa had remained in the Southern pole, some human activities like agriculture would not be possible. Moreover, continental drift resulted into features like sea, ocean, rift valley and mountains. These features have caused various human activities such as fishing and tourism to emerge.

Critiques of the theory of continental drift

Despite the causes and evidence explained, continental drift still faces a number of critiques. Here are some of the main critiques: It is claimed that, Wegener has failed to explain convincingly the causes and mechanisms of continental drift theory. For instance, Wegener presumed that tidal influence of the moon gave the continents westward motion, a counter movement to the revolution of the Earth. Another critique is by Jeffey (1920), a physicist, pointed out that tidal friction of such magnitude which needed to displace the continents would bring the earth's rotation to a half in a matter of few years. On the other hand, the idea of centrifugal forces was rejected by a scientific community, primarily because the actual force generated by the rotation of the Earth were calculated to be insufficient to move the continents. Moreover, the use of jig-saw puzzle analogy as one of the evidence of Wegener's theory was not easily accepted. The argument was that, it was not a perfect fit because not all continents can fit exactly to each other and the continents true shape was discovered not to be the shoreline around them, but the edges of their continental shelves.

Wegener's explanation of the physical process that separated the continents was considered weak and strongly criticized on valid physical grounds. He proposed that a continental layer of less dense rock had moved like a great floating raft through a sea of denser oceanic crustal rock but geologists used established principles of physics to show that the proposed mechanism was impossible. Lastly, it was observed that Wegener had failed to explain the development of glacier in the hot desert such as Iran that exists to the present. Despite all the critiques, Sea floor spreading theory came into existence to support the continental drift theory, by mainly focusing on oceanic environment.

Activity 1.3

Read from various sources on the mechanisms that drives continental drift. Write short notes on what you have read.

Seafloor spreading theory

This is one of the modern theories put forward by Harry Hess, an American geologist in 1960. It provides explanation on the formation of the oceanic mountain ranges called *mid-oceanic ridges* as a fundamental result of plate tectonic movements that necessitated a continental drifting. Hess states that new crustal materials are being formed along the mid oceanic ridges as a results of earth's mantle which behaves like a giant convectional system in which materials are heated by radioactive elements and rise to the surface to form new oceanic crust. As new crustal materials form, new materials push apart the old seafloor on both side of the ridges and this process leads to the spreading apart of the seafloor at a rate of 1 – 10 cm per year. A good example is the Atlantic Ocean that widens at a rate of 1 to 10 cm per year.

Seafloor spreading does not lead to the enlargement of the crust. This is because as the new seafloor gains materials at the mid ridge it also loses the old ones in the deep trenches where the crust of the new floor moves downward to the mantle, melts and becomes part of the mantle which will eventually be forced out in the form of vulcanicity. Through this process, the continents carried above are forced to move along it (Figure 1.6).

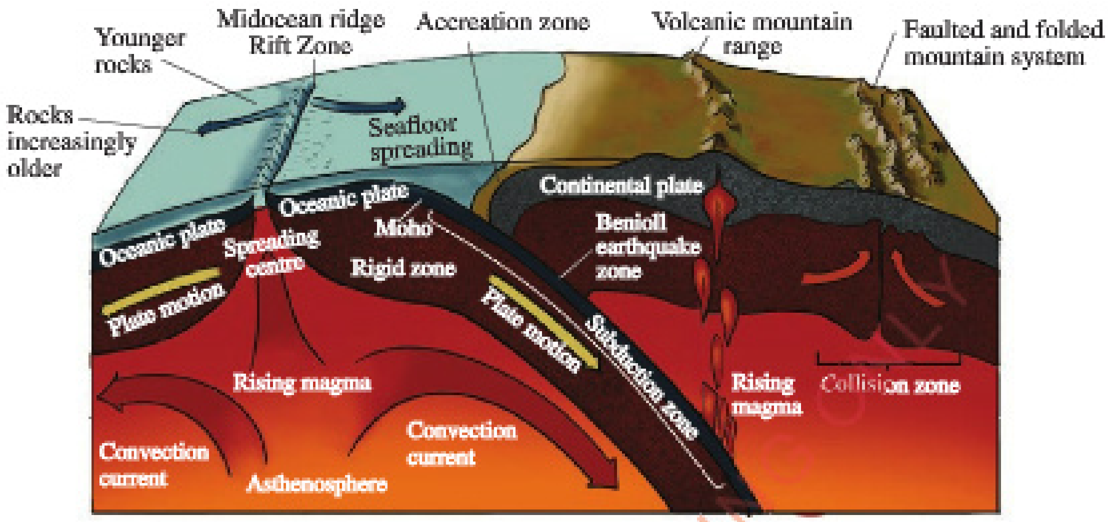


Figure 1.6: *Processes and features of seafloor spreading*

Evidence of Seafloor spreading

There are several evidence that support seafloor spreading theory namely presence of oceanic ridges, rifts, differences in the ages of rocks along the seafloor and magnetic evidence.

Presence of oceanic ridges: A mid-oceanic ridge is a seafloor mountain system formed by plate tectonics. Typically, it has the depth of 2600 metres and rises about two kilometres above the deepest portion of an ocean basin. It is at this feature that seafloor spreading takes place along a divergent plate boundary.

Presence of fractures and rifts at the mid oceanic ridge: The centre of the mid ocean is marked by a deep and steeply walled valley. It is believed that this is the valley through which the molten rock comes up through from the mantle. The molten materials cool and harden to become part of the ocean floor. The addition of these materials creates new crust on each side of the mid ocean ridge. This process is manifested through the spread of the seafloor of Atlantic and Indian Oceans, the presence of oceanic trenches which form as the seafloor buckles in response to the outward push of the molten rock and evidence from seismic devices which show that crust is bending downward in the trenches.

Differences in ages of rocks along the seafloor: Exploration of the mid ocean ridge has shown that rocks at its centre are younger than rocks in the seafloor on either sides. Thus, a move away from the ridge in either direction marks an increase in the age of the rocks of the seafloor. Furthermore, evidence show that seafloor rocks are younger than continental rocks. The youngest rocks along the seafloor are along the rifts of mid oceanic ridges and older rocks are found further away from mid-oceanic ridges.

Magnetic evidence: In molten rock, iron atoms move about and point to the magnetic poles of the time. After cooling and solidification, iron atoms are locked in one place. Rocks of different ages show different directions to magnetic poles, thus, rocks that hardened at different times show different directions in mid oceanic ridges. It should be noted that magnetic poles have been discovered to be reversing from year to year. That is to say, a magnetic pole can be in the South for a particular period of time and then in the North for another period of time. It is therefore claimed that there have been 171 reversals in over 76 million years. Therefore, if basaltic lava is formed when the magnetic pole was in the North, new basalt iron atoms would be aligned to the North. After the reversal, new lava would be oriented to the South.

Presence of oceanic trench: This is an indicator that subduction has taken place after seafloor spreading.

Strength of the Seafloor spreading theory

The Seafloor spreading theory explains the features of the seafloor as it offers reasons for the presence of oceanic ridges, rifts along the oceanic ridges, formation of deep trenches as well as the reasons for seafloor spreading. It also help us to understand the causes of lithosphere movement. However, the theory fails to explain the mechanism that would allow continents to move through ocean basins.

> ***Exercise 1.1***
>
> 1. With examples from Africa, support the continental drift theory.
> 2. Explain the forces behind continental drifting.
> 3. Elaborate the contention that 'continents are restless'.
> 4. Discuss the strengths and weaknesses of the continental drift theory.
> 5. How does seafloor spreading theory connect to continental drift theory?
> 6. Show how the seafloor spreading theory explains the formation of landforms.
> 7. Discuss the strengths and weaknesses of the seafloor spreading theory.

Plate tectonic theory

Geologically, the word **plate** means a slab of a rock made up of continental and oceanic lithosphere. The word **tectonic** comes from the Greek word **tekton** which means 'a builder or to build'. The development of plate tectonic theory began in 1915 following the early criticism of Continental drift theory. Essentially, plate tectonics are geological components of study related to the origin and arrangement of the broad structural features of the earth's surface including not only folds and faults but also mountain belts, continents and earthquake belts. The basic idea of plate tectonics is that the lithosphere (earth's crust and the upper rigid part of the mantle) is divided into separate parts called tectonic plates, which move slowly. At present it is believed that there are seven (7) large plates and about thirteen (13) or more small plates, making a total of about twenty (20) plates or more.

The major plates

The seven major plates are:

(a) North American plate - It includes the surrounding oceanic crust up to the mid-Atlantic ridge.

(b) South American plate - It includes surrounding oceanic crust up to the mid-Atlantic ridge.

(c) Pacific Plate - This plate is the largest of all covering about one-fifth of the earth's surface, hence occupies the whole of Pacific region

(d) Eurasian plate - It is a continental plate, thus it occupies both Europe and Asia continents and includes their surrounding areas.

(e) Antarctic Plate - It covers the Antarctica continent and the surrounding Southern Ocean

(f) African plate - It takes all of Africa and its surrounding area to the mid-Atlantic ridge.

(g) Australian-Indian plate - This includes the continental crust of India and Australia as well as the oceanic crust of India and parts of Pacific Ocean.

The minor plates

The minor plates are greater in number than major plates reaching to about 13. These include; Caribbean, Philippine, Arabian, Nazca, Cocos, Scotia, Caroline, Somali, Fuji, Burma, New Hebrides and Juan de Fuca plates (Figure 1.7). These plates move over the hot and partially molten asthenosphere though their speed is low.

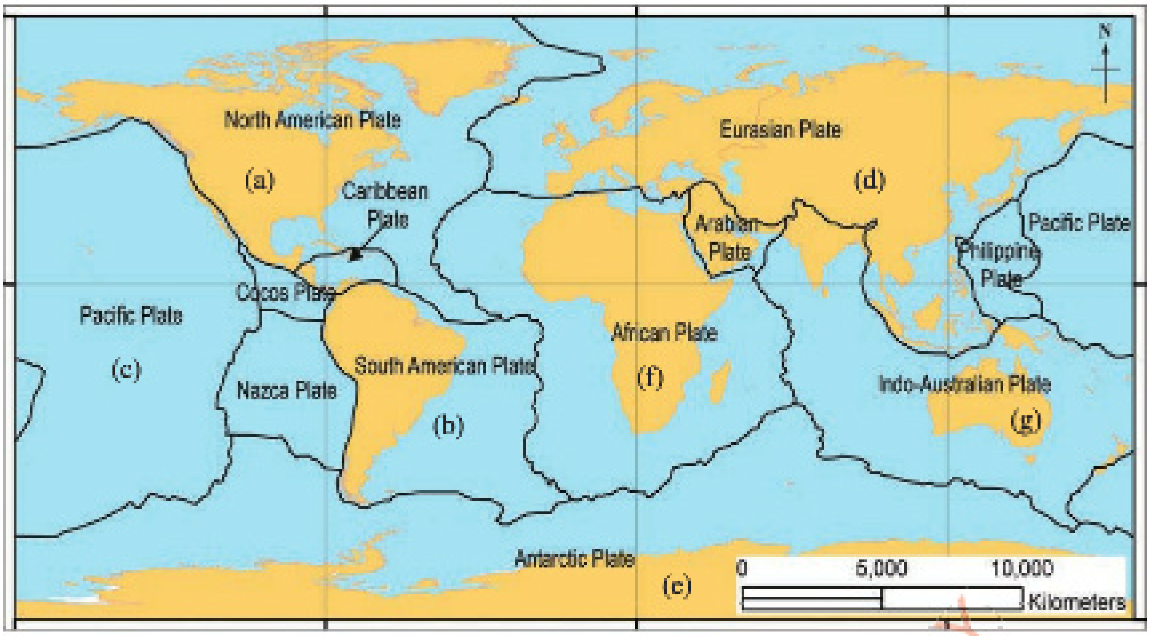


Figure 1.7: *Major and Minor Plates*

Assumptions of the plate tectonic theory

The plate tectonic theory states that the earth's crust is divided into separate parts called tectonic plates. These plates are mobile and they float on underlying semi molten mantle (the asthenosphere) and are moved by convectional currents. The theory can also said to be the study of the movement of the plates and their resultant landforms. The plates are divided into two types which are continental and oceanic plates.

Continental plates

These are plates which carry the continents also known as continental mass. They are composed of old rocks mainly over 1500 million years and lighter rocks of granitic type dominated by minerals rich in silica and aluminium (sial). The continental plate of Africa, North America, and South America are good examples of continental plates with old rocks.

Oceanic plates

These are made up of simatic younger and denser rock of basalt composition, dominated with silica and magnesium minerals. They are younger mainly under 200 million years. The boundary between the crust (continental or oceanic) and the underlying mantle is known as *Moho or Mohorovicic discontinuity* and it was named after a study conducted by Andrija Mohorovicic in 1909.

Causes of plate movement

The causes of plate movement are mantle convectional current generated by heat from the centre of the Earth, formation of new oceanic crust, cooling and sinking of oceanic crust, differences in force of gravity between the oceanic ridge and trench and oceanic topography (elevation of the mid oceanic ridge).

Mantle convectional current: Radioactively generated heat in the upper mantle produces convectional currents which carry plates along them with the continents as passengers. The heated material in mantle expands and becomes less dense and slowly rises. When it reaches near the crust, it cools down slowly and contrasts hence it becomes denser and sinks down again (Figure 1.8). The new oceanic crust gradually cools down and thickens with age and it is pushed downhill as new magma emerging from the active zones of divergence behind it. This force is regarded as secondary force.

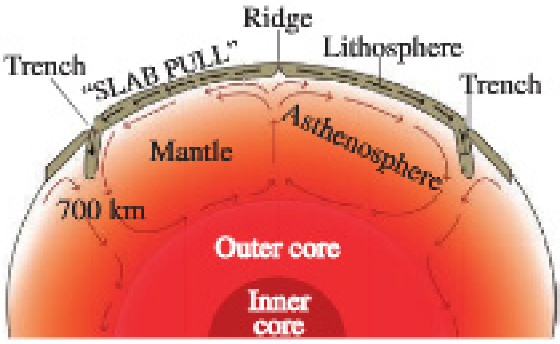


Figure 1.8: *Mantle convectional current*

Formation of new oceanic crust: New oceanic crust is formed at the mid oceanic ridge as the magma pushes the earlier old rocks on either sides of the seafloor before it cools down and solidifies. This action causes the plates to move. It is common at mid-Atlantic Ocean where the African plate moves away from American plates.

Cooling and sinking of oceanic crust: Oceanic crust is less dense than asthenosphere. However, it becomes more denser when it is old. When it is denser than asthenosphere, it sinks into the mantle, thus acts as a driving force for the plates to move. As a new crust slowly drifts away from the ridge, it cools down and becomes denser, thus causing the sea bed to sink to subduction zone. As it moves down into subduction zone, the crust is pushed down under another plate. It bends down and sinks into the mantle, thus keeping the plates moving.

Differences in forces of gravity between the oceanic ridge and oceanic trench: The existing differences of gravitational pool between the ridge and trench causes the ridge to be pulled down to the deep trench, hence causing the motion of the plates.

Oceanic topography: Oceanic topography is also known as elevation of the mid oceanic ridges. When the elevated parts of the oceanic floor is subjected to extra weight it results into sinking of the materials which in turn lead to plate motion. As plates move, they can either collide, move apart or slide past each other and result into the formation of various landforms such as mountains trenches, earthquakes, volcanoes, and mid oceanic ridges.

Plate movement and resulting landforms

Tectonic plates move slowly over time. Some plates moves towards each other forming a convergent movement. At a time, some plates move away from each other forming divergent movement, while other plates may also move horizontally and past each other and form a transform movement. The movement of plates creates plate margins or tectonic boundaries from which landforms formation occur.

However, due to its relatively low density, continental crust does not sink but floats permanently on a denser oceanic plate.

Oceanic crust is being formed and destroyed continuously. Continental plates, such as the Eurasian plate, may consist of both continental and oceanic crust. the Earth is neither expanding nor shrinking in size. Thus, when new oceanic crust is being formed in one place, older oceanic crust must be destroyed in another part. Continental crust may extend far beyond the margins of the land masses. Plates cannot overlap. This means that either they must be pushed upwards on impact to form mountains or one plate must be forced downwards into the mantle and destroyed.

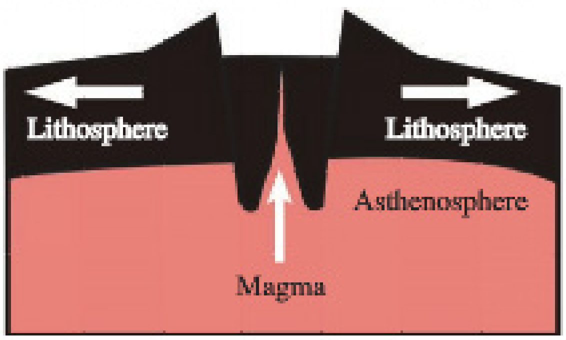
Moreover, plate movement is slow, though not in geological terms, and is usually continuous. Sudden movements are detected as earthquakes. Most significant landforms (fold Mountain, volcanoes, island arc, deep sea trenches and batholith intrusions) are found at plate boundaries. Very litle change occurs in plate centres (shield lands).

The plate margins

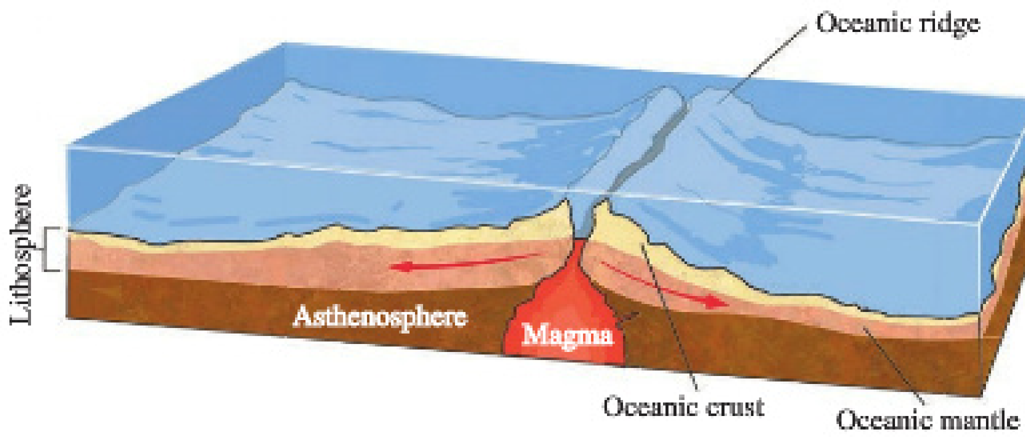
These are important regions, zones or boundaries where plates either meet, slide or move apart from one another. The margins are also active seismically and tectonically. Plate margins are characterized by a combination of tectonic and topographic features such as oceanic ridges, Benioff zones, young fold mountains, and transform faults. Plate boundaries can be classified into three main types which are divergence, convergence and transform/conservative/ shear boundaries.

Divergence plate boundary

This boundary (zone) is also known as constructive zone. It is a zone whereby two plates move away from each other. They are called constructive zones because new materials from the interior part of the earth are added to the surface and form new features like the mid-ocean ridge, island arcs, and new oceanic crust. A divergence zone can be found among continental plates (Figure 1.9a), oceanic plates (Figure 1.9b) and continental and oceanic plates. When divergence occurs in the ocean floor no gap is left on the ocean floor as new crustal material from mantle fills them. Moreover, when divergence occurs on the continent, the continent breaks up and drift apart and the central block subsides. For instance, the land giant troughs such as the Great Rift Valley in Africa were formed when plates moved apart. The continent to continent divergence zones are associated with different features.



(a) Continental divergent plate boundary



(b) Oceanic divergent plate boundary

Figure 1.9: *Divergence plate boundary*

Formation of rift valley occurs if the divergence boundary is on the continental land. A good example is the Great East Africa rift valley. Volcanic features like volcanic mountains, such as Mount Kilimanjaro in Tanzania, are formed as magma forces along the faults. A divergent zone on oceanic to oceanic boundary is associated with formation of oceanic ridges if two oceanic plates move away from each other. An example of this formation is the Mid Atlantic Ridges which are 1000 kilometres wide and 2500 metres high.

The formation of a rift valley at the mid-oceanic ridges happens when the oceanic ridge breaks at the centre. The Atlantic Oceanic trench is an example of seafloor spreading. It was formed due to the divergence of South America and African plates. Moreover, volcanic islands are formed from the rising submarine volcano at divergent zone that solidified to form an island. Volcanicity and shallow earthquakes are also resulting features at divergent zones on oceanic boundary.

Convergence plate boundary

The convergence plate boundary it is also known as a destructive or consuming plate margin. This occurs when two plates move towards each other and result into the formation of trenches such as Marianas, fold mountains like the Himalaya and volcanic islands like Japan. Convergence boundary is divided into three main categories namely; continental-oceanic, continental-continental and oceanic-oceanic convergence boundaries.

Continental - oceanic convergence boundary

The continental - oceanic convergence boundary forms when oceanic floors (plate) and continental plate meet. As they meet, the heavier rocks (oceanic floor) will be forced to sink (making subduction zone) while the lighter continental rock will be forced to rise. The sinking oceanic rock will be destroyed in hot mantle and come out in the form of volcano (Figure 1.10). The subduction zone is active in volcanicity and earthquakes zones. Examples of these include Java trench and Mariana trench which were formed when the Philippine plate subducted under the pacific plate.

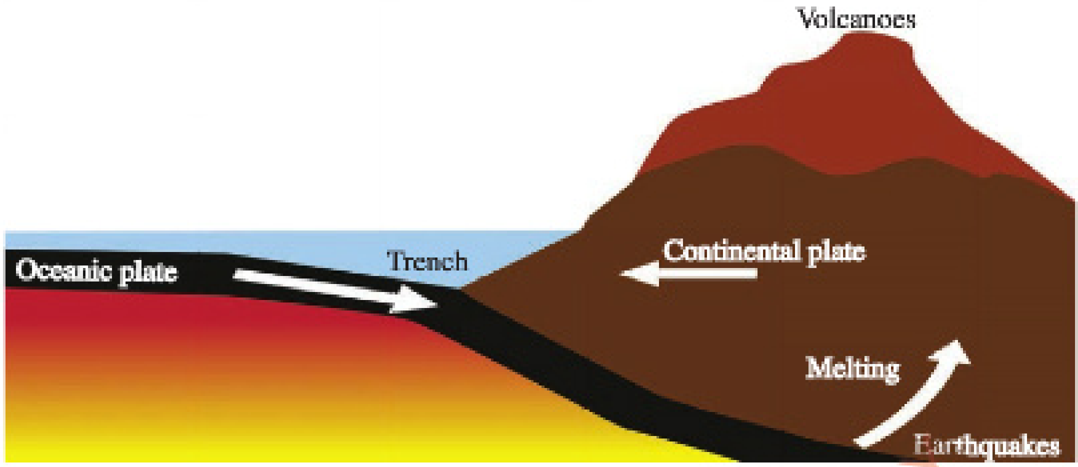


Figure 1.10: *Continental - oceanic convergence boundary*

Continental - continental convergence boundary

Continental - continental convergence boundary is the zone where two similar plates (continental and continental) collide such that neither of them sinks below the other, rather they are forced to bend leading to the formation of fold mountains such as the Himalaya, Alps and Atlas (Figure 1.11). It is also known as a destructive zone because the plates tend to lose the materials at their margins where collision occurs.

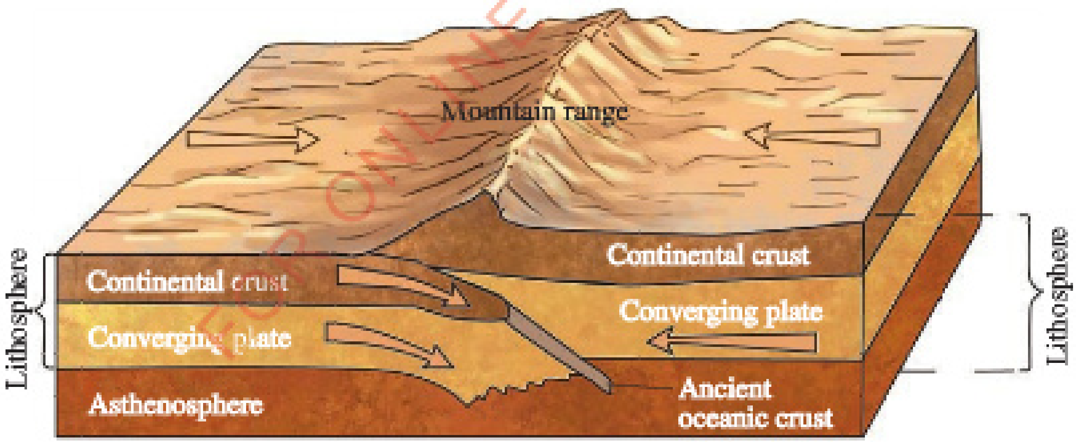


Figure 1.11: *Continental - continental convergence boundary*

Oceanic - oceanic convergence boundary

Oceanic - oceanic convergence boundary occurs when two oceanic plates converge and one is subducted beneath the other along an oceanic- oceanic plate boundary. Specifically, it happens when one oceanic plate is slightly denser than the other. (Figure 1.12). On the non-subducted plate, a volcanic island arc forms from the rising magma generated from the subducting plate. A good example is an island arc of Japan and West Indies.

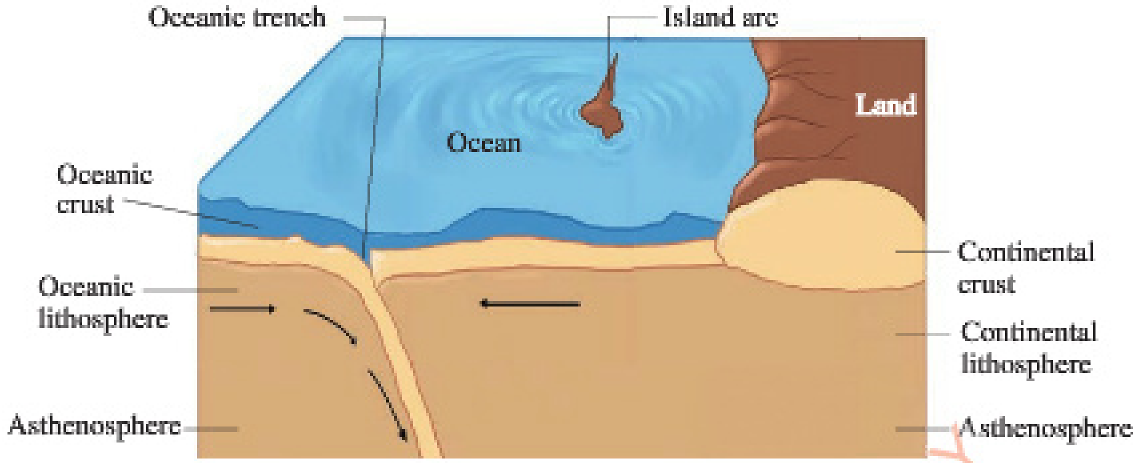


Figure 1.12: *Oceanic - oceanic convergence boundary*

Transform boundary

Transform boundary is also known as conservative or tear or shear plate boundaries. This occurs when two lithospheric plates slide past each other along a transform fault (Figure 1.13). During that process neither is the plate created or destructed. As a result transform faults which are accompanied with tremors and earthquakes may occur. Examples of faults in the transform boundaries are the San Andreas Fault in California and North Anatolian Fault in Turkey.

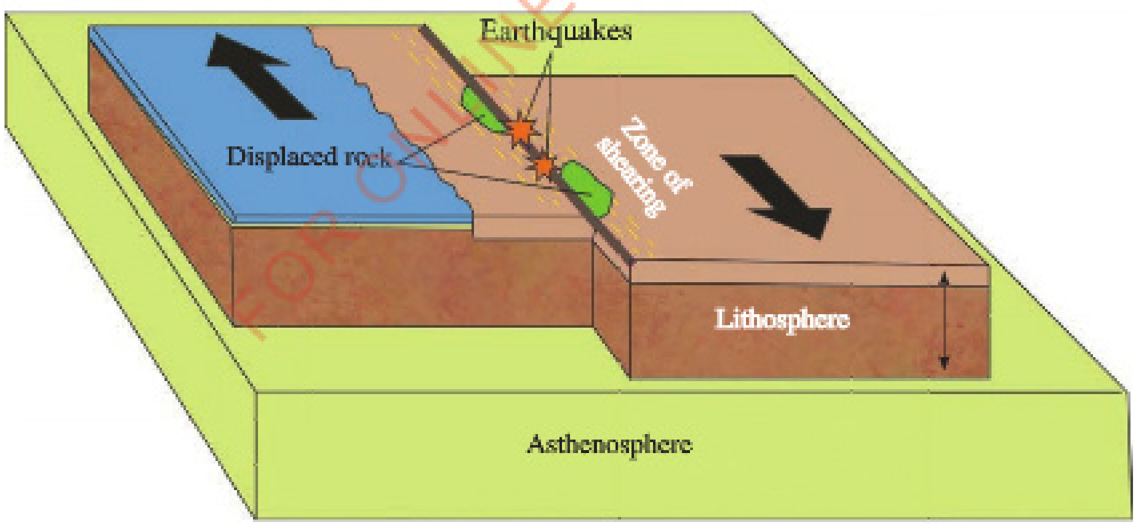


Figure 1.13: *Transform boundary*

Activity 1.4

Search for appropriate readings from school library or online platforms about plate tectonic theory. Write a summary elaborating the applicability of the theory in explaining the formation of landforms on Earth.

Exercise 1.2

1. Substantiate the contention that plate tectonic theory is a new version of a continental drift theory.
2. Relate the theory of plate tectonics with landforms formation in Africa.

Isostasy theory

This theory was proposed by Clarence Dutton, an American Geologist in 1889. The term isostasy is derived from two Greek words *isos* which means 'equal' and *stasis* which refers to the state of equilibrium or balance or standing still. Literally, isostasy refers to 'equal standstill'. Generally, the theory explains the tendency of the earth's crust to attain an equilibrium state and the distribution of the materials in the earth's crust which conforms to the observed gravity values.

Assumption of the Isostasy theory

The theory assumes that the earth's crust is floating on the molten rocks of the upper mantle, like a raft floating in the water rather than resting on the mantle like a raft sitting on the ground. The theory states that, the lithosphere which has a constant density of 2.7 grams per cubic centimetre, floats in the asthenosphere which has a constant density of 3.3 grams per cubic centimetre. It further states that, there is a state of gravitational equilibrium between the earth's lithosphere and asthenosphere, in such a way that the tectonic plates floating at an elevation depend on their thickness and density (Figure 1.14). This means that, a continental rock (*sial-silica and aluminium*) has low density, underlie denser oceanic rocks (*sima-silica and magnesium*) which results to a state of balance.

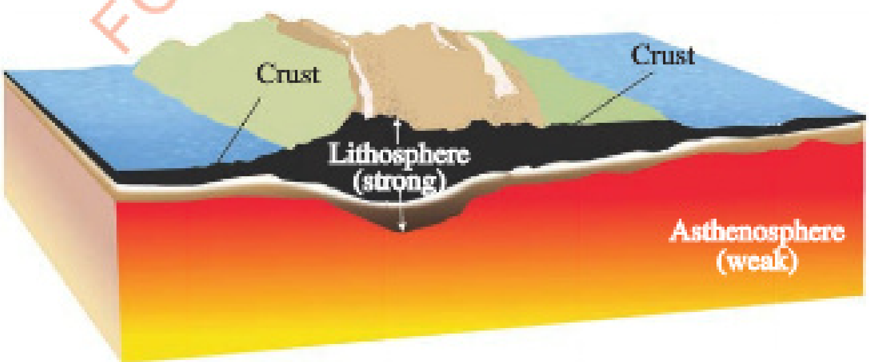


Figure 1.14: *Lithosphere floating on asthenosphere*

The theory further states that, where the continental masses (*Sial*) rise to form a mountain, the penetration of *Sial* downward to *Sima* is greater to compensate the excess mass. Moreover, where the continental mass is thin, the Sima layer draws near the surface or reaches the surface of the Earth and form the ocean floor. The principle of the theory postulates that, the height of the mountain is proportional to the depth of its root. Hence, the deeper the root, the higher the mountain. This state of balance between different parts of the earth's crust is called *isostasy* where equal mass underlies equal surface area. This concept helps to explain the existence of different topographic heights on the earth's surface.

The theory further states that any disturbance or restoration in the earth's crust will cause a sinking and uplifting movement of the Earth in order to balance itself. The disturbance can either be the erosion or melting of the accumulated snow while restoration can be deposition or accumulation of large snow or a volcanic hill. The theory therefore, describes the state of balance achieved between erosion and deposition.

Analogy of Isostasy theory

Analogy of Isostasy theory may be made with things like; floated icebergs, floated pieces of wood, and loaded and unloaded ships.

A floated iceberg: An iceberg or ice mountain is a large piece of freshwater ice that has broken off a glacier or an ice shelf and it is floating freely in open water. It may subsequently become frozen into pack ice (one form of sea ice). An iceberg always floats with a certain proportion of its mass below water surface.

The portion below water surface is compensation portion (Figure 1.15). If a layer of ice is somehow sliced off on the top of the iceberg, the remaining iceberg will rise. Similarly, the earth's lithosphere 'floats' in the asthenosphere the same as the iceberg floats on water.

Figure 1.15: *Iceberg floating in water*

Floated pieces of wood: The idea of isostasy may be grasped by considering a series of wooden blocks of different heights floating in water. If such woods are immersed in water, the long one will sink down more than the short one (Figure 1.16). Therefore, when wooden blocks are submerged, the height of the submerged part of the pieces is proportional to their respective emerged parts.

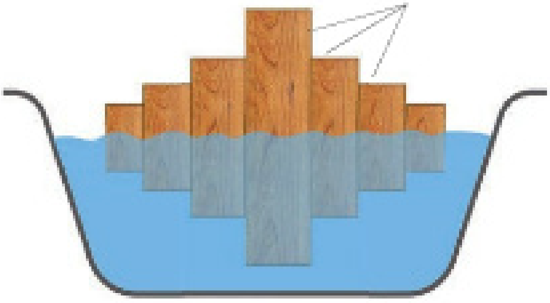


Figure 1.16: *Propotions of submerged pieces of wood to their respective emerged parts*

Loading and unloading ship: Floating ships show how isostasy affects the behavior of the crust as it floats on the heavy mantle rock. For instance, when cargo is transferred from ship 'A' to ship 'B', ship 'A' floats higher in the water and ship 'B' floats lower. This happens as a response to the process of loading and unloading of cargo (Figure 1.17).

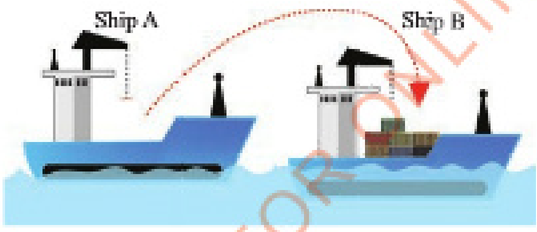


Figure 1.17: *Compensation process*

The Earth maintains its balance in the same way as ships. The process of loading and unloading the eroded materials of the earth's surface disturbs the balance on the Earth, therefore, the process of compensation takes place to restore it. The restoration process is extremely slow as it happens over thousands of years.

Isostatic movements and resulting landforms

There are two main movements of isostasy namely; vertical and horizontal movements. Vertical movement is also known as the movement of weight while horizontal movement is referred to as the movement of heat accumulation.

Vertical movement

It involves upward and downward movements of materials which enhance isostatic readjustment. The process is slow and takes thousands of years in maintaining the balance between oceanic mass and continental rocks. The existence of vertical movements can be indicated in various parts of the world, especially in the poles in connection to the formation of ice (ice age) and its melting. Therefore, it evidenced that, when the great ice caps are formed, the weight of ice causes the sinking or sagging of the crust, and when the ice melts, recovery gradually takes place, thus producing considerable changes in the level of the land relative to that of the sea. Examples of vertical movement can be evidenced in different parts of the world including, the continental shelf of Antarctica which is deeper than others as its water depth is about 750 metres compared with 180 metres around other continents. This may be a result of the weight of the present ice sheet.

Another example is the ice cap of Greenland whose landscape is covered by enormous weight of ice. Unless otherwise, the surface of underlying plateaus would be 1100 metres higher.

Furthermore, changes in weather and climate in northern Europe caused disappearance of ice sheets which caused a raised land and formed a beach in Scandinavia.

As the weight of continental rocks increased due to restoration, it resulted into extra weight which disrupted the balance in the area and finally cause the sinking. Several reasons cause extra weight including volcanic eruption, deposition of sediments, accumulation of snow and ice, the decrease of continental rock weight as well as denudation and melting of ice. *Volcanic eruption:* The outpouring of lava due to volcanic eruption that forms volcanic mountain/ arch may cause extra weight, hence a sinking movement. *Deposition of sediment:* When large amounts of sediments are deposited on a particular region, the enormous weight of the new sediments may cause the crust below to sink. *Accumulation of snow and ice:* The formation of ice sheets and the falling of snow for instance in the northern hemisphere like Arctic, Alaska, Greenland, Siberia or Antarctica in the South pole have caused the earth's surface to sink. *The decrease in continental rock weight:* If the weight of continental rocks is decreased because of erosion/denudation at the mountain and melting of ice in one area, it results in the uplifting of a given area. *Denudation:* When large amounts of materials are eroded away from a region, the land may rise to compensate the lost height and weight. Therefore, as a mountain range is eroded away, the reduced range rebounds upwards to a certain extent (Figure 1.18 a, b and c).

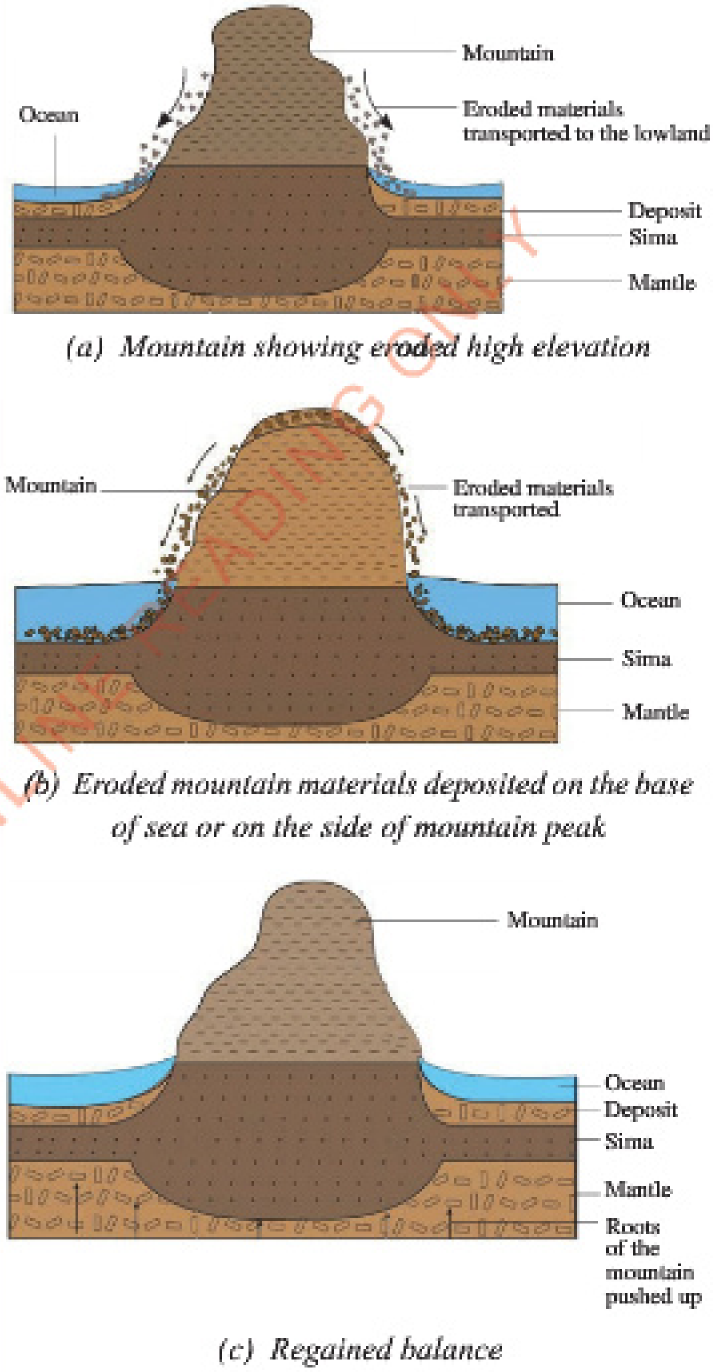


Figure 1.18: *Isostatic movements*

Melting of ice. Isostatic post glacial rebound is observed in areas once covered by ice sheets which have now melted. Example are found around the Baltic-sea and Hudson Bay. As the ice retreats, the load on the lithosphere and asthenosphere is reduced and they rebound back towards their equilibrium levels. In this way it is possible to find former sea cliffs and associated wave-cut platforms hundreds of metres above present day sea level. The rebound movements are slower such that the uplifting caused by the ending of the last glacial period continues.

Horizontal movement

This occurs when there is a horizontal flow of mantle from the depressed area to the uplifted area for adjustment. The adjustment involves a horizontal flow or convection current that involves accumulation of heat. It takes place in the simatic layer, especially in the asthenosphere where there is maximum plasticity (Figure 1.19). There is a continuous radioactive disintegration within the simatic layer specifically in the asthenosphere. The disintegration releases heat which may be accumulated and prevented by overlying more solid layer from escaping the earth's surface through radiation. The heat, therefore, makes the sima mobile resulting to the sinking of the *sialic* continents, hence periodic ocean transgression. On the other hand, if it happens that, the accumulated heat is degenerated due to various processes such as widespread volcanic activities, the sima becomes less fluidy and continents begin to rise. Therefore, it produces a regression of the sea, hence the exposure of former seafloor. These major transgressions and regressions in the Earth are affected by the warping and tilting of the sialic blocks.

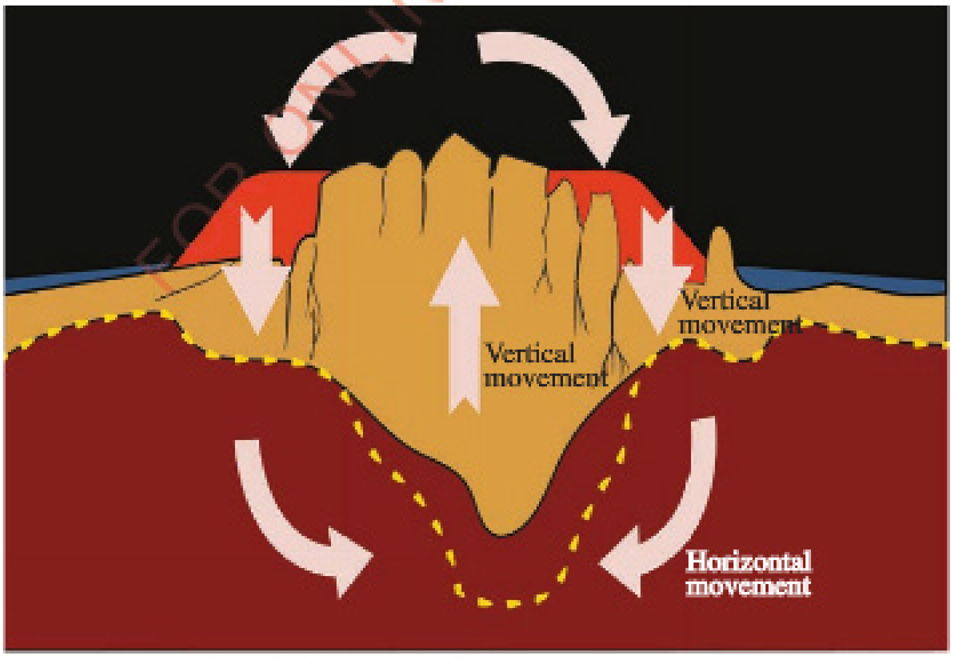


Figure 1.19: *Combined isostatic movements*

The evidence of isostatic movement on earth's surface

The evidences of isostatic movements can be seen in different parts of the world as explained below;

Presence of raised beach: The raised beach in Scandinavia which was covered by a vast ice sheet about 10000 years ago, is still rebounding isostically at the rate of up to 1 metre per century. The result is the formation of raised beaches which lie between 8-30 metres above present beaches. Similarly, the Ballyhillin beach in Ireland is rebounding isostatically to form raised beaches.

The evidence of coastal cities in Scandinavia as old constructed dock, have been uplifted rapidly enough and the docks which were constructed several centuries ago are now far from the shore. The coastal areas are rebounding to maintain balance due to the areas covered by vast ice sheet during ice age. Moreover, in East Africa, the raised beach was witnessed through past studies. For example, studies conducted in the 1970's marked some evidence of the raising shore line in Mombasa coastal area, in Kenya.

Depression formation: This is another evidence which means landform sunken below the surface area. Depressions may be formed by various mechanisms such a erosion-related. With this one, features like blowouts are created by wind erosion typically in either a partially vegetated sand dune ecosystem or dry soils. Moreover, area of subsidence caused by the collapse of an underlying structure such as sinkholes in karst terrain. In Greenland and Antarctica, the surface has been depressed below sea level by the weight of a glacial ice so as to maintain balance.

Land uplift: This is another evidence with which isostatic rebound has also occurred in different areas. For example in the eastern and central Canada and southern Ontario where the land has risen as much as 100 metres in the last 6000 years. During the ice age, the weight of the glaciers depressed the surface of the land. The depressed land began to rise when the glacier melted because of the isostatic adjustment.

Depth of continental shelf: An example of this evidence is the continental shelf around Antarctica, covered with water to a depth of about 500 feet (750 metres) compared with 600 feet (180 metres) around other continents. This may be a result of the weight of the present ice. The current Antarctic ice sheet acts as a surface load causing deformation of the Earth. This explains why continental shelf of Antarctica is deeper than that of the entire Antarctica continent including the subsided continental shelf due to presence of the Antarctic ice sheet as a significant load on the earth's surface compared to other continental shelf in the world. The Antarctic continent is almost isostatic equilibrium.

Existence of mountain ranges: Despite the continuous process of erosion, several mountains have maintained their heights. For instance, Mt. Kilimanjaro has maintained its height of about 5895 metres above sea level for thousands of years.

Existence of water bodies: Despite the continuous deposition activity which accumulate and deposit millions of tons of materials, water bodies like Indian ocean, Lake Victoria, and Lake Tanganyika have not disappeared. There is also, the emergence of emerged coast formed as a result of land uplift around the coast of Scandinavian countries.

Significance of the Isostasy theory

Several implications of the Isostasy theory can be provided. However, the most significant ones are; the theory signifies the state of equilibrium in the earth's crust with equal mass underlining equal surface area. Therefore, it gives an understanding on the earth's crust dynamic state as it is influenced by internal and external forces. Also, the relationship which is made as the crust floats on mantle just like the iceberg on the ocean or seawater is important in the understanding of plate tectonic and continental drift theories. Precaution can be taken depending on the nature of the climatic condition of a given area especially in the occurrence of ice sheet and the melting of ice. Furthermore, it provides a basis for predicting the future of the crustal state at any place on the earth's surface and understanding how different landforms were formed and mechanisms involved in their formation.

The effects of isostatic movements

The isostatic movements causes several effects on the earth's surface. The vertical and horizontal movements of isostasy result into occurrences of faulting and folding of the earth's crust. Faulting and folding have a prolonged impact of causing rift valleys, mountains as well as volcanic eruptions with their associated features. Despite the geomorphological effects of the Isostasy theory, still it is criticized due to its failure to explain the formation of inland and undersea mountains or the presence of volcanic islands.

Activity 1.5

Read books and other online sources, then write a summary elaborating the weaknesses of the following theories;

(i) Sea flow spreading theory.
(ii) Plate tectonic theory.
(iii) Isostatic theory.

Revision exercise

1. As a geographer student, why do you think it is necessary to learn about theories of landforms formation?
2. Examine the interrelationships between erosion and deposition in the context of isostatic balance.
3. 'Isostasy theory has never been realistic.' Argue for or against this view.
4. Using examples, explain the observation made by Alfred Wegener to support his continental drift theory.
5. Substantiate the contention that 'isostasy is isostatic adjustment'.
6. How does sea flow spreading theory relate to the plate tectonic theory?

Chapter
Two

Earth System

Introduction

The Earth is a system that comprises interconnected spheres that interact with each other. This system changes over time and can be observed on temporal and spatial scales. In this chapter you will learn about the four major components or spheres of the Earth and how they interact with each other. The competences developed will enable you to demonstrate an advanced understanding of the concepts that explain the interactions of the earth components. It will also enable you to conserve the environment and support life existence on Earth.

Think about

The complex and dynamic earth systems and their interactions

Earth as a system

Activity 2.1

Search from online sources or library about Earth's system. Illustrate layers of atmosphere and explain the characteristics of each layer.

The Earth is a complex system made up of interacting subsystems and consisting of both living and non-living things. The Earth system is composed of the atmosphere, hydrosphere, biosphere, and geosphere. These spheres are the main components that interact with one another within the Earth system. They are intricate, dynamic, and interconnected in such a way that changes in one component may result in the change of another component. As a result, it is essential to comprehend the components and the interactions that exist among them to predict how the Earth system may evolve in the future under different scenarios. Therefore, subsequent sections provide a detailed description of each sphere and the forms of interactions that exist among them.

Solar energy

The sun is the main source of energy which power the Earth systems as it drives many of the environmental processes operating in the four spheres of the earth system. The solar radiation, also known as *short wave* or *insolation* emitted by the sun travels through space from the sun in a form of electro-magnetic energy. At the outer limit of the atmosphere the solar radiation consists of visible rays of about 41% in total, gamma rays, alpha rays, x-rays and ultraviolet rays of about 9% and the longer infrared and heat rays of about 50%. During a clear day, there is net gain of heat from the Sun and temperature rises reaching its maximum in the early afternoon. During the cloudy day, incoming solar radiation is minimal, and during the night incoming solar radiation ceases while outgoing radiation continues.

Solar radiation balance

As solar radiation passes through the atmosphere, three processes take place which are absorption, reflection, and scattering.

Absorption refers to the process through which solar radiation is retained by a substance and converted into heat. The solar energy is trapped and retained by various atmospheric components such as carbon dioxide, water vapour, ozone, and particles of dusts and ice. As a result, the heat gained by atmospheric components enables them to emit their own radiation (infrared). Absorption of solar radiation by substances in the earth's atmosphere results in temperatures of utmost 1800°C. About 19% of the solar radiation is absorbed by the atmospheric contents. The absorbed proportion of solar radiation is so small (low) because they are in the form of short waves which pass with little check through the atmosphere.

An object or substance that is a good radiator is also a good absorber, and the vice versa is also true. For example, mineral materials like rocks and soils are generally excellent absorbers; snow and ice are poor absorbers, and dark coloured surface is a much more efficient absorber of radiation in the visible portion of the spectrum than light coloured surface.

Reflection is a process whereby sunlight is redirected back after it strikes an atmospheric substances (Figure 2.1). It occurs when the radiation hits on the substances like clouds that are available in the atmosphere. Redirection of sunlight causes a 25% loss of the insolation. The ratio of the incoming radiation to the amount of reflected sunlight is known as *albedo* and it is expressed in percentage. The albedo varies with cloud type from 30 – 40% in thicker stratus clouds and 90% in cumulo-nimbus clouds. However, only 10% of albedo reaches the atmosphere below cloud level. Furthermore, albedo varies over different land surfaces. The ocean and dark soil have less than 10%, coniferous forest and urban areas have 15%, grassland and deciduous forest have 25%, light-coloured deserts have 40% and fresh snow have 85%.

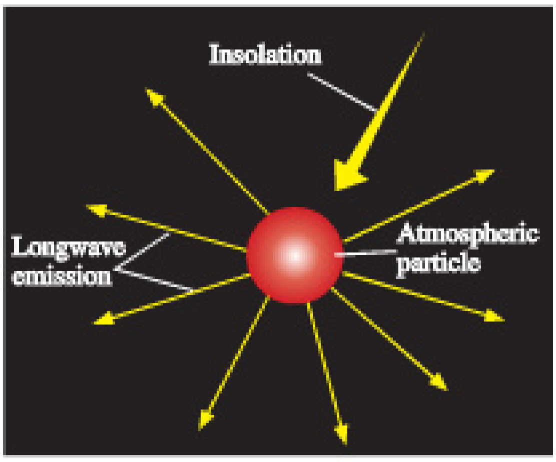


Figure 2.1: *Reflection of solar radiation*

Scattering is a process whereby, sunlight is diverted from its straight path upon striking atmospheric obstacles like clouds, dusts, gases molecules and water vapour. Scattering takes place in all directions, and about 8% of the incoming solar radiation is lost in that process. Scattering therefore, reduces the amount of incoming solar radiation reaching the earth's surface. Moreover, significant proportion of scattered shortwave is redirected back to space (Figure 2.2).

The scattering effects always depend on two factors which are the wavelength of the incoming radiation, and the size of the scattering particle or gas molecule. Based on such grounds, scattering has three forms which are *Rayleigh*, *Mie*, and *Non-selective scattering*. Rayleigh scattering occurs when the particles causing scattering are less or smaller than the wave lengths of radiation in contact. This form is therefore, wave length dependent.

Mie scattering is caused by solid particles such as pollens, dust, and smoke in lower atmosphere. It occurs when the size of the particles that cause scattering is similar to the wave lengths of the incoming radiation. Non-selective scattering occurs when the size of the particles are much bigger than the incident radiation, usually in lower atmosphere. Scattering is a non-wave length dependent. Particles responsible for this effect are atmospheric water droplets and larger dust particles. The common example of non-selective scattering is the appearance of white clouds as white. The presence of a large number of particles with a size of about 0.5 microns in the earth's atmosphere, results in shorter wavelengths being preferentially scattered. This factor causes the sky to appear blue as the colour corresponds to the wavelengths that are best diffused. If scattering was absent in our atmosphere the daylight sky would appear black.

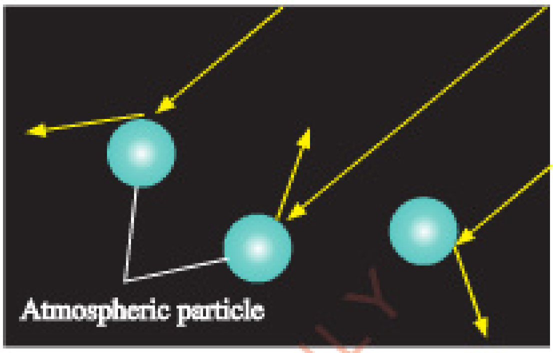


Figure 2.2: *Scattering of solar radiation*

It should be noted that, the presence of absorption, reflection and scattering processes of solar radiation, allows about 46% of incoming solar radiation to reach the earth's surface directly (Figure 2.3). The incoming solar radiation is converted into heat energy when it reaches the earth's surface. As the ground warms up, it radiates energy in a form of long waves back into the atmosphere where 6% is absorbed mainly by water vapour, methane, carbon dioxide and other atmospheric gases. The atmospheric gases, which have a tendency of absorbing the incoming short wave radiation from the sun and long wave radiation from the Earth are known as greenhouse gases. Out of all grenhouse gases, water vapour has a great impact in the absortion of incoming radiation and its conversion into heat energy. Without greenhouse gases, much of the outgoing radiation would have been lost and consequently the world temperature would be cooler than it is at present. Therefore, the existing mechanisms between the incoming and outgoing radiation creates a natural balance which is called *heat budget* or *heat balance*. However, the rise in greenhouse gases, notably carbon dioxide and other gases caused by human activities, is linked to global warming, which alters the natural heat balance, giving rise to the phenomenon known as *climate change*.

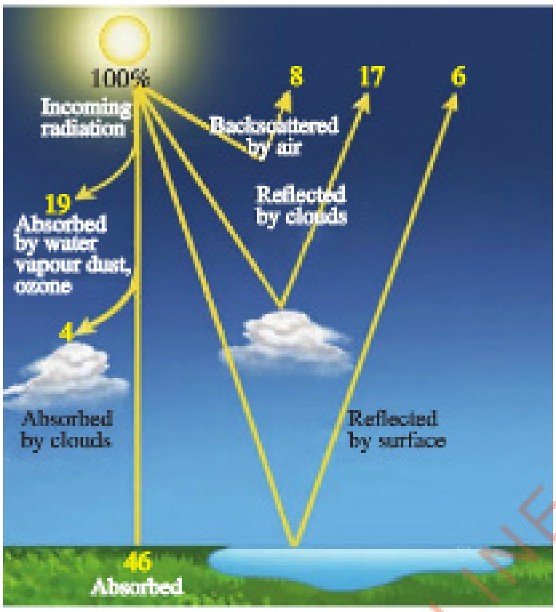


Figure 2.3: *Solar energy transfer*

However, the amount of energy received by the Earth is determined by astronomical factors including incidence angle of the sun rays, length of the day, transparency of the atmosphere, variations in the distance between the earth and the Sun, and the solar constant (the quantity of radiant). 46% of solar radiation that passes through the atmosphere and become available on the earth's surface is used for various purposes including heating the earth's surface and the lower atmosphere, evaporating and melting of ice, snow, and glacier, controlling weather and climate, as well as running photosynthesis processes in plants. Moreover, this energy is converted into food substances that support all forms of life on Earth. Therefore, it is this radiation from the sun that drives the Earth system.

Atmosphere

The word atmosphere comes from two Greek words; *atmos* meanly vapour and *sphaira* meanly sphere. It is a layer of gas surrounding the planet Earth or other materials of sufficient mass that are held in place by gravity. In other words, the atmosphere is comprised of a mixture of odourless gasses, suspended solids, and liquids that surround the Earth. The earth's atmosphere is about 600 - 1000 kilometres thick.

Atmospheric composition

The atmosphere constitutes both living and non-living things. Living things include bacteria while non-living things are gaseous (Table 2.1), dust, and particles. The atmosphere is composed of the following gases;

(a) *Nitrogen gas:* 78% and it dilutes oxygen and prevents rapid burning on the earth's surface. Living things need it also to make proteins.

(b) *Oxygen gas:* 21% and it is used by all living things for respiration. It is also necessary for combustion or burning.

(c) *Carbon dioxide:* 0.03% and it is used by plants to make oxygen. It also acts as a blanket and prevents the escape of heat into the outer space.

(d) *Argon:* 0.93% and it is used in light bulbs.

(e) *Water vapour:* 0.20 to 4.0% and it is essential for life processes and it also prevents heat loss from the Earth.

(f) *Trace gases:* They are found in very small amounts, including neon, helium, krypton, and xenon.

(g) The atmosphere is also composed of sulfur dioxide (SO_2), Nitrogen Oxide which when mixes with rain results into acid rain and Methane and Nitrous Oxide which are greenhouse gases.

Table 2.1: *Atmospheric gaseous composition*

Gas name	Chemical formula	Percent (%)
Nitrogen	N_2	78.085
Oxygen	O_2	20.95
Water vapour	H_2O	0.20 to 4.0%
Argon	Ar	0.93
Carbon dioxide	CO_2	0.03
Neon	Ne	0.0018
Helium	He	0.0005
Methane	CH_4	0.00017
Hydrogen	H_2	0.00005
Nitrous oxide	N_2O	0.00003
Xenon	Xe	0.0000087
Ozone	O_3	0.000004
Kryton	Kr	0.000114

Other compositions of the atmosphere

Water vapour

Water vapour is a gaseous form of water present in the atmosphere. At any time the amount of water vapour in the atmosphere ranges from 0.20 to 4 percent. Maximum amount of water vapour is found in hot-wet regions and its least amount is found in the dry regions. The amount of water vapour decreases with an increase in latitude and altitude. In the same way, its amount goes on decreasing with increasing altitude. About 90 percent of the total vapour lies below 6 kilometres and about 50 percent is within 2 kilometres of height. Water vapour is a source of precipitation through cloud formation. It has reflective/absorptive characteristics of the incoming radiation. It also contributes in keeping the global temperatures constant and it is one of the naturally occurring causes of greenhouse effect.

Dust particles

Dusts are small solid and liquid particles suspended in the air. These particles come from both natural and human activities. They include; fine desert sand/soils, ash, and disintegrated particles of meteors. Dust particles are in higher concentrations in temperate and subtropical regions due to dry winds in contrast to the polar and equatorial regions. Their concentration is high in the atmosphere during dry seasons since the sands/soils are loose and easily carried by winds compared to a rainy season when soils/sands are settled and compacted. In terms of size, coarse dust particles are plentiful near the surface while fine dust particles are found several kilometres above the surface. Generally, large amount of dust particles are found in the lower layer of atmosphere and in a suspended form. Dust particles act as hygroscopic nuclei over which water vapour of the atmosphere condenses to create clouds. They also absorb/reflect the incoming radiation.

Aerosols

Aerosols are extremely fine-sized solid particles which continue to be in a suspended form in gas for a long time. They are invisible, though they can be seen when they are in a high concentration in the atmosphere. Aerosols are grouped into two; hygroscopic aerosols which absorbs and retains atmospheric moisture and non-hygroscopic aerosols which are non-absorbing. Aerosols are released in the atmosphere from various sources, both naturally and humanly created. Aerosols includes; pollen, minute earthly dust, sea salt, carbon soot from burning fuels and volcanic dust. Concentration of aerosols is more over the industrial and urban areas where burning of fossil fuels and generation of smoke pump the aerosols in the air in high quantities. Hygroscopic aerosols form the nuclei for condensation and thus help in precipitation.

Exercise 2.1

1. How does the atmospheric radiation process support sustenance and flourishing of life on Earth?
2. How do human beings influence the radiation processes on the Earth system?

Layers of the atmosphere

There are five main layers in the atmosphere namely; troposphere, stratosphere, mesosphere, thermosphere, and exosphere and they are categorized based on temperature.

Troposphere

The troposphere is the first and lowest layer of the atmosphere that directly touches the earth's surface. It extends from the ground to an average of 12 kilometres although that extension varies from 8 kilometres at the poles to about 17 kilometres at the Equator. As altitude increases, the temperature in the troposphere decreases by 0.6°C for every 100 meters. This decrease is referred to as the environmental lapse rate. Additionally, the pressure falls with altitude as a result of the decrease in gravity. At the top of the troposphere, the air pressure is only 10% of that at sea level.

Throughout the troposphere, a variety of atmospheric phenomena occur, including; cloud formation, precipitation, and intense storms. As altitude increases, wind speed also increases, and nearly all water vapour is concentrated within this layer, making it the most humid part of the atmosphere. Additionally, the troposphere makes up a significant portion of the entire atmosphere's mass, with three-quarters of its total mass contained within this layer. Lastly, there exists a narrow transition zone known as the *tropopause* between the troposphere and the stratosphere, with a consistent temperature range throughout its 12-20 kilometres span.

Stratosphere

This is the layer above the tropopause, extending up to approximately 50 kilometres, and it is characterized by a gradual rise in temperature. This is due to the concentration of ozone (O_3), which absorbs ultraviolet radiation from the sun and provides a protective shield against harmful particles that typically burn up upon entering the earth's gravitational field. As altitude increases, winds become stronger while air quality worsens and air pressure continues to decrease.

About 90% of the ozone layer is located in stratosphere extending from the top of the troposphere to about 50 kilometres (31 miles). The Ozone layer, which is a molecule containing three oxygen atoms, forms a thin shield found between 16-50 kilometres (10-31 miles) above the earth's surface, protecting us from the sun's harmful ultraviolet (UV) radiation. Unfortunately, there is a growing concern that man-made fluorocarbon is contributing to the depletion of the ozone layer. This could have potentially devastating consequences for life on Earth. The *stratopause*, marking the boundary between the stratosphere and mesosphere, is located between 49 and 52 kilometres above the earth's surface. Despite its constant formation and destruction, the total amount of ozone in the stratosphere has remained relatively stable over the decades. The ozone layer is crucial as it absorbs harmful ultraviolet radiation, which can damage animal tissues. Additionally, the temperature in the stratosphere increases with height. This is a convenient layer for flying planes as it is free from turbulence that is common in the troposphere.

Activity 2.2

Search from library or internet sources about factors contributing to ozone layer depletion. Write a summary on how human activities contribute to the depletion.

Mesosphere

The mesosphere is a layer of the atmosphere that lies between the stratosphere and the thermosphere, at an altitude of 52 - 80 kilometres. This layer is known for its extreme cold temperatures, reaching as low as -90°C as the altitude increases. It also has the strongest wind speed reaching up to 3000 km/hr. Unlike other layers of the atmosphere, gases in the mesosphere are mixed instead of being layered by mass. The air is also incredibly thin, making it unsuitable for human breathing.

The mesosphere is a protective layer as most meteors and asteroids burn up before they reach the earth's surface, producing the shooting stars seen in the night sky. The *mesopause* marks the end of this layer and it is characterized by the lowest temperature, with no change in temperature observed.

Thermosphere

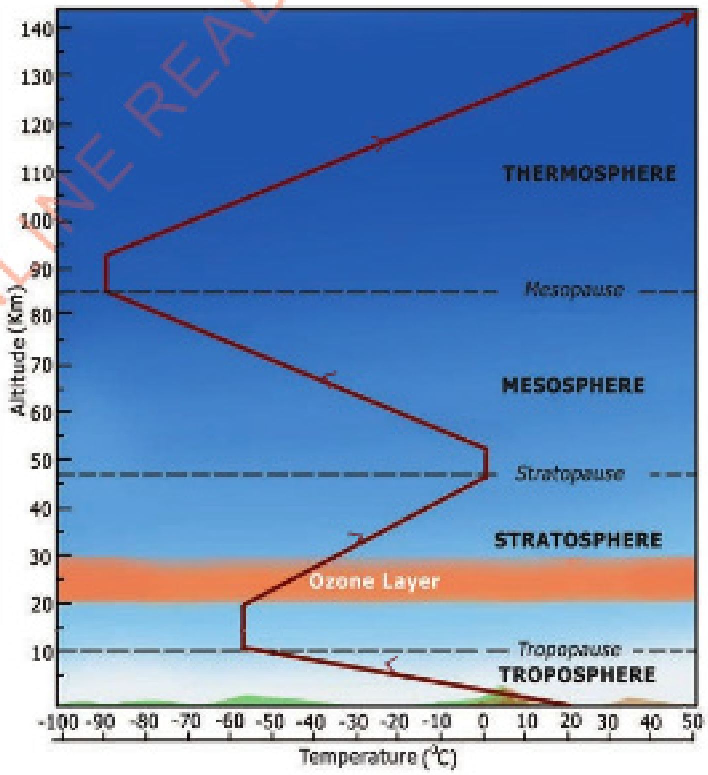
The thermosphere is the outermost layer of the homosphere and it constitutes the ionosphere. It extends from about 80 kilometres into space and boasts an extremely high temperature that can reach up to 2000°C. However, this temperature is not felt as the air molecules are widely dispersed. The atomic ions, like oxygen, present in this layer absorb a short wave of solar energy by absorbing oxygen and nitrogen, thus causing high temperature. The thermosphere is an almost gravity-free, thin layer of air that is primarily composed of helium, atomic nitrogen, and atomic oxygen, rendering it unsuitable for breathing.

Though the thermosphere is uninhabitable to humans, it is an indispensable component in protecting lives on Earth. It absorbs X-rays and extreme ultraviolet radiation, supporting space exploration and making communication easy. The charged particles present in the thermosphere facilitate long-distance communication via radio, as radio signals can travel in straight lines and bounce back and forth between the earth's surface and the ionosphere.

Exosphere

This layer, located at the highest altitude of the atmosphere, begins at about 700 kilometres and marks the edge of space. It is primarily comprised of hydrogen and helium along with nitrogen, oxygen, and carbon dioxide in trace amounts. It serves as earth's initial barrier against harmful sun rays and protects from meteors, asteroids, and cosmic rays. The vertical structure of the earth's atmosphere, including this essential layer, is illustrated in Figures 2.4 (a) and (b).

(a) Layers of the earth's atmosphere by height



(b) Vertical structure of the atmosphere by change in temperature

Figure 2.4: *Layers of the atmosphere and their vertical structure*

Hydrosphere

Hydrosphere is the area that includes all the earth's water in the state of liquid, frozen or floating ice in the upper part or beneath the soil. Hydrosphere covers about 71 per cent of the earth's surface. The seas and oceans make about 97% of the water on the surface of the Earth, while the fresh water found in glaciers, lakes, rivers, streams, wetlands, ponds, soil moisture, groundwater and polar ice caps and snow forms about 3% (Figure 2.5). Hydrosphere is referred to as a major setting of the earth's hydrological cycle. Freshwater amounts are essentially held at a constant level by the hydrologic cycle that is driven by the sun. The hydrological cycle continuously moves water around the planet by exchanging water molecules from the vegetation and oceans to the atmosphere and back to the around. It further hydrates life on the planet and transfer the energy from terrestrial to aquatic systems.

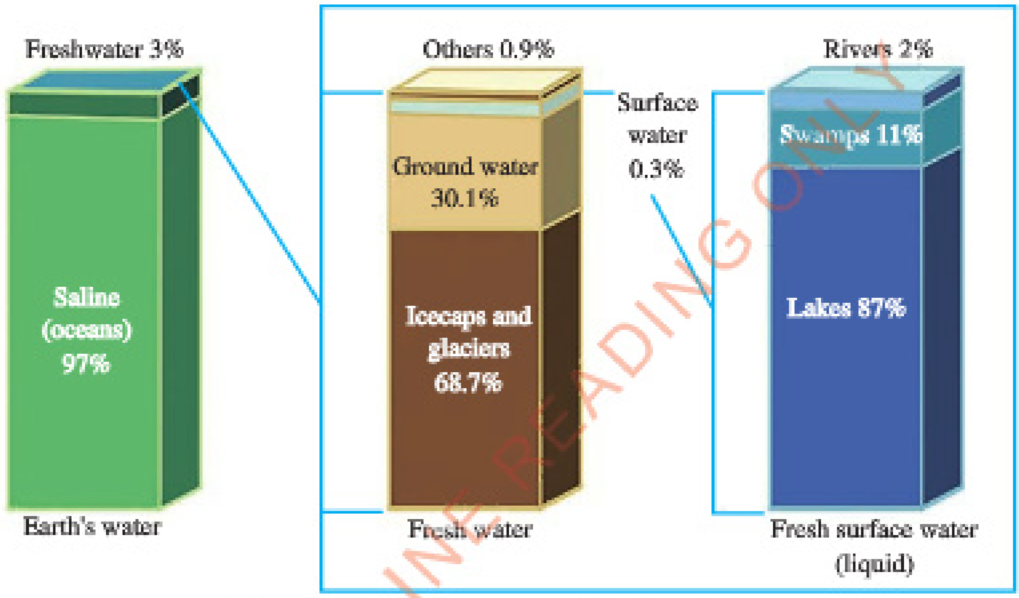


Figure 2.5: *Proportions of hydrosphere*

In some places on the Earth water exists in a form of solid ice or snow (Figure 2.6 a and b). These frozen places of the Earth are called *cryosphere*. The word cryosphere comes from the Greek word, *kryos* which means 'cold' and *sphaira* which means 'sphere'. The cryosphere are places where water is in solid form, where very low temperature freezes water and turns it into ice. The cryosphere forms the earth's most important fresh water reservoir, of which the inland ice of Antarctica accounts for about 80% of the cryosphere. This is the coldest region of our planet what influences our entire world's climate. Cryosphere covers most of the top and bottom of our planet in the polar regions. These are areas around the North Pole, the Arctic and the area around the South Pole, the Antarctic. Moreover, it covers many other locations on Earth far away from the cold poles including high elevations such as the snow on top of Mount Kilimanjaro found in Tanzania. Frozen soil can be found in the high mountains of the United States, as well as in the northern reaches of Canada, China, and Russia. The cryosphere expands during the cold winter months. Seasonal areas of the cryosphere include places where snow falls, and where soil, rivers, and lakes freeze. The cryosphere is central to the daily lives of people, plants, and animals. It has a great impact on the global cooling and distribution of cold winds without which life would cease to exist on the planet Earth.

(a) Snow

(b) Sea ice

Figure 2.6: *Water in the form of solid ice and snow*

Biosphere

Biosphere refers to the narrow zone of the Earth in which all life forms exist. The zone extends vertically into the atmosphere to about 10 kilometres, downward into the ocean to a depth of about 10.4 kilometres. The biosphere is composed of living organisms such as plants and animals. There is an estimation of at least eight million species of animals and plants existing on Earth. These include human beings, plants, micro-organisms and macro-organisms. Moreover, biosphere is not only about all the living organisms, but also about the remains of organisms that have died and not yet decomposed. It also includes the regions of the other parts of the Earth system (atmosphere, hydrosphere, geosphere) occupied by living organisms. Human activities in this layer for example, generate carbon dioxide and chloroflouro carbons which are of concern due to their respective effect in global warming and depletion of the ozone layer. Furthermore, agricultural, industrial and mining activities generate wastes that compromise the natural status of geosphere, atmosphere and hydrosphere.

Geosphere (lithosphere)

This is the solid portion of the Earth which includes the continental and oceanic crust and all other layers of the earth's interior. It also includes the rocks, sediments, soils, minerals, and landforms of the surface and the interior. Geosphere extends from the earths' surface all the way to the innermost layer of the Earth. About 94% of the geosphere is made up of the following elements; oxygen, iron, silicon, and magnesium. Despite its solid nature, the geosphere is a dynamic sphere which is always in constant motion and processes. This motion creates continents, oceans, and their landforms. The geosphere is in a constant process of rock cycle such as metamorphism, melting and solidification, weathering, erosion, transportation and deposition which are responsible for the constant recycling of rocks on Earth between sedimentary, igneous, and metamorphic states. Moreover, the geosphere includes the abiotic (non-living) parts of soils and the skeletons of animals that may become fossilized over geologic time.

Exercise 2.2

1. Explain the earth's surface as a whole does not accumulate too much heat.
2. Although the Ozone layer is located in the atmosphere, approximately 16 – 50 kilometres above the earth's surface, it plays a crucial role in supporting life on the Earth. Discuss its importance to life on Earth's surface.
3. How is studying layers of the atmosphere useful in the aviation sector?

Interactions among earth's spheres

There are several and complex interactions among the atmosphere, hydrosphere, biosphere, and geosphere. The most six forms of these interactions include; atmosphere-biosphere interactions, biosphere-hydrosphere interactions, hydrosphere-geosphere interactions, geosphere-atmosphere interactions, atmosphere-hydrosphere interactions, and geosphere-biosphere interactions (Figure 2.7). However, the interactions covered are not the only ones.

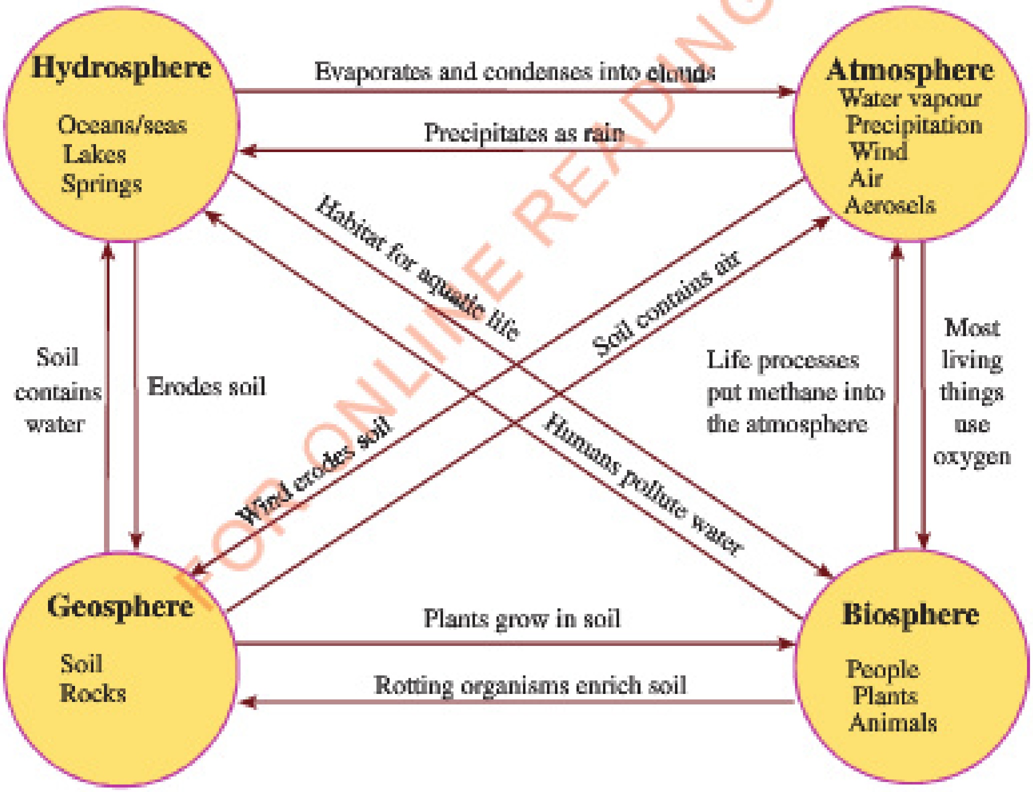


Figure 2.7: *Interactions among earth's spheres*

Atmosphere-biosphere interactions

The atmosphere and biosphere constantly interact with each other. However, these interactions are numerous and complex. A few examples of how these subsystems interactions, include the exchange of gases and the deposition of particulates.

Gaseous exchange; Earth system as a set of interacting spheres involves constant cycling or movement of gases through different media such as the atmosphere, geosphere, hydrosphere, and biosphere, collectively known as *biogeochemical* or *nutrient cycles*. The term biogeochemical is made up of three terms; *bio* meaning biosphere, *geo* meaning geosphere and *chemical* meaning elements such as nitrogen, oxygen, carbon, hydrogen, phosphorus, and sulfur. The flow and interaction of these elements in the Earth system plays an essential role in the existence of life on the Earth. Vital gas cycles exist between the atmosphere and the biosphere. Living organisms depend on air or gases for survival. For example, humans and other animals inhale oxygen from the atmosphere and exhale carbon dioxide back into the atmosphere during respiration. On the other hand, plants absorb carbon dioxide from the atmosphere for photosynthesis and release oxygen gas. These exchanges are what make the gas cycle continuous and maintain life on Earth. Moreover, the decomposition of vegetations such as trees and grasses releases gases like carbon dioxide, methane, and others into the atmosphere.

Carbon cycle

Elements of carbon are available in the atmosphere in the form of carbon dioxide. Plants receive about one quarter of the carbon dioxide from the atmosphere which with the support of sunlight is used for making food for plants through a process known as *photosynthesis*. Through this process, plants create carbohydrates in the form of food which is used as food by all living organisms. Carbon dioxide dissolving (absorbed) in the water bodies such as lake, sea and ocean, through direct air-water exchange is again collected in the form of lime on the Earth. After the dissolution of lime stone, carbon dioxide reaches the atmosphere again through a process called carbonization.

Furthermore, carbon dioxide is also added to the atmosphere naturally. When animals respire, living organisms decompose or decay and through human activities such as the burning of fossil fuels like coal, petroleum and natural gases. This is a continuous process through which carbon dioxide circulates between the four subsystems of the Earth (Figure 2.8).

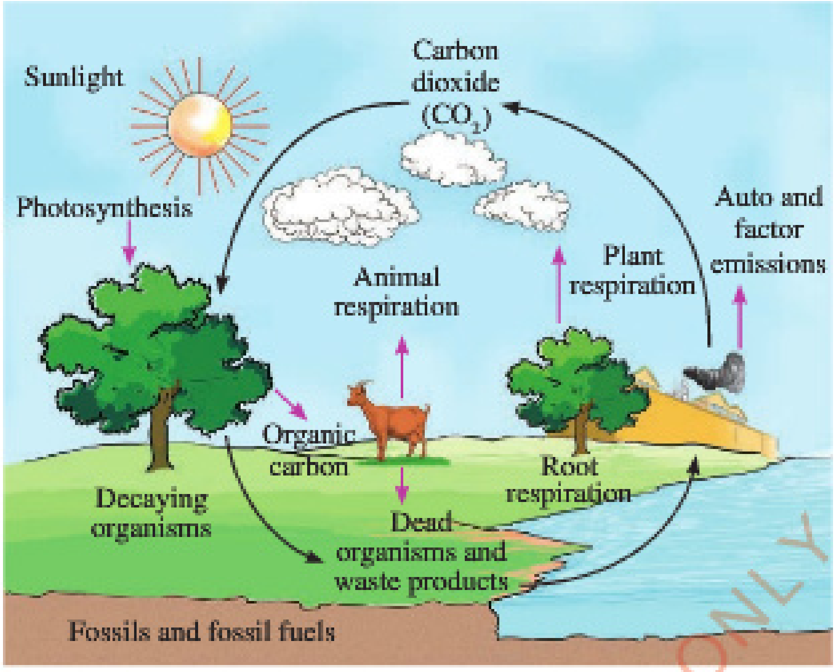


Figure 2.8: *Carbon cycle*

Oxygen cycle

The oxygen cycle is the process through which oxygen is produced and reused in the atmosphere (Figure 2.9). Oxygen which is the second most abundant gas in the atmosphere is produced by plants through photosynthesis with the support of sunlight. Through photosynthesis, plants convert carbon dioxide and water into oxygen and releases it into the atmosphere. The released oxygen is used by all animals for respiration. It is also used by human beings for burning fuels like wood, coal, and gas. The oxygen cycle occurs due to the exchange between the atmosphere and the oceans. The cycling of oxygen is also accomplished by the weathering of carbonate rock.

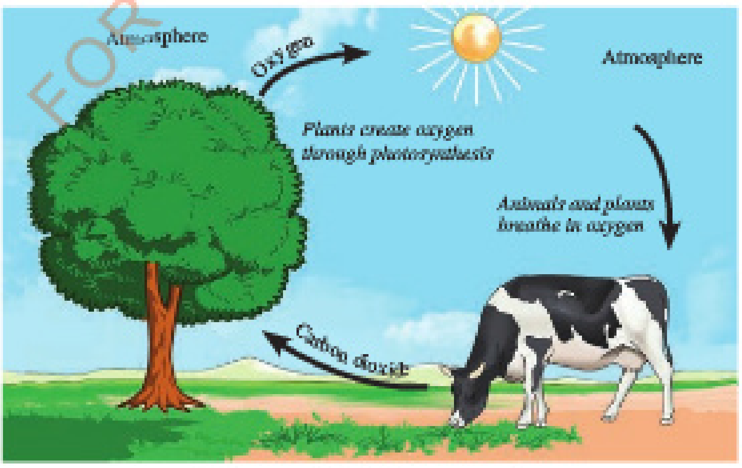


Figure 2.9: *Oxygen cycle*

Nitrogen cycle

Nitrogen is an important element for life and the largest constituent of the gaseous envelope that surrounds the Earth. The main source of nitrogen are the nitrates present in the soil. From the atmosphere, nitrogen enters bio components through the biological and industrial processes. Regardless of the process involved, nitrogen gets to plants through the biological process known as Biologreal Nitrogen Fixation (BNF). It involves the incorporation of nitrogen gas into the roots of some plants. Such plants are legimes, cloves, alfalfa, soybeans, peas, peanuts and beans. The bacteria living in the nodules around these plants roots chemically convert nitrogen in the air to form nitrates (NO_3^-) and ammonia (NH_3) and make it available to plants. Nitrogen compounds available in plants are transferred to animals through food chain. Animals that feed on the plants ingest the nitrogen and release it in organic wastes. Bacteria decompose dried plants and dead animals and produce nitrogen gas which goes back into the atmosphere. In this way, a continuous cycle of nitrogen gas is completed (Figure 2.10).

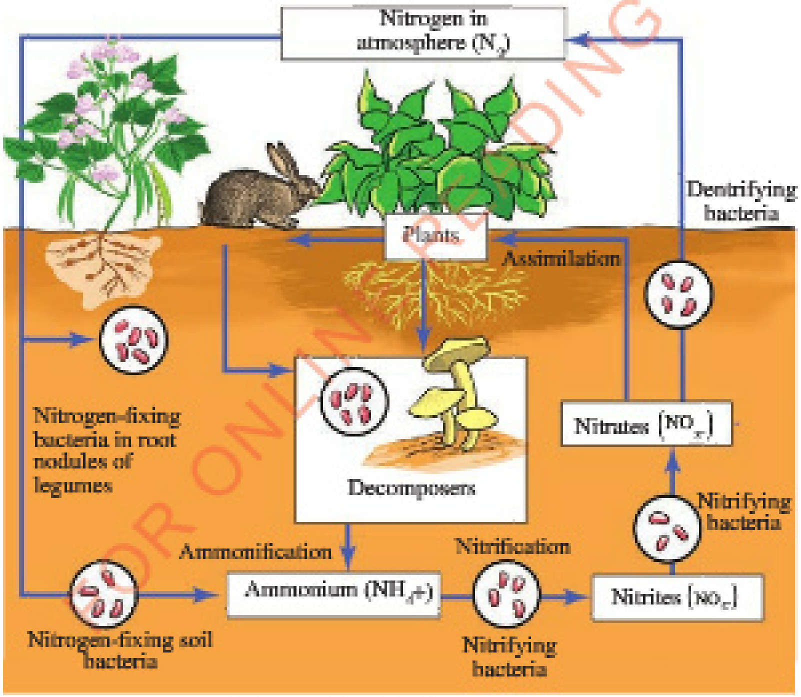


Figure 2.10: *Nitrogen cycle*

Deposition of particulates; as human beings engage in various activities such as agriculture, mining, and transportation, they may inadvertently produce fumes and aerosols that have a significant impact on the environment. These emissions can contribute to the deposition of particulates, which in turn affect atmospheric conditions.

Hydrosphere-biosphere interactions

The hydrosphere and biosphere share a complex relationship that impacts the environment. Their interplay can significantly influence the distribution and abundance of living organisms, as well as the state of the hydrosphere. Here are some examples of various interactions between these two spheres.

Life support: All living organisms depend solely on water. Plants require water during photosynthesis and for growth, while animals depend on water for hydration and other bodily functions.

Habitat: Many plants and animals live in the hydrosphere, including aquatic plants like water hyacinths and animals like fish and crocodiles.

Water cycle: The biosphere plays a crucial role in supporting the water cycle. For instance, plants release water vapour into the atmosphere through transpiration. Although human actions such as environmental conservation and management aid in evapotranspiration, unfortunately, deforestation practices by humans, especially on a large scale, negatively impact the water cycle.

Energy: The hydrosphere is an abundant source of energy for all life on Earth, especially humans. Through the use of water, humans can generate energy for a variety of purposes such as cooking, heating, transportation, and lighting. In Tanzania, Kidatu, Kihansi, Mtera, New Pangani, and Hale waterfalls have been the primary sources of hydropower for some years. However, with the completion of the construction of the Julius Nyerere hydro-power station (JNHS) at Stiegler's Gorge in Morogoro region the country is ensured sufficient energy supply.

Atmosphere-hydrosphere interactions

The Earth is fundamentally a water planet, defined by the intricate interplay between its atmosphere and hydrosphere. These two subsystems are deeply interconnected, and their interaction takes on many different forms. Examples of forms of interaction between these spheres include the following;

Atmospheric water circulation: The hydrosphere, consisting of rivers, streams, seas, and oceans, contributes water vapour to the atmosphere through evaporation. This water vapour then undergoes condensation to form clouds, ultimately resulting in precipitation that replenishes the evaporating surfaces.

Carbon sink: The ocean serves as a crucial carbon sink, as it can absorb more than 31% of the carbon dioxide gas (CO_2) present in the atmosphere. However, as atmospheric carbon dioxide levels rise, the ocean's carbon dioxide levels tend to follow suit. Chemical reactions occur when carbon dioxide is absorbed by the ocean, leading to an increase in acidity levels. This process is commonly referred to as ocean *acidification*.

Temperature regulation: The process of temperature regulation, also known as *heat sinking*, is a vital component in maintaining a balanced environment. Both the atmosphere and hydrosphere work together to achieve this. In instances where the atmosphere is warmer than the ocean surface, heat energy is transferred from the air to the ocean. Conversely, when the air is cooler, heat energy is released from the ocean into the air.

Geosphere-biosphere interactions

The biosphere and geosphere are interconnected through processes such as the carbon cycle and denudation.

Biological weathering: Biosphere and geosphere interact through weathering and erosion. Living organisms like animals and plants which form biosphere can break down rocks in the geosphere to form sediments. This not only affects the landscape but also releases nutrients into the soil.

Hydrosphere-geosphere interactions

The hydrosphere and geosphere work together in a way that supports the hydrological cycle and sustains life in the biosphere. Some of interactions that occur between the hydrosphere and geosphere, are;

Chemical weathering: Over time, water can weather down rocks through a natural process of erosion. This happens when rain water comes into contact with minerals forming the rock and breakdown the rock into sediments. The sediments or broken rocks can then be transported by water, wind, or ice, eventually settling in a different location. This can result in a change in the landscape's shape.

Water storage: Water is a vital component of earth's subsystems, as it continuously circulates through the atmosphere, biosphere, and geosphere. When surface water enters the soil, it forms groundwater that flows down to the water table due to gravity. Large portion of water is stored on the surface as surface water and into the ground as groundwater.

Atmosphere-geosphere interactions

While the atmosphere and hydrosphere are distinct, they are closely interconnected and they impact one another in numerous ways.

In terms of *energy exchange*, the atmosphere provides the geosphere with the necessary heat and energy for weathering and erosion. For instance, wind blowing leads to erosion. Conversely, the geosphere releases heat back into the atmosphere via conduction.

Additionally, water vapour in the atmosphere condenses to form clouds that eventually result in precipitation. This precipitation falls onto the geosphere, contributing to the formation of water bodies, which form part of the hydrological cycle.

Activity 2.3

1. With examples, use the knowledge developed from this chapter to create a summary using the table provided.

	Atmosphere	Biosphere	Hydrosphere	Geosphere
Atmosphere	X			
Biosphere		X		
Hydrosphere			X	
Geosphere				X

2. Use physical and online sources to read and write short notes about the following;
   (a) Ozone layer (b) Magnetosphere (c) Ionosphere
   (d) Homosphere (e) Auroras and Turbopause (f) Greenhouse effect
   (g) The relationship between greenhouse effect and climate change

Revision exercise

1. Results from current research activities show that Ozone layer is continuously destroyed by human development activities. As an expert in Earth system interactions, explain how you can contribute on the protection of ozone layer.
2. Explain how the interactions among the earth's spheres support lives of human beings and other living organism?
3. Explain how human actions alter the natural interactions of the earth's sphere, and outline the possible consequences of such alteration to human development.
4. With examples, argue for or against the statement that, "the atmosphere is never stable".
5. Substantiate the statement "humans impact all spheres of the Earth".
6. Why is the Earth considered to be a system?

Chapter Three

Endogenic processes of the Earth

Introduction

The earth's crust might seem fixed and rigid but evidence show that it is constantly moving as a result of forces exerted within. In this chapter you will learn about the internal forces of the Earth such as folding, faulting, vulcanicity, and earthquakes, and the resulting landforms. The competences developed will enable you to demonstrate an understanding of the internal forces responsible for formation of the major relief features of the Earth. It will also enable you to predict the occurrence and control of earthquakes and vulcanicity and their effects.

Think about

Forces operating from the earth's interior and the resulted resulting features

Concept of endogenic processes

Activity 3.1

Search videos or simulation from internet sources about endogenic processes of the Earth then write down the processes observed.

These are processes or forces operating from/within earth's interior and which can cause deformation of the earth's surface. These forces are mainly caused by internal heat and weight of the Earth. The Earth is constantly shaped by various forces that originate beneath the earth's surface. The driving force for the occurrence of geomorphic features is derived from rotation, tidal friction, radio activity and primordial heat from the origin of the Earth. The internal processes lead to the formation of earth's topographic features. These features include oceanic basins, ridges, trenches, mountain ranges, rift valleys, folds, faults, and vulcanic features. Endogenic forces largely operate within the earth's crust mainly in two ways which are horizontal and vertical movements. Understanding these forces and their resulting landforms makes one give the required consideration on the internal evolution and the surface history of a geologic body (Figure 3.1).

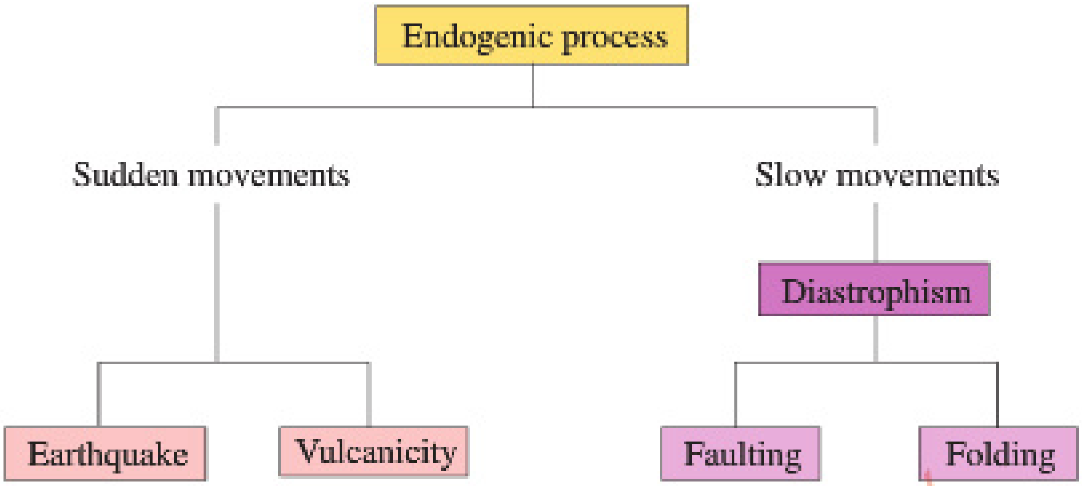


Figure 3.1: *Endogenic processes of the Earth*

The endogenic processes of the Earth are shown by several movements which are described below:

Earthquakes

An earthquake is a sudden shake or tremor shaking of the surface of the Earth, caused by the release of energy in the earth's crust which is stored in the rocks beneath and that which creates seismic waves. The seismicity of an area refers to the frequency, type and size of earthquakes that has occurred over a period of time.

Classification of earthquakes

Earthquakes are classified in three ways based on the causative factors. These factors can be either natural or human induced. *Natural earthquakes* are caused by natural processes such as vulcanic activity and plate movement. This involves both the plutonic earthquakes, occurring deep in the interior of the earth's crust and the volcanic earthquakes that occur near the surface of the Earth with eruptions of both explosive and fissure types. These types of earthquakes occur mostly in volcanic areas. Examples of these earth quakes include; the volcanic eruption of Mt. Etna in Italy which occurred in 1968; the tectonic earthquakes caused by the displacement of tectonic plates during faulting activity, for example, the earthquake that occurred in Gujarat India in 2001; isostatic earthquake which is triggered by sudden disturbance in isotactic balance at regional scale due to an imbalance in the geological processes. *Artificial* or *man-made earthquakes* are human induced earthquakes which are caused by human activities such as mineral and oil extraction using heavy explosives materials, dam construction activities using rock breaking tools like dynamites and water pumping.

Earthquake classification based on the areas or depth of focus. The area of focus is the depth at which an earthquake occurs. These kinds of earthquakes are grouped into three categories which include shallow earthquakes which are the ones whose focus is set or occurs from about 0-70 kilometres deep in the earth's crust. There is also, the intermediate earthquakes whose seismic focus is located at about 70-300 kilometres deep in the earth's crust. Lastly is the deep earthquakes which include seismic focus that occurs deep in the earth's crust between 300-700 kilometres from earth's surface.

Earthquake classification based on the rate or magnitude of human casualties. Under this classification there are three kinds of earthquakes. The moderate hazardous earthquakes which occur and cause human deaths of below 50 000 people. For example, the Kamakura earthquake in Japan in 1293 recoded the death of atleast 23 024 people. The highly hazardous earthquakes which cause human deaths ranging from 51 000 to 100 000 people. For example, the Chimbote earthquake in Peru in 1970 from which at least 67 000 people died. The last type is the most hazardous earthquakes causing human casualties above 100 000 people. An example of that earthquake occurred in Tang-Shan, China in 1967 whereby, atleast 240 000 people died.

Activity 3.2

Search simulations from online sources about earthquake occurrence. Observe the point where earthquake originates and the effects of its occurrence.

Nature of earthquakes

The point at which an earthquake originates is called *Focus*. The focus is divided into three categories, namely; *shallow*, *intermediate* and *deep* focus. Shallow focus ranges between the earth's surface and 70 kilometres depth, while intermediate and deep focus range between 70 - 300 kilometres and 300-700 kilometres, respectively. Most of the earthquakes occur at shallow depth. The point on the earth's surface immediately above the focus is called *the epicentre*. The epicentre is where the shock waves first hit the surface, it is these shock waves which give rise to an earthquake (Figure 3.2). The energy generated by an earthquake is called *seismic waves*.

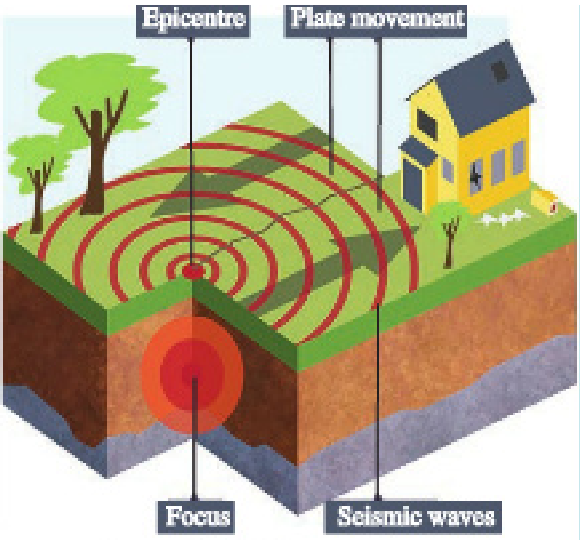


Figure 3.2: *The occurrence of earthquakes*

Seismic waves are the waves traveling through the earth's crust. Also, these waves are known as shock waves. The seismic waves are divided into two categories, namely; Body waves and surface waves.

Body waves

Body waves are seismic waves that travel in rocks within the earth's crust. They occur very far deeper into the interior part of the earth's crust where the earthquake originates. Body waves are further divided into two types, namely; Primary (P) waves and Secondary (S) waves.

Primary waves

Primary waves are also known as longitudinal or P-waves. These are type of body waves that travel through a continuum and are the first waves from an earthquake to arrive at a seismograph. They are also called compressional waves because the waves compresses and then stretches the particles of materials in the same direction that the waves are moving (back and forth) (Figure 3.3). They are very fast and can travel through both liquid and solid materials.

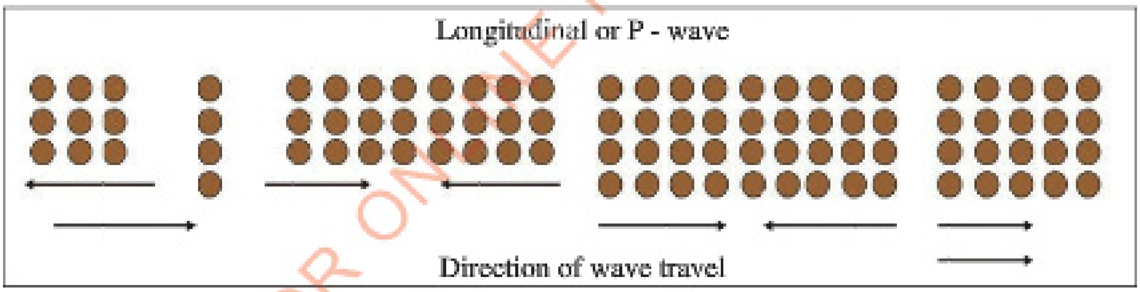


Figure 3.3: *The direction of the P- waves*

Secondary waves

Secondary waves are also known as shear waves or S-waves. In this type of waves, the particle motion is perpendicular to the direction in which the wave is moving. The motion is similar to a guitar string which is set in motion by being plucked in a direction that is perpendicular to the string (Figure 3.4). The vibrating molecules perpendicular to the direction of the waves produces an upward and downward movement that creates alternating high points (crests) and the low points (troughs). The waves move sideways to one another and this motion is called shear movement. The waves cannot travel in the liquid materials.

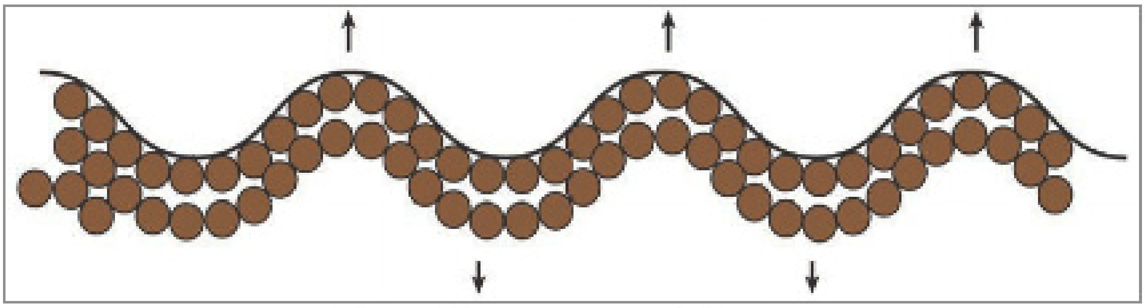
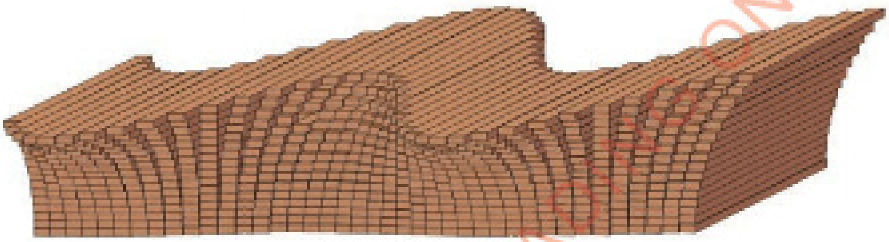


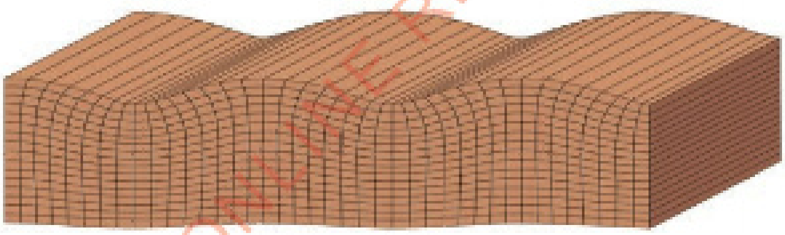
Figure 3.4: *Movements of S- waves*

Surface waves

These are waves traveling through the surface. The surface waves are divided into love (L) and Rayleigh (R) waves (Figure 3.5 a and b). Love waves cause the surface rocks to move from side to side at the right angle and to the direction of wave movement while Rayleigh waves cause the surface rocks to have a vertical circular movement very similar to that of water in a sea wave.



(a) Love waves



(b) Rayleigh waves

Figure 3.5: *Surface waves*

The causes of earthquakes

Earthquakes are primarily due to lack of equilibrium in any part of the crust of the Earth. There are various causes of earthquakes, these include; plate movement, volcanic eruptions, faulting and folding, up-warping and down-warping, gaseous expansion, contraction inside the Earth, and human activities. All these causes disturbs part of the crust of the Earth. However, majority of the earthquakes are associated with plate movements.

The surface of the Earth is in a continuous slow motion. The motion portrays plate tectonic movement whereby, the motion of huge rigid plates at the surface of the Earth are in response to the flow of molten rock materials within the Earth. The plates cover the entire surface of the globe. Since they are all moving, they sometimes collide against each other or sink beneath the other. Due to the collision of plates, faults and trenches occur. Good examples of this are the San Andreas Fault in California, Peru-Chile trench, Atlantic ridge and Indian ocean trenches. At such places the motion is not smooth as the plates strike on another at the edges but the two plates continuing to move, hence causing the distortion of their edges. As the motion continues, the strain builds up to the point where the rock cannot withstand any more bending. Eventually, the disintegrated rock lurches and breaks and the two sides move. The shaking that radiates out from the breaking rock cause an earthquake. The earthquakes may be accelerated by two major factors; the sliding of a tectonic plate over the other plate along fault-line, and the occurrence of volcanic eruptions which cause the movement of molten rock below or on the earth's crust, which then cause the movement of plates.

Therefore, the causes of earthquakes are collision between plates. This occurs when two plates collide and one the denser plate slides beneath the other. In that movement, the friction between the rough surfaces of plates occur and causes vibration of the Earth. There is also a sudden faulting that occurs when the plates are colliding and causing the rocks to bend. The breaking suddenly causes the rocks to vibrate back and forth. Another source is the diastrophic movement resulting from strains in the rocks of the crust on divergent boundary also causes shallow earthquakes. Volcanic eruptions is another source that causes earthquakes when magma moves below the surface with an explosion causing the crust to shake. Furthermore, there are other causes of earthquakes such as mass movement and human activities which include quarrying of rocks using explosives like dynamites and nuclear explosion and storing of huge volume of water in big reservoir. Human activities may generally cause disturbance that eventually may lead to an earthquake.

Distribution of earthquakes

Distribution of earthquakes is closely related to certain seismic zones of the Earth. Earthquakes mostly occur in three zones which are at the convergent plate margins, divergent plate margins, as well as in the oceanic trenches. In convergent plate margins, earthquake occurs when two plates collide with each other. The collision of the colliding plates can cause the edges of one or both plates to buckle up into a mountain ranges or one of the plates may bend down into a deep seafloor trench. A chain of volcanoes often forms parallel to convergent plate boundaries and powerful earthquakes are common along these boundaries. Furthermore, divergent plate margins occur when two tectonic plates move away from each other. Along these boundaries earthquakes occurrence is very common and the magma will rise from the earth's mantle to the surface to form new oceanic crust. It may also occur across oceanic trenches, island arc, and young fold mountain ranges. These are areas prone to earthquakes because they lie in the areas of crustal instability.

The common earthquakes regions are the great African Rift Valley which runs along the red-sea and through East Africa to Beira, the circum-pacific belt that extends from the West Coast of America to West Indies, the East Coast of Asia from the Aleutian Islands, through Japan to New Guinea and New Zealand. There is also the Alpine-Himalayan belt (the Mediterranean East Indies Belt) extending from West to East along the Mediterranean and Himalaya to join the circum-pacific belt near the New Guinea, and The mid-Atlantic ridge, a range of submarine mountains from Iceland through the Azores, Ascension Island and Tristan de Cunha. Generally, these zones are categorized as the zone of young fold mountain, the zone of faulting and fracturing, the zone of active volcanoes and along plate boundaries.

Methods of determining and recording earthquakes

As the shock waves travel out from the focus, they set of vibrations that may be as high as 200 per minute. The violent shaking of the surface rocks often causes great damage to the buildings and sometimes loss of life. The earthquake is measured and detected by using an instrument called *seismograph* or *seismometer* (Figure 3.6).

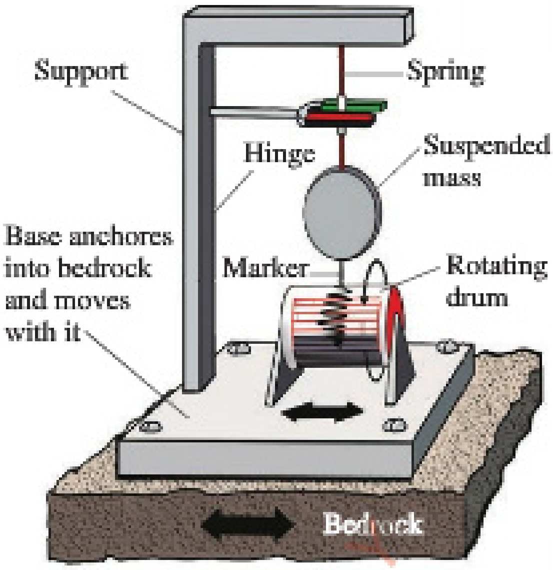


Figure 3.6: *Seismometer*

Seismograph records an earthquake even if its origin is thousands of kilometers away. The seismograph consists of the following: heavy suspended weight that remains motionless while the earth beneath it moves, a recording device similar to a pen which is attached to the weight; and a pen that touches a strip of paper which is wrapped around a revolving drum. When seismic waves vibrate the bedrock, the drum vibrate along it, but the heavy weight remains motionless. As the vibrating drum revolves motionless, the pen records a zigzag line on a paper. This instrument records three distinct types of vibrations: P-waves, S-waves, L- waves.

Measuring earthquakes

The severity of an earthquake can be expressed in terms of both intensity and magnitude. Magnitude is related to the amount of seismic energy released at the hypocentre (focus) of the earthquake whereas intensity is based on the observed effects of ground shaking on people, buildings, and natural features.

Earthquake magnitude: The magnitude is the number that characterises the relative size of an earthquake. Magnitude is based on the measurement of the maximum motion recorded by a seismograph. Several scales are used to measure the magnitude which include local magnitude (ML), Richter magnitude (RM), surface-wave magnitude (Ms), body-wave magnitude (Mb), and moment magnitude (Mw). All magnitude scales should yield approximately the same value for any given earthquake.

The moment magnitude scale

Moment magnitude scale is used to provide accurate estimates for large magnitude earthquakes. This scale works over a wide range of earthquake sizes and it is applicable globally. The scale is based on the total moment release of the earthquake and it is derived from modeling recording of earthquake at multiple stations. Moment magnitude estimates the same as Richter magnitudes for small to large earthquakes. However, the moment magnitude scale is capable of measuring M8 (read 'magnitude 8') and greater events accurately. The moment magnitude (Mw) scale is regularly applicable to all sizes of earthquakes.

Richter scale

One way of measuring the severity of an earthquake is by measuring its magnitude on the Richter scale, which ranges from 0 to over 8.6. Richter scale was discovered by an American seismologist, Charles Richter in 1935. Magnitude is a measure of the amount of energy released in the earthquake and it is indicated by the amplitude (size) of the vibrations when they reach the recording instrument. The Richter scale determines the rate of an earthquake as insignificant (less than 4 on the Richter scale), minor (4-4.9), damaging (5-5.9), destructive (6-6.9), major (7-7.9), and great (over 8). For example, the Hokkaido earthquake of September 2003 measured 8 on the Richter scale in Japan. The Richter scale does not vary from one place to another thus, it is uniform.

Earthquake intensity: This is the degree of damage which diminishes as it moves away from the main shock source zone. The intensity is the measure of shaking at each location and it varies from place to place. Mostly, it depends on the distance from the epicentre. Intensity is expressed in Roman numbers, for example, V-IX and it is based on the level of observed severity. Intensity is measured through observations of people who experienced the earthquake and the amount of demage that occured. It is also measured through instrumental data collected from different measuring stations. The observations and collected data are calculated and an estimated intensity is established. The scale is used to show the intensity of the earthquake and the effects or damage caused by the earthquake.

Factors determining the degree of damage caused by earthquake

The degree of damage caused by an earthquake depends on the following factors:

Location: An earthquake that hits a populated area is more likely to cause more damage than the one that hits on unpopulated area or the middle of the ocean.

Magnitude: The more energy released by an earthquake, the more destructive it can be.

Depth: Earthquakes can happen anywhere at a depth of about 700 kilometers from the earth's surface. In general, deeper earthquakes are less damaging because their energy dissipates before it reaches the surface.

Distance from the epicentre: The epicentre is the point at the surface where the earthquake originates and it is usually the place where the earthquake's intensity is the greatest. Intensity of an earthquake will therefore depend on how far the epicentre is from the population.

Local geologic conditions: The nature of the ground at the surface of an earthquake such as loose, sandy, soggy soil can have a profound influence on the level of the damage. That is why buildings constructed on loose sediments 100 km from an epicentre may experience more damage than buildings built on granite.

Architecture: Even the strongest buildings may not survive a bad earthquake, but architecture plays a big role in what and who survives a quake. For example, the January 2010 Haiti earthquake became worse to poor construction, and weak to cemented buildings. Wood frame buildings, for example, may suffer less damage than buildings made of materials that are cemented together. In an earthquake, some flexibility within the individual structures is desirable.

The consequences of earthquakes

The common effects experienced from earthquakes depend on where the earthquake occurs. When it occurs in urban, densely populated, and highly developed areas it will cause much devastations. Whereas in rural areas with sparse population and underdeveloped places, less devastations will be experienced. The consequences are:

Landslide: Earthquakes can cause landslides, especially on slopes that are already weak. A good example is the Las Colinas slide in the city of Santa Tecla, El Salvador, which was triggered by a M7.6 offshore earthquakes in January 2001.

Destruction of properties and resources: Earthquakes can destruct water and sewage systems. This threatens lives of people. For example, during the Great San Francisco earthquake in 1906 most of the damage was caused by fire that could not be controlled because the water infrastructure had broken. Earthquakes may also cause destruction of buildings especially when the buildings are made up of soft sediments, and multi-stone materials. For examples, the earthquake that occured in Kagera region in Tanzania in September, 2016 caused the collapse of buildings largely made up of soft sediments. The Kagera earthquake measured a magnitude of 5.9 Mw with an intensity of VII. Moreover, the destruction of buildings can be enhanced by liquefaction processes. Soil liquefaction occurs when saturated or partially saturated soil lose strength and stiffness in response to an applied stress from an earthquake.

Fire outbreak: Fire occurs during ground shaking due to the disruption of gas and electrical lines. For example, most of the damage during the earthquake in San Francisco in 1906 was caused by massive fires in the downtown area of the city. In that incident, 250 000 buildings were damaged by fire which was fuelled by gas leaking from broken pipes.

Tsunami: Tsunami is caused by an earthquake or volcanic eruption on the seafloor. During an earthquake, seismic waves can produce powerful ocean waves. These waves tend to be very deep, with long distance between the peaks. In deep water there may be no noticeable evidence of the tsunami at the surface but when the wave enters shallow waters, the energy is forced to the surface and produces a tall wave that travels at high speed and moves far inland. Tsunami can cause death to both human and animals. For example, on 26^{th} December 2004, an earthquake occurred in Sumatra, Banda Aceh in Indonesia and caused a tsunami which killed over 250 000 people. The affected areas were the Indian Ocean coastline and 11 people were reported to have died in Tanzania.

Stress and panic: During the occurrence of an earthquake people usually panic, run away, jump out through windows and exhibit many other unusual behaviours. Although earthquakes last for a very short time, a large number of people suffer psychological traumatic consequences which may last for many years. Moreover, many people lose their relatives and others are forced to relocate to either temporary or permanent homes.

Damage to transportation and communication systems: Earthquakes cause damage to transportation and communication systems such as railways, highways, telephone lines, electrical lines, roads and other accompanying structures which include bridges, tunnels, embankments, retaining walls, overpasses and underpasses. Such damage results to economic loss, breakdown of timely food, medicines, and equipment supply which in the final analysis affect human population.

Damage to industrial and other technological systems: Earthquakes cause damage to industrial and other technological systems. The damage may cause some systems to fail to operate. Failure of some technological systems especially those using toxic, explosive, and inflammable materials may result into other dangers that include loss of human lives and serious environmental damage.

Precautionary measures to prevent damage from earthquakes

Most of the earthquake incidents occur as a result of natural processes, hence it is difficult to predict their occurrence. Therefore, it is important to look at the historical records of earthquakes and conduct a geological field research to get information about the recent activity of a fault line such that the time frame of the last movement along a fault. Moreover, the actual prediction of earthquakes has to be based primarily on precursor phenomena events that precede an earthquake as well as on the pattern and frequency of earthquakes in an area. There is also a need to construct buildings which have protective mechanisms from earthquake disasters.

Earthquake warning signs

There are several signs that can be observed before an earthquake occurs. However, most of these signs are associated with earthquakes caused by volcanism. Some of these signs include; thermal indicator, water indicator, seismo-electromagnetic indicator, animal indicator and human indicator.

Thermal indicator: A few months before the occurrence of an earthquake, the average temperature of area keeps increasing. Often on the day of an earthquake the temperature of the place may record about 5 to 9°C above the average temperature of a day.

Water indicator: A few days (1-3 days) before an earthquake, there is a sudden rise or fall in the water level in wells to as high as one meter. Water in a well may also turn muddy and a few hours before the earthquake, a fountain appears inside a well or in the ground. There will also occur a sudden increase or decrease of water flow in rivers 1 to 2 days before the earthquake.

Seismoelectromagnetic indicator: Before the earthquake the subsurface temperature rises and it reduces the geomagnetic fields and adversely affects the propagation of the electromagnetic waves. This effect is experienced on radio, television and telephone signals 10 to 20 hours before the earthquake. Mobile telephones stop functioning about 100 to 150 minutes before the quake.

Animal indicator: Between 10 and 20 hours before the occurrence of the earthquake, the entire animal kingdom become highly restless. They fear and move to safer places. On the other hand, birds do not perch on trees but move about at low height emitting a shrill noise. Rodents like rats and mongooses go into panic and domesticated animals like cows, dogs struggle against being tied up and may even turn on their owners.

Human indicator: Doctors and nurses have observed that some sensitive patients in hospital become highly disturbed before an earthquake. They exhibit a sudden rise in blood pressure, heart trouble, headache, migraine and respiratory disorders. The number of child deliveries in hospital also increases for about three to five times.

Precautions to be taken during an earthquake

The following are some precautions to be taken to minimize injuries or deaths of human beings when an earthquake occurs;

(a) Go to a safe place where things will not fall on you. This may be away from windows or tall and heavy furniture; such safe places are known as assembly areas.

(b) Wait in your safe place until the shaking stops, then check if you are hurt and check other people around you and help if need be.

(c) Move carefully and watch out for things that have fallen or broken, and be ready for additional earthquake called the *aftershock*.

(d) Be on a lookout for fire.

(e) In the process of leaving a building after it has shaken, use stairs and not an elevator. If you are in an elevator, stop it at the nearest floor and get out immediately.

(f) If you are outside during the earthquake, move away from buildings, trees, and power lines, crouch down and cover your head.

(g) If you are driving, do not stop suddenly. Turn on your car hazard light to give an alert to other drivers, then slow down slowly.

(h) In public buildings, follow attendant's instructions.

(i) If in a train, do not rush to the exit. Hold on tightly to the strap or a handrail.

Tsunami

Tsunami is a Japanese word meaning 'harbor wave'.

It is a series of ocean waves generated by any disturbance that displaces a large water mass. Such disturbances include earthquakes, volcanic eruptions, and earth and submarine landslides which displace large water masses.

Earthquakes: This is generated by the movement of plates along the fault line. Usually, Tsunami occurs when the earthquake magnitude is 7.5 or greater at a subduction zone where oceanic plate slides under the continental plate. There are four necessary conditions in which an earthquake can cause tsunami. These conditions include the occurrence of an earthquake beneath the ocean that allows materials to slide. The earthquake magnitude of 7.5 Richter scale and above which must rupture the earth's surface at shallow depth of less than 70 km below the surface and which is caused by the vertical movement of seafloor.

Volcanic eruption: Violent volcanic eruptions cause disturbances which displace a great volume of water and generate extremely destructive tsunami waves in the source area. Usually these mechanisms generate waves by a sudden displacement of water caused by volcanic explosion. For example, one of the largest tsunami was recorded in 1883, after the explosion and collapse of the Krakatoa Volcano in Indonesia.

Sub-marine landslides: These are rare events but have been witnessed in Alaska. The most famous occurrence was witnessed on 9th July 1958, in Lituya bay on Alaska's southeast coast, when a nearby earthquake caused 40 million cubic yards of rocks to slide over 2000 feet equal to 0.6 kilometres into the narrow inlet of Lituya. Once tsunami is generated it can travel across an entire ocean and cause devastation far from its source.

In the open sea, tsunami travels at several hundred kilometers per hour. It commonly goes unnoticed as it passes beneath ships. It happens so because the waves are usually less than 1m high and the distance between wave crests is typically hundreds of kilometers. In any case, the tremendous energy possessed by a tsunami is concentrated on a shoreline when it hits either as a large breaking wave or in some cases, as what appears to be a very rapid rising tide. For instance, when it occurred in South East Asia (Malaysian, Singapore, Indonesia and parts of Thailand and India) on 26th December 2004, it is believed that more than 230 000 people died. Generally, Tsunami causes high rate of mortality, illness and injuries leads to the spread of infectious diseases and creates physiological traumas.

Activity 3.3

Read from various sources about areas affected by Tsunami. Identify the effects of the phenomenon and measures taken to overcome them.

Exercise 3.1

1. Assume you are invited as a seismologist in an area affected by an earthquake. What precautionary measures will you advise the community members to take in case of other earthquakes occurrences in the future?
2. Discuss how earthquakes contribute to the deformation of different landforms.

Vulcanicity

The term vulcanicity is a range of processes by which molten, gaseous, or solid rock materials are intruded into or extruded onto the earth's surface. The molten rock materials are called *magma* before reaching the earth's surface but after reaching the earth's surface they are called *lava*. Vulcanicity or vulcanism includes all processes resulting into the formation of *volcanoes* and *lava plateaus* (as extrusive vulcanicity), and *intrusive igneous features*. Volcano is a hill or mountain formed by the eruption of molten materials from a central opening or vent in the crust. Lava plateau is an upland with a generally level summit, and it is made of successive layers of lava. Volcanoes and lava plateau are extrusive vulcanic features formed onto the surface of the Earth after the cooling and solidification of the molten materials from the earth's mantle. Molten materials or rocks originate in the upper plastic layer of earth's mantle. Although the material in the mantle has a high temperature, it is kept in a semi solid state because of the greater pressure exerted upon them. However, if this pressure is released locally by folding, faulting or other movements at plate boundaries, some of the semi-solid materials become molten and rise, forcing their way through weaknesses in the crust or onto the surface, where they cool and solidify. Basically the nature of volcanic eruption is of two types which are fissure, and central eruptions. Fissure eruption is the type of eruption where lava erupts from a long, narrow, crack or fissure. Lava flow from the fault line spreads to form lava plateaus. Many fissure eruptions are associated with basaltic lava floor. Central eruption is on the other hand the type of volcanic eruption where lava is expelled through a central vent. It gives rise to volcanic cones and domes, with or without summit craters. Volcanoes may be single, form clusters or be distributed in chains. The Mount Kilimanjaro is an example of an isolated, single, giant volcano.

Classification of volcanoes

Volcanoes can be classified based on mode of eruption and the period of eruption. Based on the mode of eruption, there is central eruption and explosive eruption or quite eruption. The central eruption is usually violent and explosive eruption of lava. Volcanic ashes and fragmental materials pass through a pipe under the impact of violent gases. Examples of central eruption volcanoes are the eruptions in Mount Kilimanjaro, and Mount Oldonyo Lengai found in Tanzania. With quiet eruptions, lava flows quietly through fissure, fracture, and fault due to low pressure. Fissure volcan are also quiet eruption. An example of this eruption is Laki fissure eruption of 1783 in Iceland.

Volcanoes are classified according to their period of eruption, namely; active, dormant, and extinct volcanoes. An active volcano is the volcano that erupts frequently. Examples are the eruptions in Mount Nyiragongo in Eastern Democratic Republic of Congo and Mount Oldonyo Lengai in Tanzania. Volcano is said to be active only when it has erupted within five hundred years. A dormant volcano also known as sleeping volcano is a volcano that has infrequent eruptions. Examples of dormant volcanoes are that of Mount Kilimanjaro and Mount Meru in Tanzania and Mount Kenya. Extinct volcano is the one that has ceased to erupt for a very long time in history. The volcano in Mount Rungwe in Tanzania is an example of an extinct volcano. Like many other landforms, volcano is also altered by weathering and erosion, particularly at its extinct stage such that with time most of it, if not all of the volcano may have been removed.

Volcanic materials

Volcanic materials include lava, vapour (gas), fragmental rock particals and ashes. This materials are known as lava when they are ejected on the earth's surface accompanied by gases. The molten rock is called magma when it is below the earth's surface. The chemical nature of the materials can either be acidic or basic (Table 3.1). Acidic materials are extremely viscous (sticky) and less mobile because they contain a lot of silica. The basic materials are fluidy (less viscous), mobile and they flow a long distance before solidifying. Basic materials contain low melting point and less silica. Lava and magma are classified on the basis of light (felsic) and dark coloured (mafic) minerals.

Table 3.1: *The chemical composition of volcanic rocks*

Chemical nature	Silica (%)	Degree of mobility	Example of rock type
Acid	More than 66	• Extremely viscous and less mobile. • Solidifies rapidly at high temperatures over 850°C	Rhyolite
Intermediate	52-66	• Fairly viscous. • Unable to flow far before solidification.	Trachyte
Basic	45-52	• Very fluidy and mobile. Able to flow long distances before solidifying.	Basalt

Vapour and gases: Volcanic eruption emit vapour and gases. Vapour and steam constitute about 60% to 90% of the total gases emitted during eruption. The vapour includes phreatic vapour and magmatic vapour while gases emitted include the gaseous compounds of sulphur, hydrogen and nitrogen. Most of the gases and vapour are scattered into the atmosphere. The interaction between the gases contained in molten magma generates great heat within the ascending lavas and so maintains high temperature within lava pods in a crater. Moreover, gas acts as a lubricant which leads to the loss of much gas from the lava which increases lava's viscosity.

Pyroclastic materials: The pyroclastic materials are also known as solid materials. When an eruption is accompanied by a series of explosion, solid materials are ejected as pyro clasts. They may include fragments of rocks when the pipe is blown through the crust, angular fragments, lava cooled down in the pipe and fine materials such as pumice, cinder, lapilli, ash and dust.

Liquid materials: These are usually the most important product of an eruption which reaches the earth's surface as lava (the molten magma). The nature of volcanic landforms, depends on the nature of eruption and lava. For example, some lava contains much silica such as acidic lava with high melting point. They are very viscous as they solidify in the vent and cause recurrent explosive eruptions. There is also basic lava which is poor in silica since it is rich in iron and magnesium minerals. It has a lava at melting point which flows at a considerable distance before solidifying. Such lavas tend to produce much flatted zones of great diameter and the eruption is quite without much explosive activity, as it is the case in shield volcano.

Resulting landforms of vulcanicity

There are two major types of features or landforms associated with vulcanicity; which are intrusive and extrusive features.

Intrusive vulcanic features

When magma is forced to the surface only a small amount of the mass actually reaches that level. Most of the magma is intruded into the crust where it cools down, solidifies, and forms a range of features or landforms. These features are often exposed at the surface by erosion. Intrusive or plutonic features formed within crust, include; batholith, sill, dyke, laccolith, lopolith and phacolith.

: This is a dome or a very large mass of igneous rock which is formed by the cooling down and solidification of magma deeply in the heart of a mountain range, in the crust. They have a coarse grained texture and in most cases they are granitic in composition. Normally they form surface features after the removal of the overlying materials through denudation. Batholiths have irregular shape with side walls that incline steeply against the host rock (Figure 3.7). The most common examples of batholiths are Sierra Nevada Batholith and Idaho batholith in the United States of America, Aswan Granite batholith in Egypt, and Cape Coast batholith in Ghana.

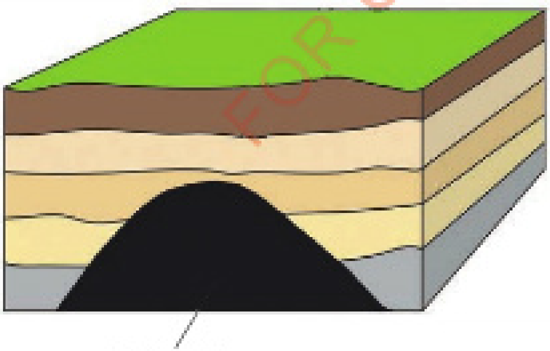


Figure 3.7:

A sill is a sheet of magma which is formed when igneous materials solidifies horizontally along the bedding planes (Figure 3.8). Usually they are concordant to rock structure and they can be of any thickness and they extend many kilometers. Sill is made up of rock composed of all types. There are three types of sill depending on the nature of magma intrusion. The types are simple, multiple and composite sills. Some sills form a ridge like escarpments, when exposed to erosion. This may give rise to waterfalls and rapids for example, Kinkon Falls in Guinea and Three sisters ridge in South Africa. Sills are more important ore deposits just like other important minerals such as gold, platinum and chromium.

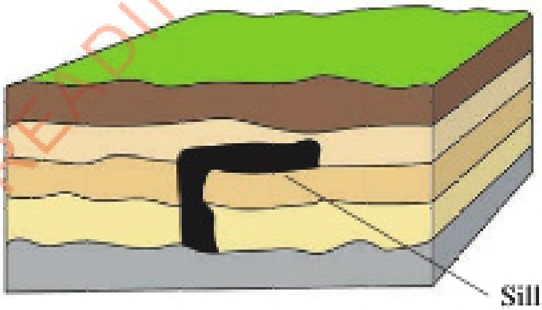
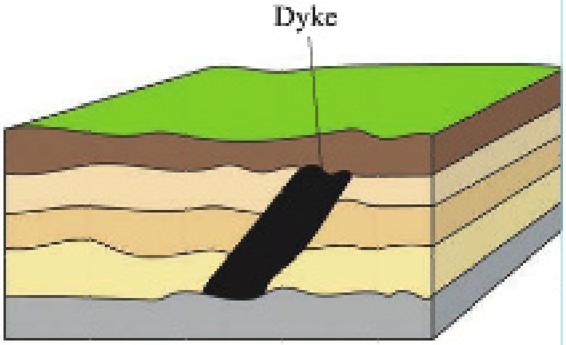


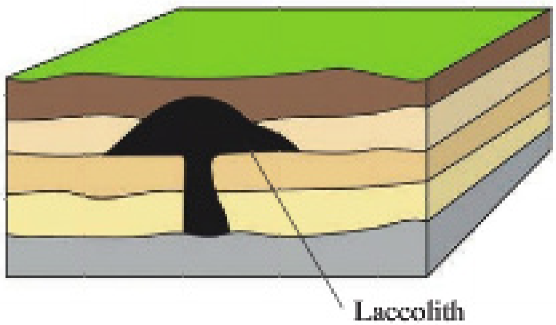
Figure 3.8:

This is a wall like feature which is formed when magma pushes up towards the surface through cracks in the rock, cools down and solidifies across the bending plane (Figure 3.9). Since it is a discordant feature, it does not follow the nature of a plane. Depending on the attitude of the host rocks, the dyke may be vertical, horizontal, or inclined, but most of them are vertical or steeply inclined. Dykes are categorized into two which are multiple dykes which occur due to successive injections of homogeneous material on the same fissure and composite dykes which occur due to a successive injection of different materials into the same fissure.



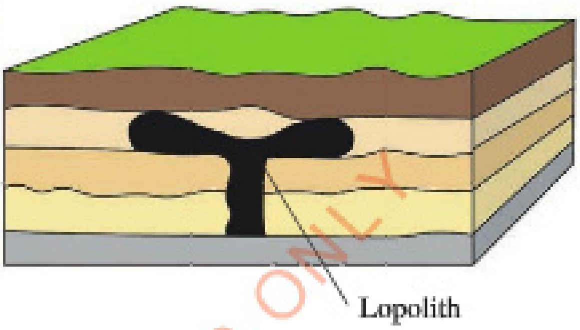
Dyke

Laccolith: Is a dome-shaped intrusion feature which is formed within or between layers of a sedimentary rock (Figure 3.10). It is formed of viscous magma which is unable to spread far and accumulates in a large mass, bending up the overlying rocks. With the continued addition of lava, the laccolith grows in height and width, until the supply of material or the propelling force diminishes lava by congelation in its conduit and the inflow. Usually laccoliths are compact in form. If the laccolith is more resistant than the adjacent rocks after denudation, it forms an upland. An example of this is Umvukwe Range in Harare, Zimbabwe.



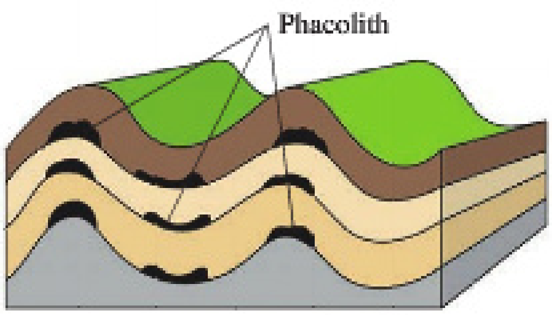
Laccolith

Lopolith: This is very large saucer -shaped intrusion feature lying concordant to the rock strata which in the end forms a shallow basin. It is formed as a result of greater weight of the overlying strata and deposits (Figure 3.11). An example of lopolith is that found in Bushveld Basin in the Transvaal in South Africa.



Lopolith

Phacolith: This is a concordant intrusion of igneous rocks which is formed after the cooling down and solidification of magma near the crest of an anticline or base of syncline (Figure 3.12). A phacolith can form along the sedimentary bed rock which is concordant by exerting great thickness along the synclines and anticlines.



Phacolith

Extrusive vulcanic features

These features when a vulcanic activity takes place above the ground and hot molten materials are released onto the surface and later cool down and solidify. The materials thrown out include lava flows, pyroclastic debris, volcanic bombs, ash, dust and gases such as nitrogen compounds, sulphur compounds and minor amounts of chlorine and hydrogen. Extrusive vulcanicity is responsible for the formation of many landforms found on the earth's surface. Examples of extrusive landforms include volcanic cones, composite cones, explosive crater, caldera, acidic lava and shield volcano.

Ash and Cinder cone (Pyroclasts cones): These are cone shaped structures which consist of predominantly fragmented materials produced by explosive volcanicity. They are formed when the lava is blown and ejected violently to a greater height and fall back to the earth and build a cone like feature (Figure 3.13). The slopes of the cone are always concave due the spreading tendency of lava at the base of the cone while a cinder is steep sided. Examples of ash and cinder cone are Sarabwe Fileko in Rungwe in Southern Tanzania and Jos Plateaus in Central Nigeria.

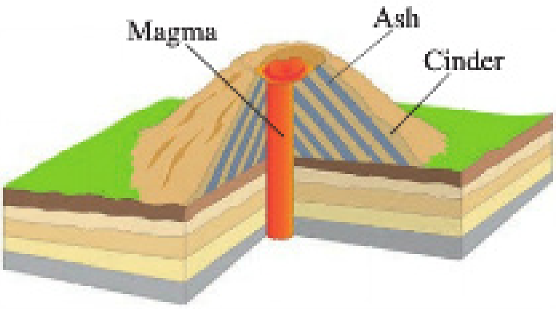


Figure 3.13: *Ash and cinder cone*

Composite cone (Strato-Volcano): These are stratified and consist of both lava flows with concaves sides and beds of pyroclastic materials. Lava often escapes from the sides of the cone where it builds up small conolets (Figure 3.14). The cone has a steep slope and it is the most common feature of volcano. Examples of composite cones are Kilimanjaro mountain, Cameroon mountains and Mountain Nyiragongo in the Democratic Republic of Congo.

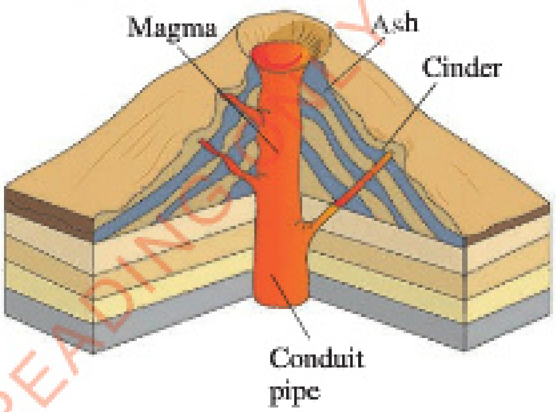


Figure 3.14: *Composite cone*

Volcanic plug (plug dome): It is a rigid cylindrical plug formed when very viscous lava is forced out by very explosive and violent eruptions. The base of the plug is surrounded by exploded debris as shown in Figure 3.15. An example of a volcanic plug is the Atakor volcanic area of the Hogger mountain in Algeria.

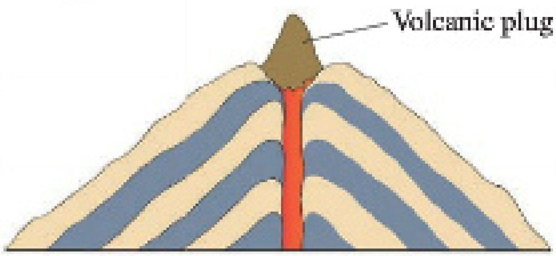


Figure 3.15: *Volcanic plug*

Crater: This is a bowl or funnel-shaped depression on top of volcanic cone after the plug dome is blown off. It has a diameter of less than 1.6 kilometer. The depression becomes a crater lake when it is filled with water from rainfall or melting ice (Figure 3.16). Examples of craters are Embakai, Olmoti and Ngozi in Tanzania and the Summit of Mountain St. Helens in the United State of America. Craters are formed into two ways; Firstly, through pouring of lava during the formation of volcano. During the formation of a volcano, a crater may form when the outpouring of lava stops. As the lava cools down, the magma in the vent cools down as well and contracts at the same time. This causes it to withdraw into the vent and in doing so, a depression forms at the top of the volcano.

Craters which have been formed in this way are found on the volcanoes of Kilimanjaro, Oldoinyo Lengai and Ngorongoro in Tanzania; and Marsabit and Ol Donyo Nyoike in Kenya. Other examples include Mahavura in the Democratic Republic of Congo and Versuvius in Italy. Secondly, through big volcanic explosion which blows a hole in the ground.

Craters formed in this way are known as explosion crater or ring crater and they are shallow, flat floored depression surrounded by a low rim of pyro clasts and local rock. They are usually less than 50 meters high and often found in groups. They have a vent blowing through the local rock by a series of gas explosions.

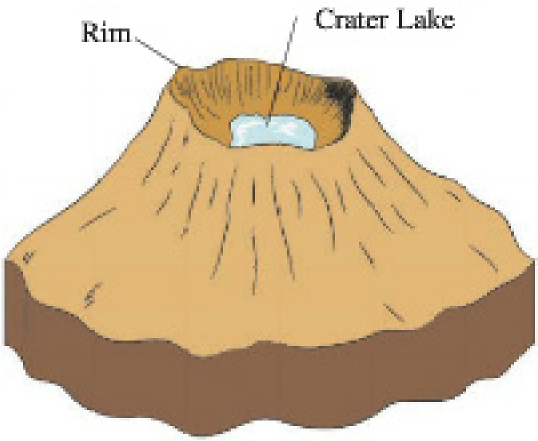


Figure 3.16: *Crater*

Caldera: These are large depressions formed when the upper part of the volcano is either blown away by violent eruptions or the top of the cone subsides into the crust (Figure 3.17). Basically, there are three main types of calderas which are collapse, explosion and erosional caldera. An example of a caldera is the Sunda Strait in Indonesia. Collapse calderas are further subdivided into Krakatau-type or explosion-collapse calderas and Glencoe-type or cauldron subsidence calderas. An example of this type is the Mokuaweo-weo caldera of Mauna Loa.

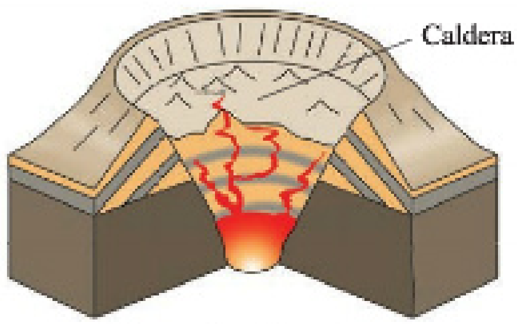


Figure 3.17: *Caldera*

Volcanic vent: This is a central opening exposed on the earth's surface, underlying the summit crater of the volcano where volcanic materials are emitted. This opening, is usually circular or nearly circular shaped through which heated materials consisting of gases, water, liquid lava and fragments of rocks are ejected from the highly heated interior to the surface of the Earth (Figure 3.18).

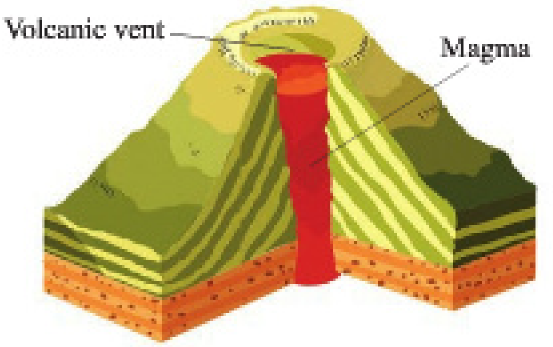


Figure 3.18: *Volcanic vent*

Acidic Lava (cumulo dome): This is a dome shaped volcano with convex slopes formed when acidic lava solidifies around the vent (Figure 3.19). Lava does not flow away, rather it piles near the vent since it is very viscous. The viscosity of the lava is a result of of high content of silica and its high melting point. An example of acidic lava is Ntumbi dome in Mbeya region, Tanzania.

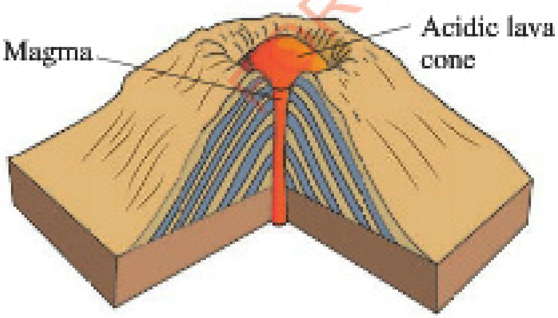


Figure 3.19: *Acidic lava*

Shield volcano: This is broad and extensive domed volcano with gentle slope sides formed when basic lava is poured on the surface and spread to occupy a large area (Figure 3.20). Lava from the earth's interior flows out through a vent.

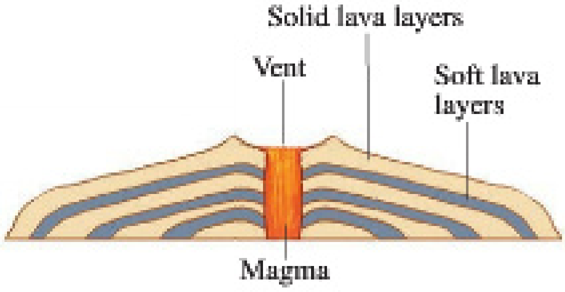


Figure 3.20: *Shield volcano*

Minor volcanic features

There are other minor volcanic features that normally start to take place when volcanic eruption is approaching the end. These features include; Solfatara, Fumarole, Mofette, Hot springs, Geyser and mud volcano.

Hot springs: This is the natural outflow of superheated water from the ground that contains mineral substances in solution or in suspension forms. They are springs produced by the geothermal heated groundwater that emerge onto the surface of the earth, whereby, shallow magma may heat groundwater or groundwater may contact the heated rocks by magma in active volcanic areas. When the heated water emerges onto the earth's surface it is known as hot spring. It can influence the production of geothermal power. Examples of hot springs are Amboni in Tanga region and Nanyala in Songwe region in Tanzania.

Geyser: This refers to the forceful emission of superheated water from the ground to the high level in the atmosphere. It is a hot spring which spouts hot water and vapour from time to time due to pressure (Figure 3.21). Geysers are of two types, namely; pool geyser and nozzle geyser. A pool geyser spouts water from open and relatively large pool. A nozzle geyser spouts water from a very small and contracted vent.

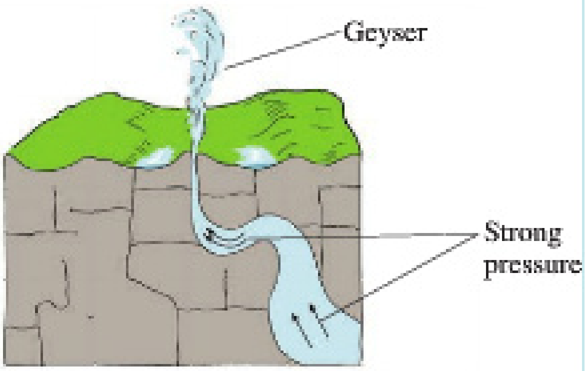


Figure 3.21: *Geyser materials being emitted through the vent*

Fumarole: It is a vent through which the emission of gases smoke and water vapour passes.

Impact of volcanic eruptions on human and the environment

Destructive consequences: Some volcanic eruptions cause great loss of life. A volcanic eruption in Krakatoa in 1883, for example, caused great sea waves which drowned 40 000 people in neighboring isles. Volcanic eruption may also cause great damage to property, houses, crops or livestock (Figure 3.22). Gases emitted during eruption cause pollution such as air pollution which in turn can cause soil pollution and affect human beings. Hot molten materials ejected on the surface can destroy vegetation leading to deforestation or loss of biodiversity.

Figure 3.22: *Destruction caused by volcanic eruption*

Constructive consequences: The lava formed from volcanic eruption leads to the formation of fertile soil when it is broken down through weathering process. A good example is the southern slopes of Kilimanjaro in Tanzania. Moreover, volcanicity can lead to the formation of mineral deposits like copper and diamond deposits of Kimberley in South Africa. Additionally, hot springs are utilized for heating and supplying hot water to buildings in cold countries like Iceland and New Zealand. Volcanic eruptions under hot spring can also be used to provide geothermal power which can be utilized for electricity generation as it is the case in Kenya, Ethiopia and USA. Furthermore, volcanic eruptions can attract tourists due to the formation of physical features like springs and geysers. Lastly, the eruption can aslo provide construction materials.

Activity 3.4

Read books and other online sources about measures to be taken to reduce the impact of vulcanicity

Exercise 3.2

1. Describe risks and preparatory measures associated with volcanic eruption that can be communicated to a community residing in close proximity to active volcanoes.
2. You have been assigned by your subject teacher to prepare a morning talk on socio-economic significance of volcanoes. With examples, explain those significance.

Diastrophism

Diastrophism is also known as diastrophic forces and it includes all processes that move, elevate or build up portions of the earth's crust through orogenic processes. An example of this is the mountain building through folding and epirogenic forces involving uplifting or submergence of large part of the earth's crust. The epirogenic processes include vertical forces responsible for upward (emergence) and downward (submergence) movements. The vertical movement of the Earth is either upward or downward (cymatogenic) along a radius from the centre of the Earth to the surface. The movement is considered to be epeirogenic process when it occurs on a large scale. Upward movement causes uplift of continental parts or coastal areas and it is called emergence. Downward movement causes submergence of part of land mass or coastal area.

Orogenic process involves endogenetic forces working in a horizontal manner. Horizontal movement, involves tensional and compressional forces that act on the earth's crust side by side tangentially or horizontally and which causes the disruption of the horizontal layer strata. It is also known as convergent force and movement. Tensional force operates in opposite directions and it is known as a divergent force and movement. Tensional forces create rupture, cracks, fracture and faults in the crustal parts of the Earth. When endogenetic operates face to face, compressional or convergence force causes crustal bending and that leads to the formation of folds or crustal warping. This also leads to the local rise or subsidence of crustal parts. The process of crustal warping affects large areas of the crust either warped (raised) upward or downward. The upward rise of land due to convergent compressional force is called up-warping while the bending of the crustal part downward due to convergent compressional force is known as down-warping. The effects of earth's movement can be categorized into two groups namely: faulting and folding.

Faulting

Faulting is the process that involves the breaking or fracturing of crustal rocks due to forces resulting from earth's movement to form faults. The movement involved in the formation of a fault may operate vertically or horizontally or in any direction. In faulting, there is a vertical displacement of rock blocks. Faulting has various effects on landscape as it causes the occurrence of uplift, depression, horizontal displacement of large block of the crust and the associated landforms.

Faults

These are fractures in the crustal rocks where rocks are displaced along a plane. *Fault plane*, is the plane along which the rock blocks are displaced by tensional and compressional forces acting vertically and horizontally to form a fault. *Upthrown side* is the uppermost block of a fault while *downthrown side* is the lowermost block of a fault. *Fault dip* is the angle between the fault plane and horizontal plane and *hanging wall* is the upper wall of a fault. On the other hand, *foot wall* is the lower wall of a fault and *fault scarp* is the steep wall-like slope caused by the faulting of the crustal rocks. A fault can be categorized into normal, reversed, transform (tear), over thrust and monocline depending on how it is formed.

Normal faults: Normal faults are formed due to the displacement of rock blocks in opposite directions due to fracture consequent upon greatest stress. This results from tension forces (splitting of rocks) when rocks are pulled apart and the crust is stretched. It is characterized by the inclination of the fault plane and the direction of down throw. Both can be found on one side, either right or left and they can be vertical or inclined (Figure 3.23). The middle part of the entire fault tends to rise up, while the hanging wall sinks down.

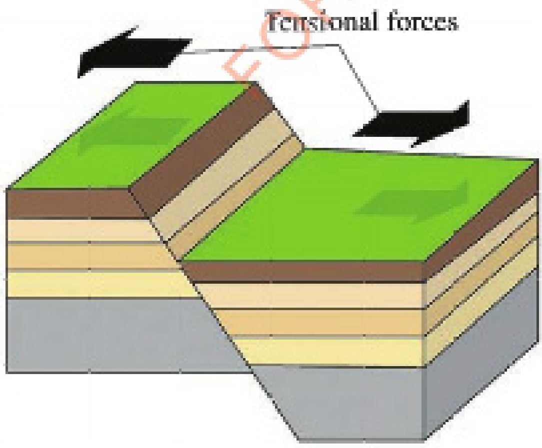


Figure 3.23: *Normal Fault*

Reverse fault: This is a type of fault formed due to compressional forces and it occurs when the beds of a rock on one side of the fault plane are thrust over the other side (Figure 3.24). The fault plane in reverse fault is usually inclined at an angle between 40 degrees and it is horizontal (0 degree).

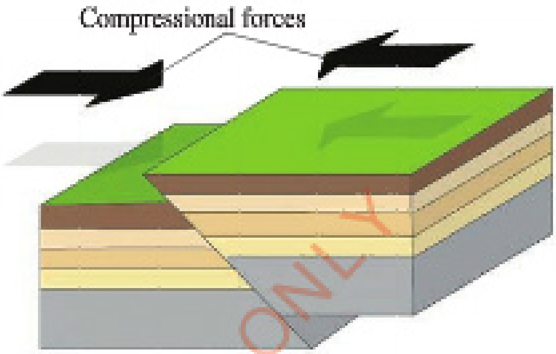


Figure 3.24: *Reverse fault*

Transform (Tear fault): The transform fault is also known as strike, slide, shear, wretch or trans current fault. It is formed when a vertical fracture is displaced parallel in opposing direction along the line of fault (Figure 3.25). A good example is San Andrea's fault of California.

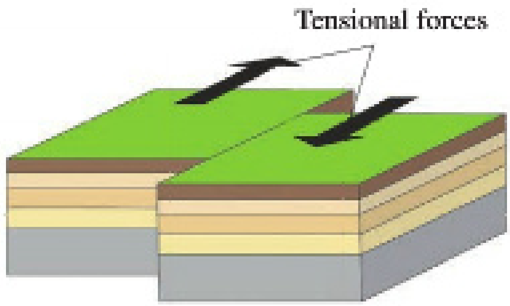


Figure 3.25: *Transform (Tear fault)*

Overthrust fault: It is formed when the top part of the fault overrides the bottom part along a fault plane because of compressional forces (Figure 3.26).

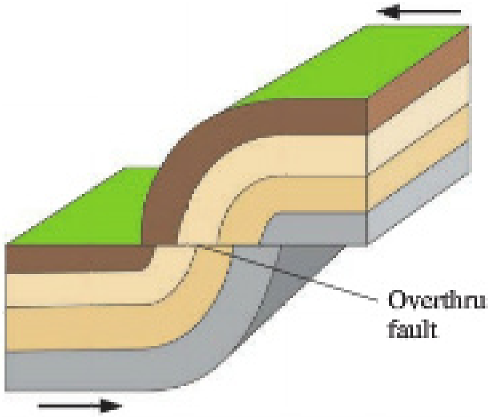


Figure 3.26: *Overthrust fault*

Monocline fault: Monocline is a tensional fracture in which the strata bends closely due to a normal fault but the normal fault has horizontal strata (Figure 3.27).

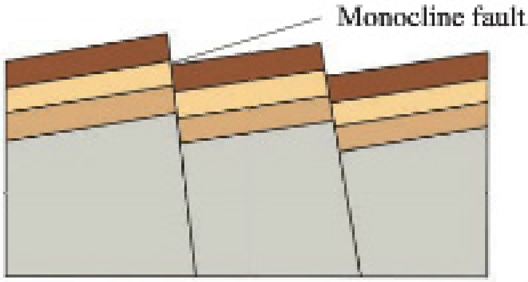


Figure 3.27: *Monocline fault*

Landforms resulting from faulting

The influence of faulting on landscape results into direct and indirect effects. The indirect effects involve the formation of landforms which are essentially structured in nature because it is a direct result of faulting on landscape.

Direct landforms

Initially faulted landforms appear as abrupt features but with time erosion tends to modify their outlines. Therefore, these are faults on the basis of a fault pattern. The following are some of the direct effects of faulting.

Step faulting: It is the process that leads to the formation of several parallel faults. Therefore, the faults appear as a series of steps on either side of a rift valley or on both sides (Figure 3.28).

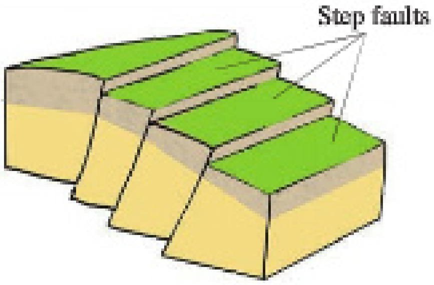


Figure 3.28: *Step faulting*

Fault block: It is also known as a tilted block. This is a block-like structure with inclined strata formed due to a faulting process. Inclination occurs as a result of one side of the block being uplifted faster than the other side. It is similar to monocline fault (Figure 3.29). In USA they are known as tilt block basin and range countries. A good example is that of Afar Triangle in Ethiopia.

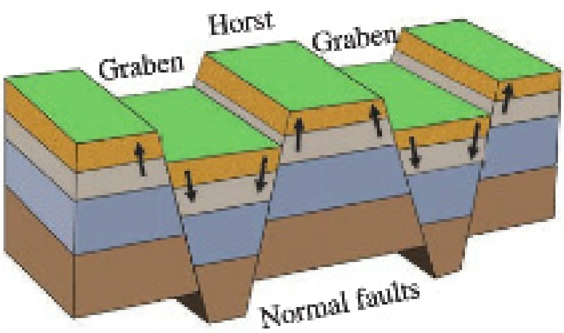


Figure 3.29: *Fault block*

Block mountains: A block (horst) mountain is a table-like mountain formed by faulting process that result to the rising of a block rock forming a table-like structure. Block mountain is an upland bordered by a fault on one or more sides (Figure 3.30). It occurs either when the land mass subsides between two normal faults or when a block remains standing while the other two on its either side drop. An example of block mountains is the Drakensberg range in South Africa.

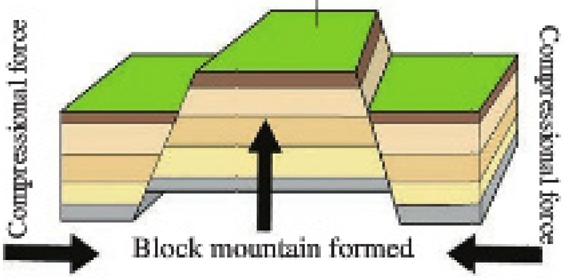


Figure 3.30: *Horst mountain*

Fault scarp: It is an escarpment or a scarp which is steep on one side and gentle on the other (Figure 3.31). The steep slope is caused by a vertical earth movement along the fault.

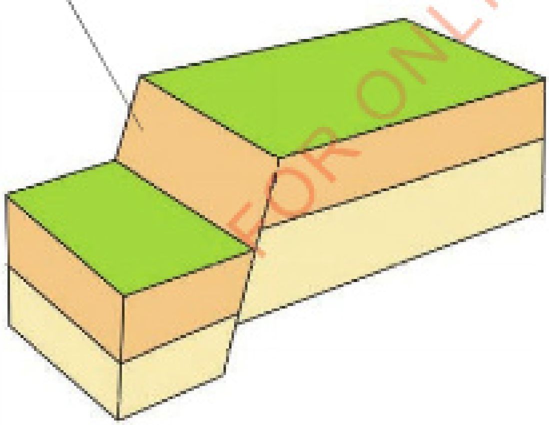


Figure 3.31: *Fault scarp*

Rift valley: It is formed at a point where the earth's crust, or outermost layer, spreads or splits apart. This kind of valley is often narrow, with steep sides and a flat floor. Rift valleys are also called grabens, which means "ditch" in German. While there is no official distinction between a graben and a rift valley but a graben usually describes a small rift valley. Rift valleys differ from river valleys and glacial valleys because they are created by tectonic activity and not by the process of erosion.

Rift valleys are created by plate tectonics which are constantly in motion, as they move against each other or tear apart from each other. When plates move apart, the earth's crust separates or rifts to form a rift valley (Figure 3.32). Many rift valleys have been found underwater, along the large ridges that run throughout the ocean called mid-ocean ridges. Examples of great rift valleys include the Baikal Rift Valley in southern-eastern Russia and the East African Rift Valley.

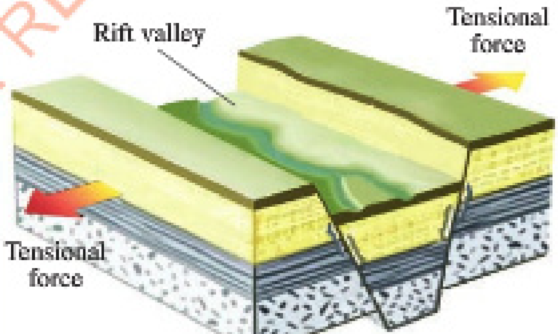


Figure 3.32: *Rift valley*

The East African Rift System (EARS) forms a narrow (50-150 km wide) elongate system of normal faults that stretches some 3 500 km in a sub-meridian direction that runs from Northern Jordan in Asia to Mozambique in South Eastern Africa. It is connected to the world wide system of oceanic rifts via the Afar Triangle to the Gulf of Aden and the Red Sea. The EARS is composed of two rift trends called the eastern and western branches.

The eastern branch is located north and east of Lake Victoria and it is a volcanic-rich system that forms the Kenyan and Ethiopian Rifts. In these places the rift system was probably initiated in the early Miocene, but there is also an evidence for earlier Paleogene rift activity in northern Kenya and Ethiopia. The rift branch is well exposed at the surface and it is dotted with relatively small lakes.

The western branch appears to have been initiated later than the eastern branch, during the late Miocene. It is composed of a series of extensive deep and shallow lakes such as Albert, Edward, Kivu, Rukwa, Nyasa, and Tanganyika, the world's second deepest lake in the world. These lakes make much of the rift structure. The western branch is associated with much less volcanism than that of the eastern branch although both branches are seismically and volcanically active today. The eastern arm, on the other hand, has popular volcanoes like Mount Kilimanjaro, Oldonyo Lengai and Meru. The lakes found on the eastern arm are not as deep or as voluminous like the ones on the western arm. Some of these lakes are Lake Eyasi and Lake Natron in Tanzania, and Lake Turkana in Kenya which is the sole large lake in the eastern branch.

Indirect effects of faulting

These are the effects resulting from landforms which were formed though faulting processes. Some of the indirect effects include waterfalls, river offset, lake formation, river reverse direction, occurrence of springs and fault guided valley.

Waterfalls: Vertical faulting across a river valley may cause a waterfall. A waterfall (cataracts) is a river or other water bodies' steep fall over a rocky or surface. Often, waterfalls form as streams flow from soft rock to hard rock. This happens both laterally (as a stream flows across the Earth) and vertically (as the stream drops in a waterfall). In both cases, the soft rock erodes, leaving a hard ledge over which the stream falls. A fall line is the imaginary line along which parallel rivers plunge as they flow from uplands to lowlands.

River offset: Tear faulting with a horizontal movement across a river causes the river to be offset at the point it crosses the fault.

Lake formation: Rift faulting that forms an enclosed basin may cause a lake if rivers flow into the basin. Good examples are Lake Tanganyika, Nyasa and Rudolf.

River flow: Rivers may follow straight and natural fault valleys especially in areas of tilt-block faulting and where differential movements have raised some parts while lowering others.

Reverse river direction: Crustal tilting or up warping across a river valley will gradually force the river to reverse its direction and flow backwards, if it is unable to maintain its original flow. For example, Kafu river and Lake Kyoga (Uganda), Katonga river, Kagera river and Lake Victoria (Tanzania).

Occurrence of springs: Due to faulting, springs can be formed because the fault provides an area of weakness through which water can came out from the aquifer.

Obsequent fault line scarp: Is a scarp facing the opposite direction to the original fault line scarp.

Fault guided valley: This is a fault that causes rocks to be shattered and crushed to the extent that rocks are more easily eroded than those further from the faulty. They are very common in river valleys where a valley is guided by a fault line. An example of this is the Santa River in Guinea.

Folding

Folding is the process that involves the wrinkling of the earth's crust to form folds. The folding of rocks produces a variety of geological structures such as fold Mountains. When the folding is gentle it results into simple upfold (anticlines) as mountains and downfold (synclines) as valleys. If the folding intensity is high it results into the over folding rocks which is very common. Rock folding is due to the tremendous compressional forces that develop as the tectonic plates of the crust move towards each other to produce folds.

Folds are wave-like bends formed in the crustal rocks due to tangential compressive force resulting the from horizontal movement of plates. These bends are caused by endogenetic forces of the Earth. The up folded rock strata which is in an arch-like form is called *anticline* while the down folded structure in a trough-like structure is called *syncline*. The two sides of a fold are called limbs of the fold. The plan that bisects the angle between two limbs of the anticline or middle limb of the syncline is called the axis of a fold or axial plan.

To understand a fold, it is important to define the following terms: Anticlines, is the up folded rock beds due to compressional forces. Syncline is the down folded rock beds due to compressive forces. Synclinorium represents a folded structure which includes an extensive syncline having numerous minor anticline and syncline.

When crustal rocks move towards each other they form different features resulting from folding namely simple fold, asymmetrical fold, over fold, recumbent fold, over thrust fold and geosyncline.

Simple fold: The simple fold is also known as symmetrical fold. This is formed when strata are bending to form up fold (anticline) and a down fold (syncline). The sides of the fold are called limbs, caused by compressional forces (Figure 3.33). Usually the limbs are similar in terms of slope.

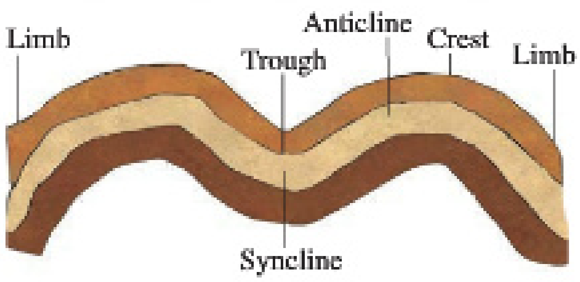


Figure 3.33: *Simple fold*

Asymmetrical fold: Asymmetrical fold is formed when compression continues and a simple fold is changed into a asymmetrical fold. One limb of a asymmetrical fold is steeper than the other (Figure 3.34). It is a fold whose limbs are unequal in length, and its axial plane is inclined, dipping in the same direction as that of the gently dipping limb. The degree of asymmetry is given in terms of the ratio of the length of a short limb to the long one. Thus, the smaller the ratio, the greater the degree of asymmetry. Folds whose axial plane is rotated clockwise from the normal to their enveloping surfaces are called Z folds or dextral or negative asymmetrical while those whose axial plane is rotated anticlockwise from the normal to their enveloping surfaces are called S folds or sinisterly or positive asymmetrical. Z and S folds normally occur on the left and right limbs of an antifoam, respectively. An example of a Z fold is the Ghisauli gneisses of Central India.

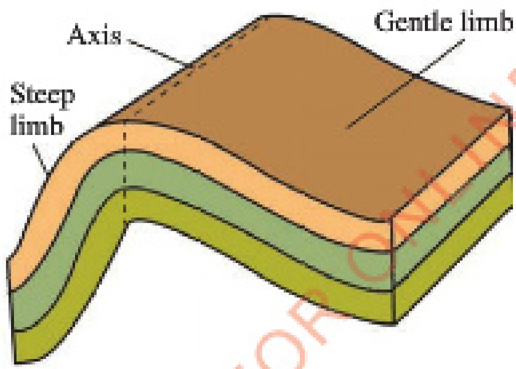


Figure 3.34: *Asymmetrical fold*

Over fold: It is also known as an overturned fold formed when the axial plane is inclined so that the fold limbs dip in the same direction, although not necessarily by the same amount. One limb is thus 'overturned 'or is pushed over the other (Figure 3.35).

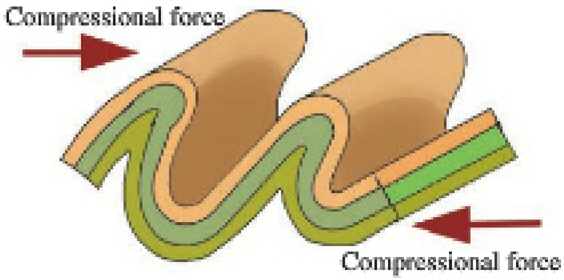


Figure 3.35: *Over fold*

Recumbent fold: This occurs when pressure continues and an over fold is pushed over another limb to a greater distance (Figure 3.36). A recumbent fold has an essentially horizontal axial plane. When the two limbs of a fold are essentially parallel to each other and thus approximately parallel to the axial plane, the fold is called recumbent.

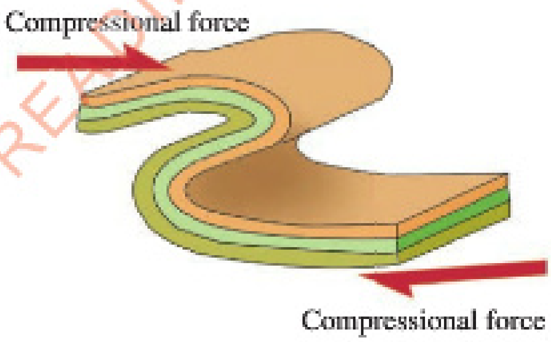


Figure 3.36: *Recumbent folds*

Over thrust fold: The over thrust fold is also referred to as Nappe fold. It is formed due to great pressure where the rocks feature and the limb fold is thrust forward over the other limb (Figure 3.37). Thrust faults with a very low angle of dip and a very large total displacement are called over thrusts or detachments. They are often found in intensely deformed mountain belts. Large thrust faults are a characteristic of compressive tectonic plate boundaries.

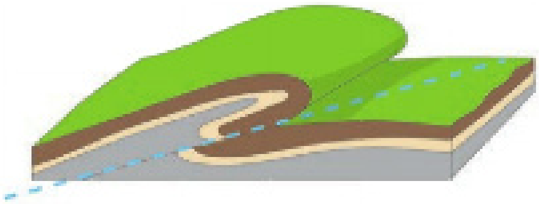


Figure 3.37: *Over thrust fold*

Geosyncline: This is a very large downfold produced as a result of subsidence of the earth's crust (down warping) caused by the increased weight of the materials deposited on a particular place or warping movement of the Earth (Figure 3.38).

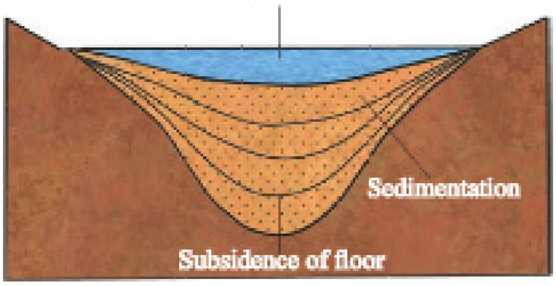


Figure 3.38: *Geosyncline*

Landforms resulting from folding

Folding processes and the resulting landforms significantly influence the topography, drainage patterns, and distribution of natural resources on the earth's surface. The resulting landforms from folding include fold mountains.

Fold mountains

Fold Mountains are a result of the folding of the earth's crust due to the influence of compressional forces. Fold mountains are classified into nature of fold and period of origin. Based on the nature of origin, there are simple fold mountains and complex fold mountains. Simple fold mountains are characterized by a well-developed system of anticline and syncline pattern. Complex fold mountains consist of a very complex structure of folds caused by powerful compressional forces such as recumbent folds. There is also a *Priceline (Centroline)* fold. It is a form of anticline usually of small dimension in which the limbs have been forced to pitch (steepen) vertically along the axis.

The period of mountain building is distinguished as an orogeny. Fold mountain building process as shown in Figure 3.39 is known as *Orogenesis*. There have been several mountains building periods during the earth's history. The periods are classified into old and new folded mountains. The old folded mountains originated before tertiary period about 3 000 milions years ago such as Caledonian and Hercynian. These mountains have been so greatly eroded. An example of these mountains is the Aravallis Mountain in India. The alpine folded mountains of Tertiary period are grouped under the category of new folded mountains formed during the Cenozoic era, 300 million years ago. Examples of these mountains include; Rockies, Andes, Alps and Himalayas.

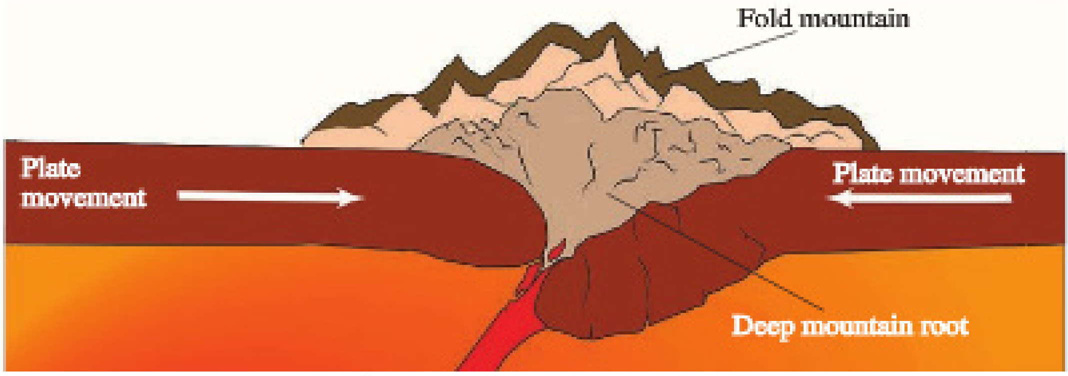


Figure 3.39: *Fold mountains*

Distribution of fold mountains

The old fold mountains were formed during the Paleozoic and Mesozoic eras. Most of these are remnants (roots) of old fold mountains. These old fold mountains are found in North America such as Appalachian mountain and Urals and Cape Ranges of South Africa.

Distribution of young fold mountains

Fold mountains are generally found along the margins of the continents either in north-south direction or east west direction. For example, the alpine chains lie along the continental margin. Most fold mountains on the earth's surface are young fold mountains belt. Young fold mountain belts consist of two belts namely; the *circum-pacific system* and *Eurasian – Indonesian Belt*.

Circum-Pacific System: Rings the Pacific Ocean (North and South America) for example, Andes, Rockies and Cordilleran ranges. In the western part of the Pacific Ocean, the belts take form of Islands, for example, Japan and Philippines.

Eurasian – Indonesian Belt: Rings the West of Atlas mountain to East of Iran and Himalaya ranges then continues to South Eastern Asia and Indonesia where it meets the circum-pacific belt. The belt includes Alps, Caucasus and Himalayas mountains.

Revision exercise

1. For several years, Kagera region has been prone to earthquakes. Using knowledge obtained in the classroom, analyse the main causes and their effects.
2. Using Indonesia tsunami of 2004 as a case study, anticipate the effects that might be caused by such a phenomenon to people of Eastern Africa and suggest possible measures to be taken to reduce the impact of a similar occurrence.
3. Examine the impact of folding and faulting on the landscape by referring to one landform for each impact.
4. Discuss the environmental impact of diastrophic activities.
5. A farming community is located in a valley shaped by folding.
   (a) How does its geological structure affect soil quality?
   (b) What possible agricultural practices would be most effective in the environment?

Chapter Four

Exogenic processes of the Earth

Introduction

Some of the landforms seen on the earth's surface are the results of external processes of the Earth which include denudation and deposition. In this chapter, you will learn about weathering and mass wasting as geographical processes acting on the earth's surface and their resultant landforms. You will also learn about the actions of wind, water and waves, and their resulting landforms. The competences developed will enable you to demonstrate an understanding of the external forces responsible for the formation of the major relief features of the Earth. It will also help you to utilise landforms resulting from denudation and deposition for the development of social and economic activities such as tourism in Tanzania.

Think about

The Earth without external processes operating on its surface

The concept of exogenic processes of the Earth

Activity 4.1

Study from different sources to identify external processes of the Earth and write a short summary.

The surface of the earth's crust is under constant sculpturing due to multiple geomorphic processes that lead into denudation and deposition. The sculpturing of the earth's crust entails the process, deformation stages and resultant features. The mature soil, regolith, and various forms of topographical landscapes seen today are the results of the geomorphological processes that took place for a long period of time. These geomorphological processes are termed as exogenic or external forces which act on the earth's surface, they include weathering, mass wasting, erosion and deposition. Figure 4.1 is a schematic representation of external processes of the Earth.

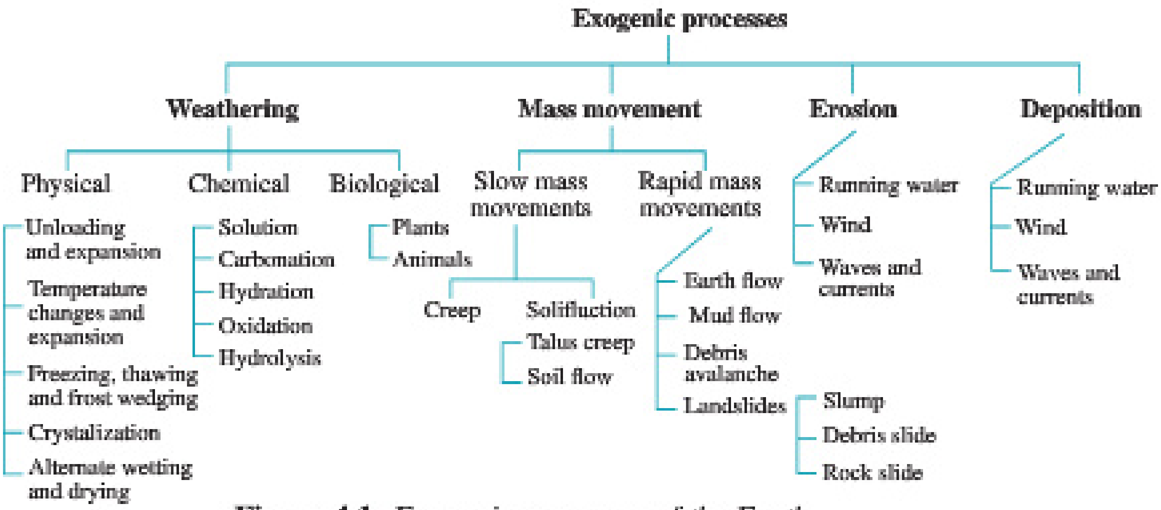


Figure 4.1: *Exogenic processes of the Earth*

Weathering

Weathering refers to the process of weakening, breaking up, disintegration and decomposition of rocks into small particles that forms the surface of the earth. The surface rocks are often exposed to elements of weather such as temperature, rainfall, pressure, wind and humidity which acts as agents of weathering. Weathering as a process, normally weakens hard rocks into fine and soft residuals. Weathering does not produce new landforms because weathered materials such as rocks and debris stay *in situ* as weathered rock or debris. For this reason, weathering is often described as the process of preparation of rock materials for transportation by the agents of erosion including water, winds and waves.

All rocks, whether soft or hard, when exposed on the surface of the Earth, are subjected to change over time due to either pressure release, temperature change or both. Most rocks and minerals within the earth's crust are subjected to changes due to temperature and pressure that greatly differ to that of the earth's surface. This happens because the physical and chemical nature of the materials in the earth's surface are not stable due to different conditions on the earth's surface. Hence they are easily attacked, decomposed, and eroded by various physical and chemical processes. Weathering does not involve the removal of weathered rocks. Instead the removal of weathered rocks is caused by forces of weather which include rain and wind. Weathering can also be influenced by organisms, a process known as biological (biotic) weathering. Generally, weathering is considered to be a combination of processes of destruction and synthesis whose main mechanisms which often take place simultaneously are mechanical (physical), chemical and biological weathering.

Mechanical weathering

Mechanical weathering is also known as physical weathering. It refers to the weakening, breaking down and disintegration of rocks without any chemical changes of rocks. Usually, it involves the breaking down of rocks into smaller fragments. It is common in desert areas, high mountains and cold regions due to their climatic conditions. The forces that strain and rupture the rock can either originate within the rock due to plate movements or applied externally. The following are different forms of physical weathering.

Thermal expansion: Thermal expansion is also known as insolation. It is often common in arid and semi arid areas where there is high daily range of temperature. When an arid area experiences high day temperature and low night temperature, the rocks' surface heats and cools down alternately. Since rocks are poor heat conductors, the absorbed heat is confined to the inner part of the rocks. Therefore, the outer parts of the rocks keep on expanding during the day and cooling during the night. The surface of the rock expands more than the interior part and eventually form cracks to which slowly extend to a greater depth into the rock. As a result, the outer layer of the rock pulls away from the layer beneath ending into rupture. The breaking of the outer layer of the rock is in a form of *granular disintegration* or *block disintegration.* The disintegrated rock can peel off as a flat or curved plate of rock from the main rock. This process is called *exfoliation*. The exfoliation process occurs in a well-jointed rock mostly in the desert, semi-desert and monsoon regions. Exfoliation causes the falling of separated plates of rock resulting into the formation of isolated masses of round-shaped rocks called *exfoliation domes* (Figure 4.2). Separated fragments of rocks continue to disintegrate into smaller pieces called *talus or screes* which often collects at the base of exfoliation dome. The exfoliation dome occurs in desert, semi desert and monsoon regions. Examples of this type of weathering can be witnessed in some parts of the Sahara Desert in Egypt, Sinai and Kalahari deserts.

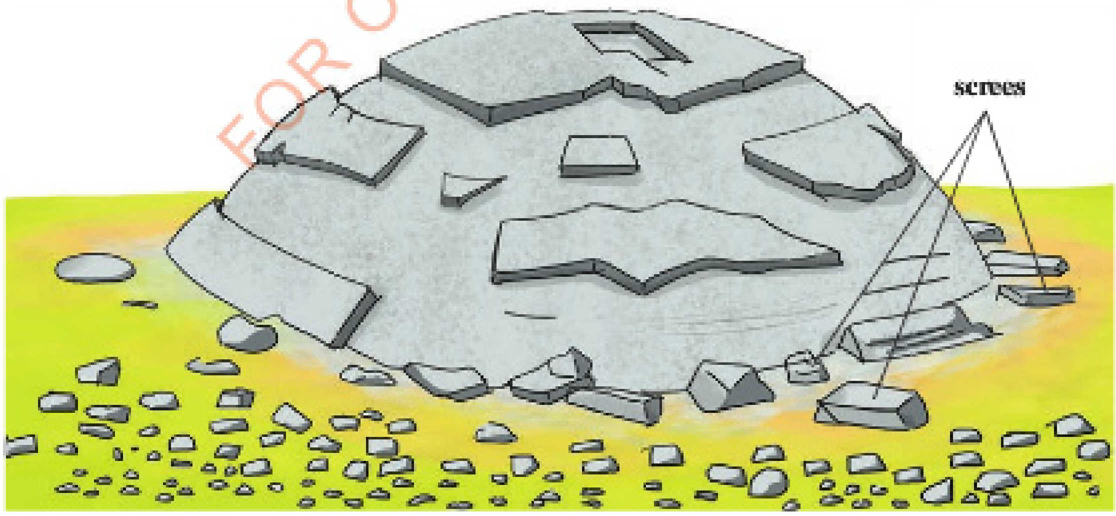
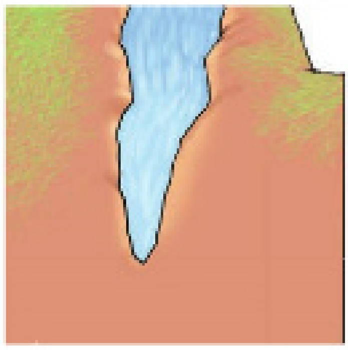


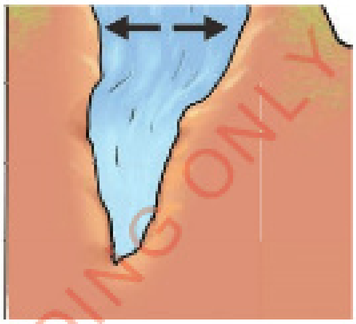
Figure 4.2: *Exfoliation dome with mounds of screes*

However, when coarse grained rock particles of the granular rocks expand and contract due to different temperatures they may breakdown into separate smaller rock particles. The grained rock particles accumulate down around the rock forming a large mass of coarsely grained igneous rock which is dome-shaped. This weathering process is called *block disintegration*. The disintegration of rocks that contain a variety of minerals is called granular disintegration

Frost action: This occurs when water penetrates through cracks and joints of rocks and freezes. When water freezes it expands. The increased expansion of frozen water exerts pressure on the sides of the cracks in such a way that the repeated freezing and melting (thawing) of water keeps widening and deepening the cracks. Alternate freezing and thawing processes over time will slowly cause the rock outcrops to break down into angular blocks which keep breaking into smaller fragments (Figure 4.3). Frost action is common in areas where temperature falls below 0 °C and vegetation cover is limited. Such an action is most active in temperate regions where freezing and thawing frequently take place and in tropics where there is high temperature like in deserts. Moreover, it also takes place in the arctic region but on a small scale because in this region water freezing period is longer than its melting period.



(a) Frozen water in the rock joints



(b) Frozen water causing expansion of rock joints

Figure 4.3: *Weathering by frost action*

Salt crystallization: This is common along the coast and in desert areas. It occurs when saline water occupies pore spaces in the coastal rocks and during evaporation due to high temperature. Under these conditions salt crystals are likely to be formed. Further accumulation and hardening of the salt crystals widen and exerts pressure upon the rocks causing them to fracture and disintegrate (Figure 4.4). Basically, the transformation from liquid to solid crystalline form produces a volumetric change, which in turn causes the necessary mechanical action for the rupturing of the rock. The process can also occur in desert areas where capillary action draws water from the ground to the surface, and where the rock is sandstone. Individual particles of sand are broken off by granular disintegration.

Figure 4.4: *Weathered rock by salt crystallization*

Pressure release: This is also refered to as unloading process. Many rocks, especially intrusive igneous rocks experienced exertion of considerable pressure for millions of years. The confining pressure originating inside the Earth, strengthens the rocks. On the other hand, the process of erosion removes the overlying rock material, in such a way that with time the intrusive rocks are exposed and the pressure on them is unloaded hense, paving way to further action by other agents and processes. The outer parts of the rocks starts to expand (Figure 4.5) and over time, sheets of a rock on the exposed part break away on the exposed parts along the fractures, a process called exfoliation. On the other hand, exfoliation due to pressure release is known as sheeting.

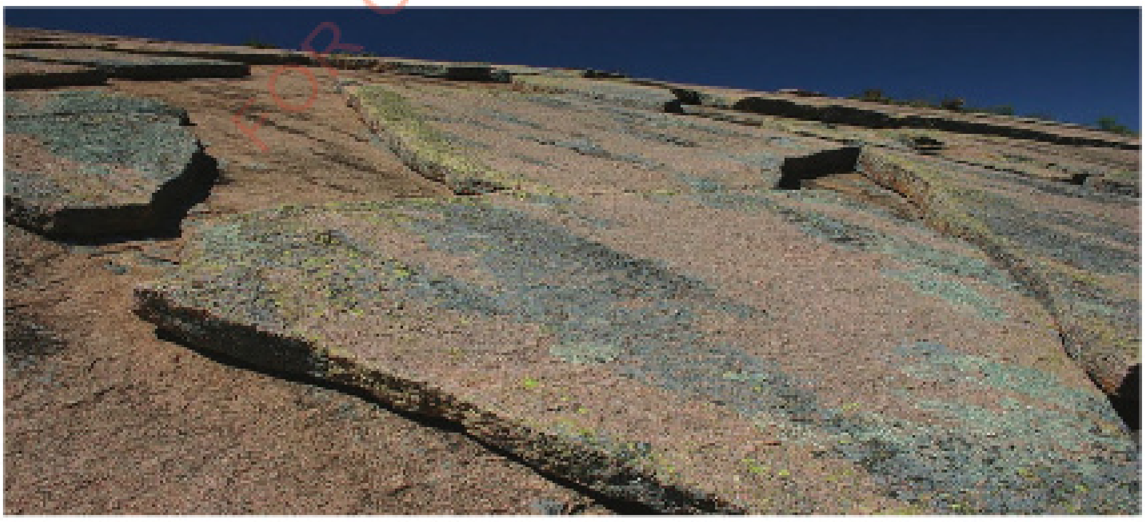


Figure 4.5: *Weathering by pressure release*

Alternate wetting and drying: The absorption of water by rocks surface cause them to swell. This process causes expansion, and on the other hand, when they dry out their outer layers shrink. The contraction of some rocks following the loss of absorbed water especially in tropical regions is a rapid process. The repeatedly wetting and drying weakens the rocks and eventually cracks and breaks them into smaller fragments. For example, when shale dries, it crumbles into small-elongated fragments. While clay shrinks and its surface cracks when it also dries. This type of weathering occurs in several parts of west Africa particularly on coastal rocks which are alternately wet and dry with the rise and fall of the tide.

Chemical weathering

Chemical weathering is the breaking of rocks by decomposition through chemical reaction. The chemical reaction involves substances of water, certain atmospheric gases, and rock minerals. When water is charged by different gases like oxygen and carbon dioxide that penetrate the rocks, it decomposes the minerals to the ultimate gradual breakup of rocks. That process occurs because chemical nature of the rock is transformed from its original mineral compounds into secondary (new) mineral compounds which are susceptible to decomposition. This type of weathering, therefore, involves decomposition and transformation of rock and minerals exposed to water and air into new chemical products. The mineral that is crystallized deep underground from a water deficient zone may eventually be exposed at the earth's surface where it can react with abundant water to form new mineral. The newly formed minerals are weathering products. In general, chemical weathering usually takes place on the exposed rock surface, and inside the rock when water enters the rock via pores, joints or cracks. Temperature is a very important factor as it speeds up the chemical reactions. Composition and strength of soil water, minerals dissolved in the soil water and soil bacteria are also determinant factors for the rate of rock disintegration.

Chemical weathering has several effects on rocks, it softens rocks (minerals) and make them more susceptible to erosive agents than the original. It produces secondary minerals from the original minerals that are soluble in water and which can be removed by running water. Furthermore, it produces chemical compounds that can take up greater volume than the original minerals, hence making them weak and susceptible to breakage.

Depending on the nature of minerals present in the rocks and atmospheric gases reacting with water, chemical weathering takes place through a number of different processes which produce different landforms (Figure 4.6). The main five chemical weathering processes include; *carbonation, hydration, oxidation, hydrolysis, and solution.*

Carbonation: It is a chemical weathering process by which the carbonic acid formed by the reaction between water and carbon-dioxide gas, reacts with rocks of calcium carbonate minerals. The reaction converts calcium carbonate converted into calcium bicarbonate, which is readily removed as it dissolves in water. The process involves carbonic acid (a weak solution of carbon dioxide and water) to change calcium carbonate into calcium bicarbonate which is easily removed in solution by ground water. For example, when rain falls, it dissolves small amounts of carbon dioxide from the air, forming a weak carbonic acid that is able to dissolve many insoluble limestone minerals into soluble ones. It dissolves even more carbonates as it seeps through the soil, hence the exposed surface rocks that contain calcium carbonate are readily decomposed when they react with weak carbonic acid.

$$CaCO_3 + H_2O + CO_2 \longrightarrow Ca(HCO_3)_2$$

(Calcium carbonates) *(Calcium bicarbonate)*

Carbonation mostly occurs in areas rich in limestone rocks which is primarily composed of calcite.

Hydration: Hydration is a process in which certain minerals absorb water and expand causing fracturing of the rocks. It causes volumetric changes in minerals, which set up strains in the rock, in which water molecules become attached to other substances and then the added water causes the original substance to swell without any change in its chemical composition. This swelling process weakens the rock mass and is usually sufficient to produce some fracturing. Some of the rocks, for example, gypsum also known as calcium sulphate dehydrated are the results of water that has been absorbed by calcium sulphate. The following equation demonstrates the hydration process.

$$CaSO_4 + 2H_2O \longrightarrow CaSO_4 2H_2O$$

(Sulphate) (water) (gypsum)

Gypsum is used as fertilizer and the main constituent in many forms of plaster, blackboard and dry wall. Hydration is in fact a physical-chemical process as the rocks may swell and exert pressure as well as change their chemical structure. This process is most effective in dry and wet seasons.

Oxidation: This is the process that involves a reaction between metallic ions such as calcium, magnesium or iron and oxygen to form oxides. Since oxygen is freely available near the earth's surface, it may react with minerals to change the oxidation state of an ion. The following equation demontrastes the process,

$$3FeSiO_3 + 2O_2 \longrightarrow Fe_3O_4 + 3SiO_3$$

(Pyroxine) (Oxygen) (Magnetic) (Quartz)

This is more common in iron (Fe) bearing minerals, since iron can have several oxidation states such as Fe^+, Fe^{2+} and Fe^{3+}. The new minerals formed by oxidation are easily attacked by other weathering processes. For example, oxidation of the iron completely breaks down rock structures where iron and silicate are joined.

Hydrolysis: This is the process whereby hydrogen in the water combines with certain metal ions in a mineral to form different chemical compounds. It occurs when acidic water reacts with rock-forming minerals such as feldspar and breaks it down to produce clay and salts that are removed in solution. The following equation demonstrates the process.

$$4KALSi_3O_8 + 4H^+ + 2H_2O + CO_2 \longrightarrow 4K^+ + Al_4Si_4O_{10}(OH)_8 + 4SiO_2$$

(Orthoclase) (Hydrogen ion) (Water) (Carbon dioxide) (Potasium ion) (Clay mineral) (Quartz)

The rate of hydrolysis depends on the amount of H^+ which in turn depends upon the composition of air and water in the soil, the activity of organisms, the presence of organic and cation exchange. Hydrolysis is regarded as a physiochemical process as rocks may swell and exert pressure as well as change their chemical structure.

Solution: This is a process in which minerals in the rocks are directly dissolved in water without altering their chemical composition (a direct chemical change). In this process the soluble mineral like rock salt dissolve in the water naturally leading to the disappearance of the rock.

Biological weathering

This refers to the weathering process brought by either animals or plants action. Biological weathering is also known as organic or biotic weathering and it is divided into three types namely *fauna*, *flora*, and *anthropogenic weathering*. Depending on the means of occurrence it can either be a mechanical or chemical weathering process.

Flora weathering: This is caused by plants. It is a mechanical disintegration of rocks occurs due to the penetration of roots. As roots penetrate due to growth of plants, a powerful force widens the cracks hence breaking rocks (Figure 4.6). Decaying vegetation produces organic acids which weakens and break the rocks by the agents of erosion.

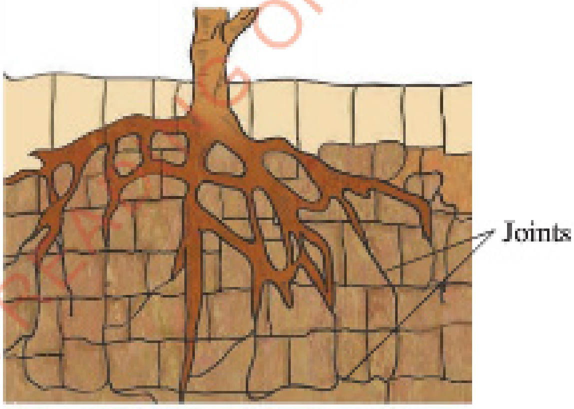


Figure 4.6: *Mechanical disintegration of rocks by plant roots*

Fauna weathering: It is caused by animals. Animals such as rabbits and rats help to loosen and weaken the soil and rock. Burrowing animals move rock fragments and sediments on the earth's surface hence aid the disintegration of rocks.

Anthropogenic weathering: This is caused by human activities. Human activities such as construction of roads, railway lines and buildings leads to breaking down of rocks. Moreover, agricultural and mining activities break rocks physically and aid the process of releasing pressure. Recently, human beings have become the most powerful weathering agent because of advancement in modern technologies.

The interdependence of mechanical and chemical weathering

Mechanical and chemical weathering operate together and are usually complementary although in a given area, one may be more dominant than the other. Chemical decomposition weakens the rocks, making physical disintegration possible, while fracturing (physical weathering) allows deeper penetration of chemical action.

However, chemical and mechanical (physical) weathering have essential differences. In physical weathering, there is no actual change involved in chemical composition of a rock, rather, a rock is weathered into smaller fragments. Chemical weathering on the other hand reaches greater depths of chemical change of the rock which result in the weakening or disintegration of the rock.

Activity 4.2

Use online sources to search on the factors affecting the rate of weathering based on the following aspects:

(a) Nature of a rock
(b) Types of climate
(c) Relief

Factors affecting weathering

Weathering is affected by several factors. The primary factors are: climate, physical properties, mineral composition and rock type while other factors include gradient, organisms, color and time.

Climate determines the kind and the rate of weathering by its elements like rainfall and temperature. For example, climate under low rainfall conditions, mechanical weathering is more dominant as compared to chemical weathering processes. Availability of high humidity encourages both chemical and physical weathering thereby generating new minerals and soluble products. The rate of weathering is relatively higher in wet and hot climates as compared to dry climates.

The physical characteristics of rocks in terms of particle size, hardness, degree of cementation determine the rate of weathering when subjected to agents. For example, rocks composed of coarse fragments such as granite are easily weathered physically than chemically. In contrast, rocks containing fine fragments such as basalt are susceptible to chemical weathering as compared to physical weathering. Hard and highly cemented rocks disintegrate slowly compared to weak and non-cemented rocks. In case of mineral composition, rocks composed of highly weatherable minerals are likely to be weathered more easily compared to rocks with resistant rock minerals. For example, biotite-bearing minerals are weathered more rapidly compared to the biotite-free rocks like basalt.

With respect to rock type, coarse

grained rocks are weathered rapidly as compared to the fine-grained rocks. The inter-granular surface increases with a decrease in grain size, hence demanding much more energy to disintegrate the fine-grained rocks. On the other hand, the highly stratified rocks like lignite weather more easily compared to non-stratified rocks like granite. Therefore, the orientation and the degree of cementation of rocks has a role in determining weathering process.

The horizontally stratified rocks are highly weathered compared to the vertically aligned stratification. For example, the horizontally stratified shales are less weathered and will result into shallow soils than the vertically stratified shales. Furthermore, sedimentary rocks are weathered more rapidly than igneous rocks. This is due to the fact that sedimentary rocks bear a combination of non-clay and clay minerals, and rocks with a considerable amount of clay size are likely to break easily compared to rocks with low clay content. Dark or black coloured minerals like olivine heat more quickly, hence vulnerable to a rapid rate of disintegration, while rocks with light minerals such as quartz and white coloured minerals like limestone heat very slowly, hence exhibit slow rate of weathering.

Other factors that influence weathering include

Gradient; a slope on which weathered material is situated affects the process. A steep slope will cause the weathered material to be washed away while a gentle slope will influence the retention of the material. Organisms; they influence weathering process based on their physical and chemical interactions with rocks. Bedding planes, joints, and fractures of the rocks are likely to influence the entrance of water hence subject the rocks into weathering process. Both plants and animals are responsible in speeding up the rate of weathering. Man through different activities such as agriculture, construction and mining weaken rock structure leading to weathering. Moreover, small organisms such as worms, rabbits and termites which live and feed in the soil, release waste products with chemicals which accelerate weathering process. Plants also influence weathering through their roots as they penetrate the land and accelerate weathering process by weakening and disintegrating rocks.

Importantly, time is crucial in explaining the rate at which the rock is weathered. Weathering can either be rapid or extremely slow. Therefore, time can explain when and at what rate weathering is likely to occur depending on all the other factors covered in this section.

Exercise 4.1

1. Road construction engineers were exploring places where they could establish quarrying sites. Surprisingly, they found clean and recently broken rock surfaces on a virgin land. What might have caused the rock surface to crumble?
2. Image that there is an area of land where weathering has caused damage. Describe ways to reduce the rate of weathering damage on that area.
3. How would physical weathering probably be affected if there were no biological and chemical weathering?

Mass wasting

Mass wasting is a movement of rock materials (regolith) down the slope primarily under the influence of gravity. It includes creeping, flowing, sliding or falling of rocks and weathered materials downhill. Although water is not directly involved in transportation of the mass wasting materials, it is very important in this process as it acts as a lubricant and also it adds weight.

Factors influencing mass wasting

There are several factors which play part in triggering mass wasting. Normally, the factors operate collectively rather than in isolation. The important factors include: nature and weight of the material involved, temperature, rainfall, amount of water, vegetation cover of an area, the angle of slope, anthropogenic activities and tectonic movement.

Nature and weight of the materials may in various ways increase the susceptibility to mass wasting. For example, the deep or thin layered weatherable rocks can greatly result into rapid mass wasting. Likewise, thin beds increase the chances of mass wasting as there are more bedding planes over which movement can occur. Massive overlying weak rocks like clay or shale can easily slide compared to areas covered by sand. In addition, large rocks have a greater chance to easily overcome gravity compared to fine weathered materials.

The angle of slope can also variably and influence mass wasting. For example, the steeper the slope, the faster the movement of the materials. This is so because gravity has much effect with an increasing angle of the slope as opposed to a decreasing angle of a slope.

Climate also plays a crucial role, through rainfall and temperature. Mass wasting depends on the nature and amount of rainfall received. Areas experiencing heavy rainfall are much more susceptible to massive landslides over the steep slopes. On the contrary, low rainfall have less effect on saturating the material and hence reducing the intensity of landslides. On the other hand, freezing and thawing encourage mass wasting as well. In dry climate, the materials may be loose but they lack water, hence movement is likely to be slow.

The amount of water also has an effect on mass wasting depending on the saturation of the materials. The more saturated the materials, the more it is likely to move fast particularly in a steep slope. A saturated material moves more rapidly than the unsaturated ones. The reason behind is that water increases the weight of the material and at the same time reduces the cohesion between particles of the materials. Moreover, water acts as a lubricant along the bedding plane thus, facilitating the gravity-initiated movements.

The availability of vegetation in an area, such as grasses, shrubs, and large trees and their roots helps to hold rock materials together, thus stabilizing the earth's surface against movement. In this case the bare surfaces have a greater chance of encountering mass wasting compared to the areas covered by vegetation. However, presence of dense vegetation cover in wet regions fuels the rate of infiltration into the soil and rocks beneath the surfaces. This causes the rate of saturation of rock materials to be fastened, hence trigger mass wasting.

Human activities like cultivation, grazing, mining, clearing vegetation, and road constructions are greatly affecting the stability of the earth's surface. Vibrations due to moving trains and vehicles can cause tremors and explosion as well as the shaking of the ground and ultimately lead to a downslope movement of some unconsolidated earth materials.

On the other hand, the tectonic movements generated by earthquake and/or volcanic activities normally generate wide spread vibrations which often trigger the movement of materials such as landslides. The forces generated by these tectonic events have far reaching effects including rock fall in steep slopes and landslides.

Types of mass wasting

There are mainly two categories of mass movement namely slow movement and rapid movement. These categories are based on the speed of movement, amount of moisture, angle of slope and nature of material.

Slow mass wasting

This involves a steady movement of earth's materials downhill. The slow movement is almost imperceptible and persists over a long period of time. The common types of slow mass movements include; soil creep, talus creep, solifluction and soil flow.

Soil creep: Soil creep refers to the slowest downhill movement of unconsolidated rock fragments and soil often in very gentle slopes depending on the repeatedly expansion and contraction of soil particles in wet and dry periods (Figure 4.7). It is difficult to measure soil creep as it takes place at a rate of less than one centimetre a year. When wet, soil particles increase in size and weight, and expand at right angles. This happens when the soil dries and contracts vertically resulting to a slow movement of the soil down the slope. The process can also occur in areas experiencing alternate freezing and thawing conditions. Movements of large groups of animals on slopping land and burrowing animals can also facilitate soil creep. Soil creep can be recognized by observing bending trunks of trees, broken fences, tilted electricity and telegraphic poles.

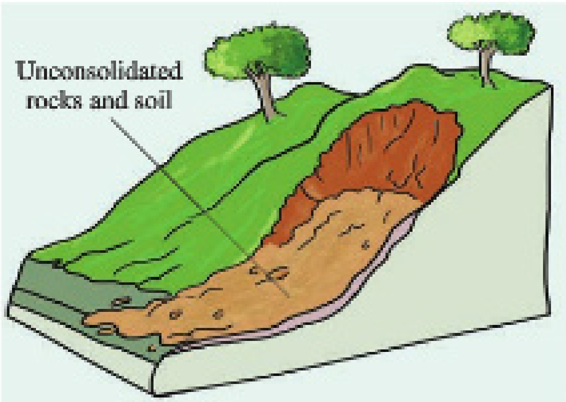


Figure 4.7: *Soil creep*

Talus creep: Talus creep involves a slow downslope movement of the layers of angular loose rock fragments, which typically occupies the foot of the escarpment. Deposits of rock fragments detached from cliffs or mountain slopes are piled up at their bases (Figure 4.8). Talus is a common geologic feature in regions of high cliffs. The angle of slope of a talus is rarely greater than 40°. The constant weathering to which a talus is subjected to, which breaks the rock fragments into finer pieces, and the impact of new material being added from above give, the base of the talus a tendency to creep and slide. The term talus is often used to refer to the fragments themselves.

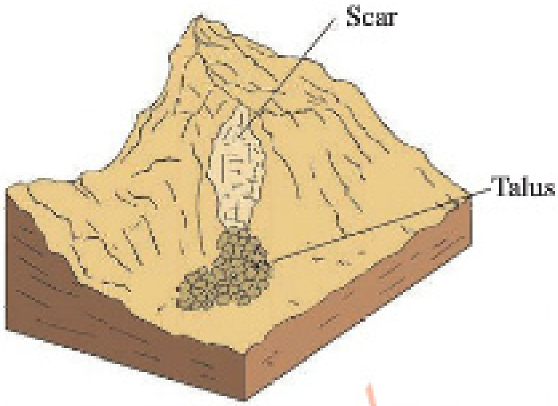


Figure 4.8: *Talus creep*

Solifluction: Solifluction is a slightly faster movement than soil creep. The process involves movement of frozen soil together with rock fragments down the slope. The movement usually averages between 5 centimetre and 1 metre in a year. Solifluction often takes place under periglacial conditions where vegetation cover is limited (Figure 4.9). During winter season both the bedrock and regolith are frozen. In summer, the surface layer thaws but the underlying layer remains frozen and acts like an impermeable rock. When the melting water cannot infiltrate and the temperature is too low for an effective evaporation, any top soil will soon become saturated and will flow as an active layer over the frozen sub-soil and rock. This process results into solifluction sheets or lobes rounded tongue like feature reaching up 50 metres in width and in a mixture of sand and clay formed in valleys and at the foot of sea cliffs.

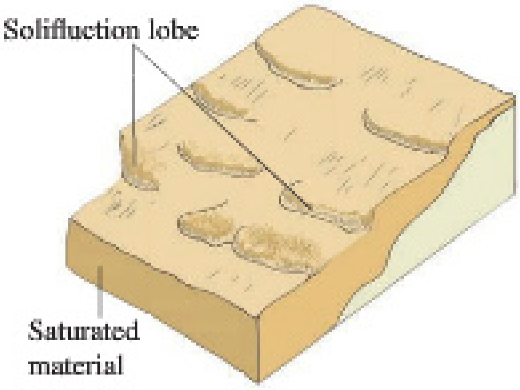


Figure 4.9: *Solifluction*

Soil flow: This is a steady movement of soil in plastic form down a gentle sloped landscape after being too much saturated with water. It readily occurs in clay soil which changes into plasticity especially in wet season.

Rapid mass wasting

This is a rapid process of downfall of materials of a rock to the lowland. It is a large scale movement which acts very suddenly. The movement is basically gravitational. The steeper the slope, the more rapid the movement will be. Presence of water is crucial for rapid mass wasting. If the debris is dry, it will slide or fall as loose mass while with water, the movement is in the nature of flow. The common types of rapid movements include; *landslide*. A rapid movement on a slope downwards which involves movements like mudflow, rock slump, rock fall and rock slide provide basic categories of rapid mass wasting.

(a) Mud flow

Mudflow occurs on a steep slope. It is a more rapid movement of super saturated sediments exceeding one kilometer per hour. The movement occurs after a period of heavy rain. When both volume and weight are added to the soil giving it a higher water content when the earth flows (Figure 4.10). It is one among the most fluidly super – saturated earthly materials consisting of wet soil combined with fine boulders and regolith moving down a slope in a speed exceeding 1 kilometre per hour or few minutes. Depending on the scale, speed and nature of the topography, mudflow might be catastrophic. It can bury and destroy human settlements, hectors of cropland and cause mass causalities. Heavy and down pouring of rain on sloped, bare land and less compacted and porous soil may cause the land to become the prone to mudflow.

For example, the mud flow that occurred in Hanang district in Tanzania in December, 2023 was triggered by heavy rainfalls.

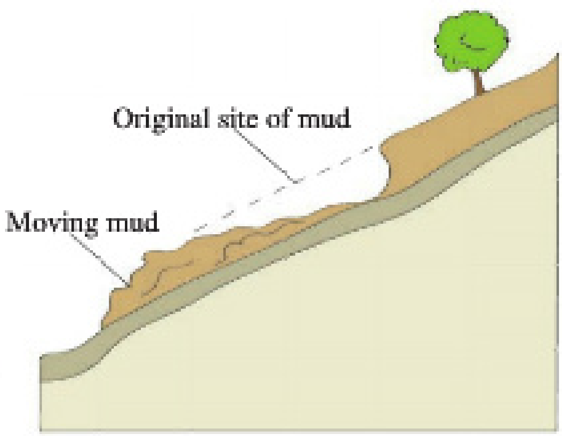


Figure 4.10: *Mud flow*

(b) Rock slump

A slump is a form of mass wasting that occurs when a coherent mass of loosely consolidated materials or rock layers move a short distance down a slope. The movement is characterized by the sliding along a concave-upward or surface. Causes of slumping movement include earthquakes, prolonged heavy rain thorough wetting, freezing and thawing, undercutting, and loading of the slope. In some regions, frost action speeds up the process. Frozen soil and sub soil on steep slope become unstable when they thaw and the movement of water down the slope together with the pull of gravity trigger off a rock slump (landslide). For example, mass wasting that occurred in 1955 at Tukuyu-Kandete area in Tanzania was caused by heavy rain of about 425 milimetres in one night that caused saturation of soil materials. Furthermore, undercutting of a land steep slope by river, sea or through steepening of a land slope by human actions such as quarrying or clearing of land may increase susceptibility of the area to landslide.

Translational slumps occur when a detached landmass moves along the surface. Common plane surfaces of failure include joints or bedding planes, especially where a permeable layer overrides an impermeable surface. Block slumps are types of translational slump in which one or more related block units move downslope as a relatively coherent mass (Figure 4.11).

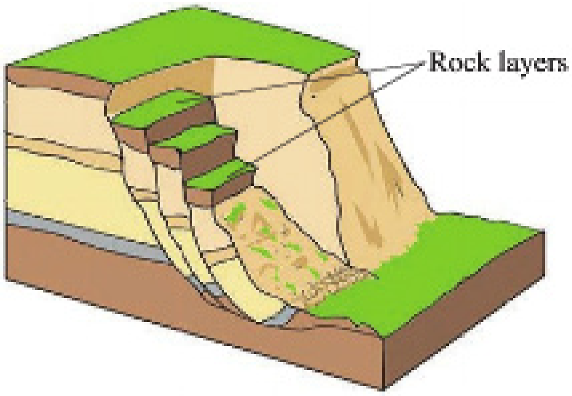


Figure 4.11: *Rock slump*

(c) Rock fall

This is a fall of a individual rock from a steep cliff. It involves a very rapid falling of huge pieces of boulders and blocks of rock down the hills, cliffs or mountains. If rock fall goes on repeatedly for a long time, debris are collected on the slope to form mound (talus). The varying type of agents of weathering and steepness of the land are the major triggering forces behind the rock fall. In the coastal areas the waves cut notch contributing to the occurrence of such falling rocks or boulders on the raised cliffs. The enormous pieces of rock materials which is broken as a result of rock fall at the base or foot of a mountain or cliff is commonly known as scree or talus (Figure 4.12). The rapidity of the rocks downs the hill or mountains depend on the profile and gradient of the slope together with the availability of abstraction. This means that the rocks or boulders rolling or bumping on a bare mountain or hill may accelerate at a tremendous speed and with possible devastating impacts on its way down the hill compared to those rolling on vegetated slopes.

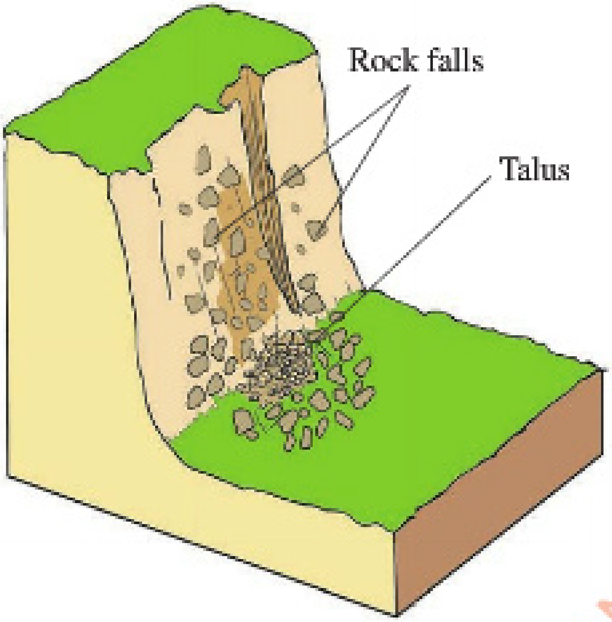


Figure 4.12: *Rock fall*

(d) Rock slide

Rock slide is a type of landslide occurring when a mass of rock moves rapidly downslopes. While a landslide occurs when loose sediments fall down the slope, rockslide occurs only when solid rocks are transported down slope. It is also one among the rapid form of mass wasting. For a rock to slide down the hill it is required to have a jointed structure whose bedding planes are roughly parallel to the angle of the slope. The rock slide may involve huge size of rock or boulders but in a sliding motion down a gentle slope. As for a rock fall, the rockslide may move at a considerable distance depending on the nature of the slope and the moving materials (Figure 4.13).

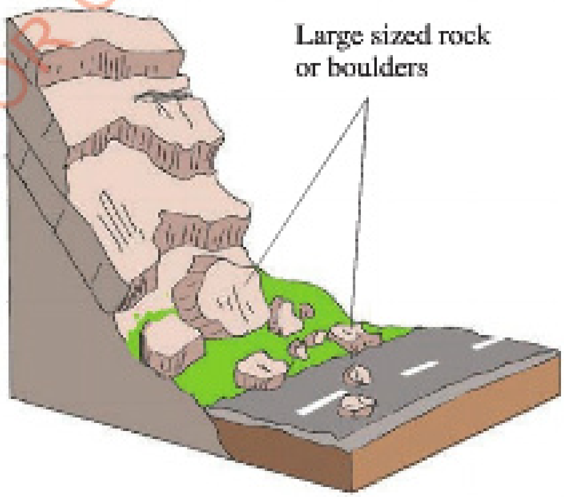


Figure 4.13: *Rock slide*

Precautionary measures to reduce occurrences of mass wasting

In order to reduce the occurrence of mass wasting in the environment, the following are some of the recommended measures;

(a) Reforestation and afforestation along the steep slopes so as tree roots may bind the soil together to reduce possibilities of mass movement in form of soil creep or mud flow caused by heavy rainfall.

(b) Population control along steep sloped area which would have cut the slope in order to set up residential areas, thus increasing loose materials along the slope.

(c) Provision of environmental education about causes, effects and control measures of mass wasting so that people get to know how to live in fragile environment.

(d) Adaption of better and modern farming methods along the steep slopes such as terracing, contour ploughing and strip cropping. These methods reduce surface run off and the possibility for materials to flow down slope.

(e) Hill slope draining so as to reduce excess water that encourage overloading and lubrication of weathered material sparking off mass wasting. It involves digging deep trenches across hills so as to control water run-off.

(f) Enacting some policies and laws about environmental conservation and management.

Exercise 4.2

1. "High risks of mass wasting are predominant in highlands than in lowland areas." Argue for this statement.
2. As an environmental officer, what guidance will you provide to lessen the occurrence of landslides in your community?

Wind action in deserts and resulting landforms

Wind refers to the moving air across the earth's surface from the region of high pressure to low pressure. The wind is caused by uneven heating ranging from low breezes to high breezes such as hurricanes and tornadoes. The movement and patterns of wind are caused by variations in insolation and earth's rotation. Although wind is commonly moving throughout various regions it has a significant effect in the deserts.

Causes of deserts

Deserts are caused by several factors, including rain shadow effects produced by high mountain ranges and presence of moist air forced to rise over mountain ranges which in turn loose its moisture. Consequently, dry air comes down on the other side of the mountain, compressed and warm, bring high evaporation with little or no rainfall. This dry region of the mountain or downwind side of the range is the rain shadow zone or the leeward side. Moreover, cold ocean currents explain the occurrence of deserts. Usually these currents do not bring moisture in the areas where they pass. Instead, they cause high evaporation or bring very little rains. This is experienced on the western coasts of continents. On the other hand, long distance from the sea is also another cause of deserts whereby most of the rainfall comes from water evaporation thus areas far from the ocean receive less rainfall unlike coastal areas.

Moreover, in sub-tropical high pressure zone where air descends, it is compressed and warmed, thus producing an area of permanent high pressure. As the air warms it can hold and increase amount of water vapour which causes the lower atmosphere to become very dry. The low relative humidity and little surface water of the area for evaporation gives a clear sky resulted to no rain formation. Other causes of deserts formation include geographical location of an area, air circulation patterns, climate, and the human activities.

Essentially, the geographical distribution of deserts is largely controlled by global and regional atmospheric circulation patterns.

Human activities such as shifting cultivation, overgrazing, deforestation for different purposes contribute to desertification. Generally, deserts cover all arid regions that normally experience an average rainfall of about 250 mm per year. Deserts are persistently dry, have high rates of evaporation, hence, poorly developed soils, and are mostly or completely covered with sparse vegetation. The deserts experience the average summer temperature of about 32°C to 38°C while the daytime winter temperature records 10°C to 18°C on average. Most of the deserts are located between 15° and 30° North and South of the equator (Figure 4.14).

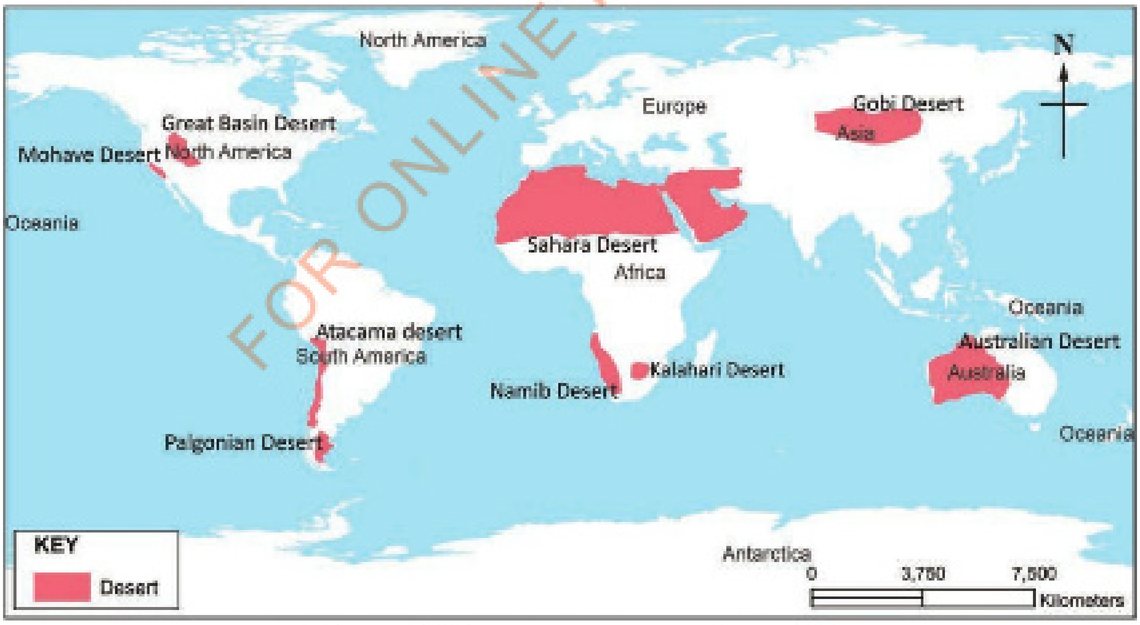


Figure 4.14: *Desert areas in the world*

Wind action in desert areas

As wind blows in desert areas it erodes, transports and deposits materials from the land surface. Therefore, wind action in the desert areas involve erosion, transportation and deposition of different materials. These processes result into the formation of different landforms on the desert area.

Forms of wind erosion

The process of wind erosion in desert areas is carried out into two main forms namely; deflation and abrasion. Deflation is the process of removal of the fine material and leaving behind pebble-strewn desert pavements (Figure 4.15). Deflation causes hollows or depressions due to the blowing away of the fine materials and ultimate by lowering the surface to some depths.

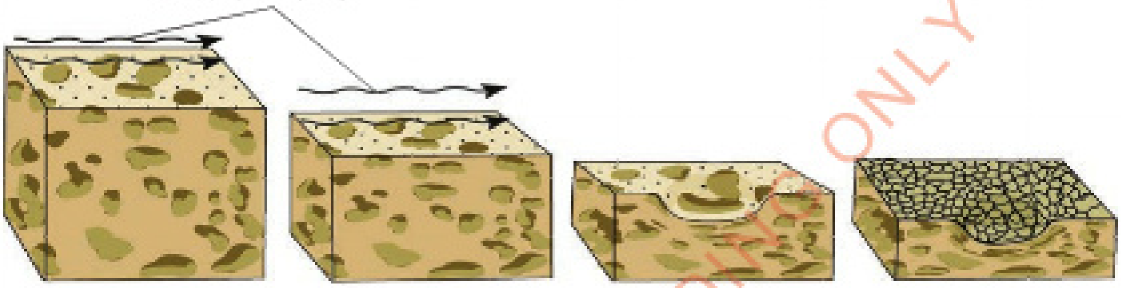


Figure 4.15: *Process of deflation*

Landforms resulting from wind deflation

Landforms formed by wind deflation include deflation hollows and depressions. Deflation hollows are enclosed hollows produced by wind erosion. A deflation hollow is one of the most graphic results of deflation that leaves behind a rocky surface especially that of homogeneous resistance. Furthermore, deflation forms both small and large depressions. A good example of such depressions is found in the limestone plateau west of the Nile valley, in Egypt. The largest depression is Qattara depression which extends about 134 metres below sea level. Some of the depressions in desert areas can extend down filled with water, resulting to the development of water table. When a depression is filled with water it is referred to as *oasis*. Good examples of oases are the Ein Gedi in Israel and Al Farafra in Egypt (Figure 4.16). A number of assumptions account for the formation of depression.

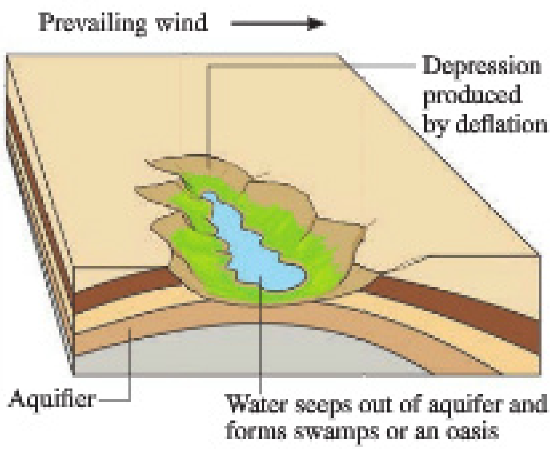


Figure 4.16: *Deflation hollow*

Deflation process is affected by the resistance of the rocks. For example, where the ground surface is made up of hard rocks the rate of wind erosion will be slow, but where it is made of soft rock the rate of erosion will be high and easy to form a deflation hollow. The relative ability of wind to erode and carry out loose particles is another factor influencing the deflation process. On the dry land wind has the ability to screw and pick sediments upslope as well as downslope until a watertable reached. Wind velocity is another factor. For example, a velocity increase from 2 to 6 meters per second causes an eight-fold increase in wind speed from 2 to 10 metres per second and generates a 125-fold increase in erosional force. Consequently, fast wind is capable of causing much more erosion than slow wind.

Abrasion as the second process of wind erosion involves blasting, grinding and scratching rock surface by sand particles carried by wind which hurls these materials against the rock. This process smoothens, polishes and wears away rocks close to the ground.

Landforms formed by abrasion

Different landforms are formed by abrasion process including *ventifacts*, *yardangs*, *rock pedestals*, *inselberg* and *zeugens*.

Ventifacts: These are individual pieces of hard rock, broken off by mechanical weathering but too heavy to be moved by the wind. They are usually worn away on the windward side (Figure 4.17). They are either sharpened or flattened by the action of sand blasted load passing over them. They are rocks that have been sculptured by wind-borne particles as they are worn, faceted, cut, or polished by abrasive action of windblown sands. Usually this occurs under arid conditions, in areas subjected to frequent, high-velocity, and sand-laden winds.

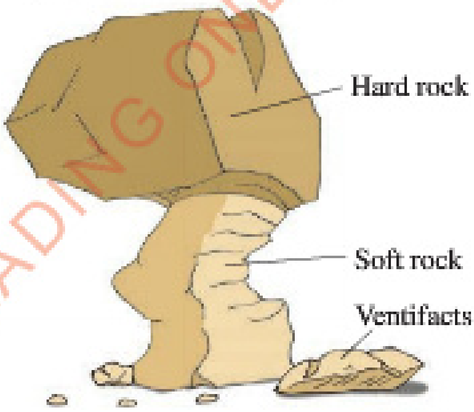


Figure 4. 17: *Ventifacts*

Rock pedestals: These are tower-like landforms formed when the weaker strata in a mass of rocks are shaped by wind abrasion to give structures of various shapes (Figure 4.18). These features are common in the Tibet Mountain of Central Sahara, and the Devils Rock of Agadez in Niger. As abrasion goes on attacking the weaker rocks, the pedestals may break at the base and collapse.

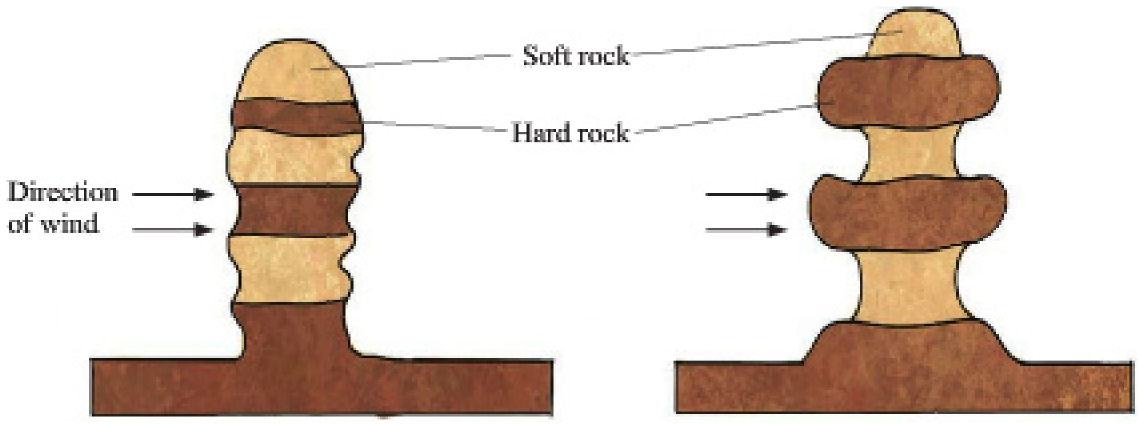


Figure 4.18: *Rock pedestals*

Zeugens: These occur when wind abrasion turns a desert surface which has horizontal alternate layer of resistant and soft rock into ridges and furrows-like structures. Furrows are developed by wind along the rock joints by widening soft rocks until the ridges are left behind protected by their resistant rocks. Therefore, zeugens are parallel flat topped ridges of hard rock up to 3 m high to the direction of wind (Figure 4.19). Examples of zeugens can be seen in Bahrain (Middle East).

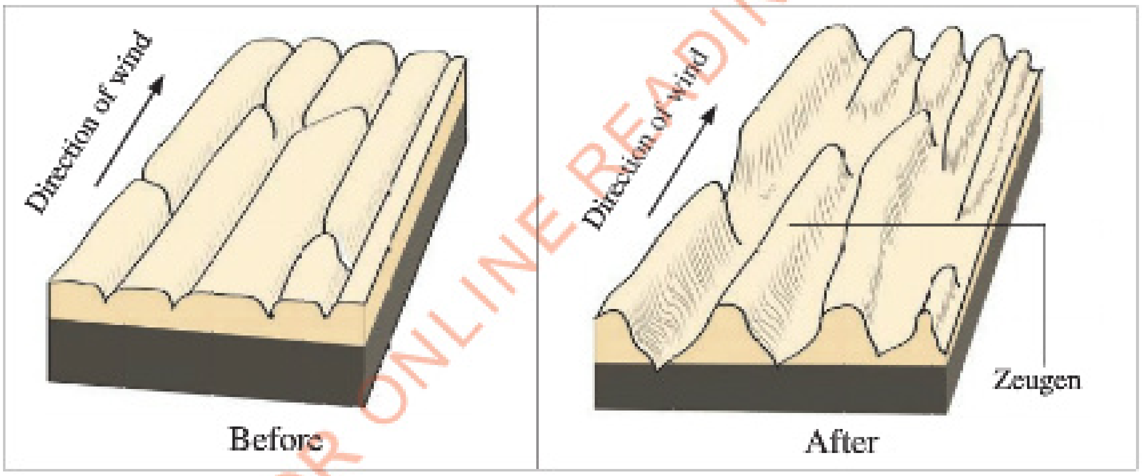


Figure 4.19: *Zeugens*

Yardangs: These are formed when bands of resistant and weak layers of rocks are laid vertically and parallel to the preceding winds in the desert and as a result, wind abrasion produces another type of ridge and furrow landscape. They are usually less than 10 metres high and 500 metres long but some are even higher (Figure 4.20). An example of these is the Silsila gap in Egypt, north of Kom Ombo.

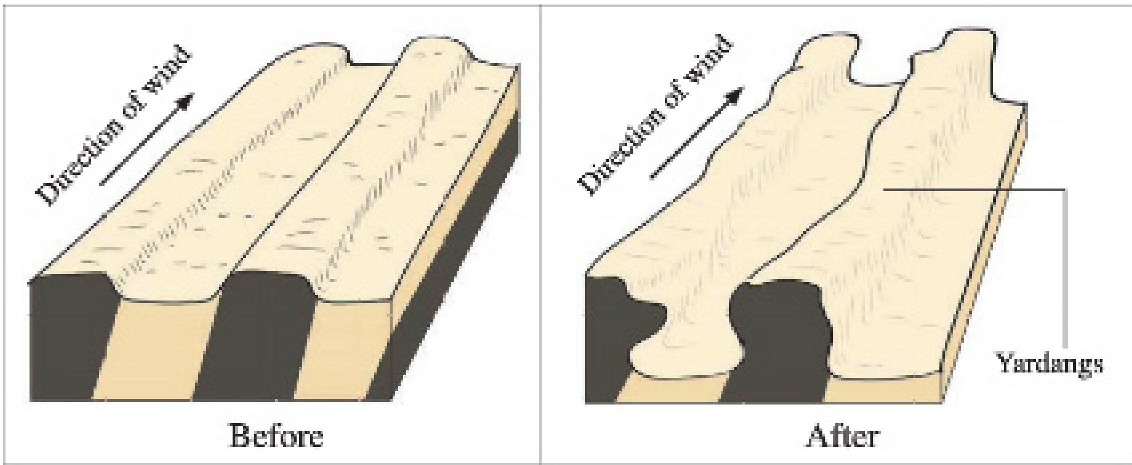


Figure 4.20: *Yardangs*

Inselberg: Inselberg is a German word which means an island mountain. An inselberg is a steep sided hill rising abruptly from pediment which extends on all sides into monotonous plain (Figure 4.21). In some desert regions, water erosion has removed all the original surface except for isolated pieces which stand up as round topped masses. Some inselbergs remain as plateau edge after weathering. Inselbergs are common in Kalahari Desert, in some parts of Algeria, North West Nigeria Western Australia and Northern Tanzania in Maasai land. Morevoer, an inselberg can be described as a residual hill or rock mass rising abruptly from the desert floor. When an inselberg is smooth and round in shape, it is called *Bornhardt* and when it is characterized by joints with rectangular rock blocks pilled together to produce castellated form, it is called *Kopjes*.

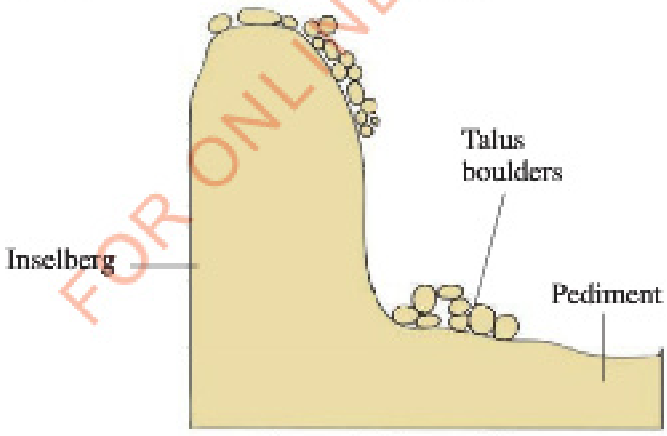


Figure 4.21: *Inselberg*

Millet Seeds: It is also known as rounded sand grains. These are formed due to the collision of sand grain with or against one another and that result into a rounded sand grains (or millet seeds). This eventually forms the dominant 'end product" of desert erosion.

Wind transportation

Transportation by wind in the desert moves away materials through three processes namely; *suspension*, *saltation* and *surface creep*.

Suspension involves movement of fine materials by wind which are then raised into a substantial height and carried to a greater distance. The movement of dust in the air to a great distance is sometimes called dust storm.

Saltation involves blowing the sand particles while bouncing them on the ground and over one another.

Surface creep involves the process of rolling materials which are heavy and cannot be lifted by wind. The materials are rolled from one place to another depending on the strength and direction of the wind. The materials which are carried by wind are transported and deposited. These materials are generally referred to as *loess*.

Transportation or movement of particles depends on several factors. A wind speed of about 20km/hr is ideal for movement of sediments. Another important factor is a constant direction and steady wind blow for a length of period of time, nature of regolith and absence of vegetation to bind them together or to absorb some of the wind energy. Moreover, dry and unconsolidated or often small enough particles can easily be transported by wind. Therefore, wind erosion in desert areas, can be effective anywhere, depending on its strength.

Wind deposition

Deposition of loads carried by wind depends on the size of material and the strength of the wind. For example, the finest-dust like grained may be moved right out of the desert areas while the heavier one may simply be resorted within the desert. Features formed due to wind deposition include:

Sand dunes

Sand dunes are hills of sand which have been deposited by wind in the desert. There are different types of sand dunes namely; *barchans*, *attached*, *transverse*, *longitudinal* or *seif*, *star* and *parabolic dunes*.

Seif dunes: These are also called longitudinal dunes. They are long narrow ridges of sand which lie parallel to the direction of the prevailing wind. They are large and extend to about 100 kilometres in length and 200 metres in height. A seif dune usually develops from a small sand ridge which as it forms it slowly moves forward in the direction of prevailing winds (Figure 4.22). Good examples of seif dunes occur in the Thar.

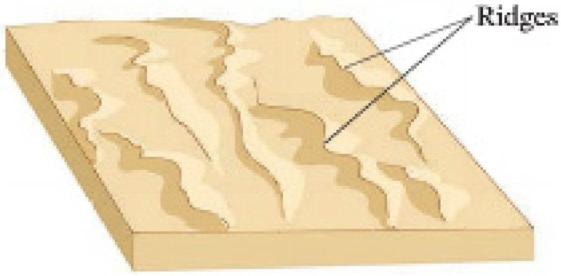


Figure 4.22: *Seif dunes*

Barchan dunes: Barchans are sometime known as barkhans. They are crescent shaped sand dunes which occur either individually or in groups. A barchan usually develops from the accumulation of sand caused by small obstruction such as a rock or piece of vegetation. As the mound grows larger, its two edges are slowly carried forward downwind and a typical crescent shape develops. The windward face of the dune is gently sloping but the leeward side is steep and slightly concave. A barchan's height ranges from few meters to 30 metres and is 400 metres wide (Figure 4.23). There are good examples of barchans in the Sahara desert and Turkestan.

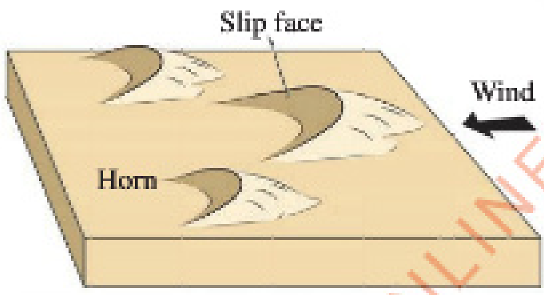


Figure 4.23: *Barchans*

Attached dunes: Attached dunes are also known as head dunes. These are sand drifts caused by an obstacle of vegetation or a rock in the path of the prevailing wind. Sand accumulates in the 'dead air space' around the rock to form 'wind line shape' on the windward side of the obstacle and formation of tail dunes on the leeward side.

Transverse dunes: These are long wave-like ridges separated from each other by flat bottomed troughs. They tend to form huge dune fields, but most of them are less than 50 metres high. They are built by light to moderate winds, blowing from one direction only. Wind usually blows perpendicularly to the dune (Figure 4.24). In the Western Sahara, they are known as *ankle*.

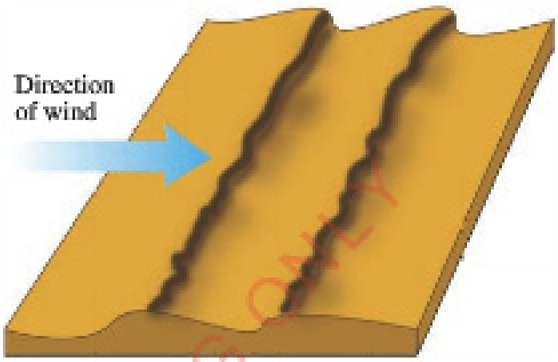


Figure 4.24: *Transverse dunes*

Star dunes: These are complex dunes with a star-shape, formed by winds blowing from several directions (Figure 4.25).

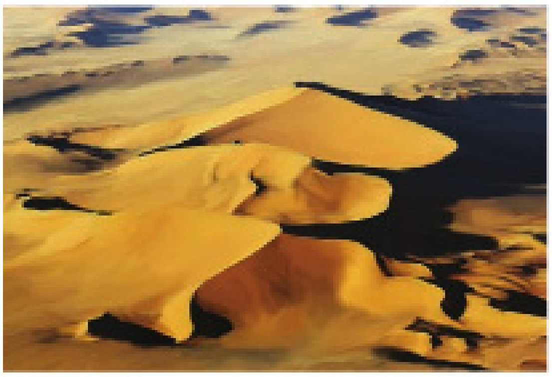


Figure 4.25: *Star dunes*

Parabolic dunes: A parabolic dune is somehow similar in shape with a barchan dune, except that it is deeply curved and is convex in the downwind direction. The horns point upwind and are commonly anchored by vegetation (Figure 4.26). The parabolic dune requires abundant sand and commonly forms around a blowout. As they require abundant sand and strong winds, parabolic dunes are typically found inland from an ocean beach.

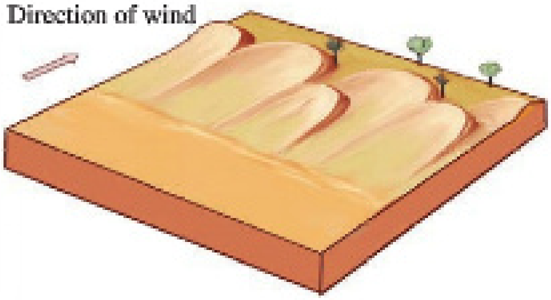


Figure 4.26: *Parabolic dune*

Ripples

These are series of small parallel ridges produced by saltation of coarse sand. They often occur on the slopes of dunes. Ripples indicate the direction of sand movement.

Loess

Loess refers to an accumulation of fine particles of sand that have been carried and deposited by wind beyond the desert limits. It occurs extensively in the loess plateaus of the Northern China in Hwang-Ho river and in the Nile river from the Sahara Desert. Loess form fertile soil and a good example is Hwang Ho basin that attracts agricultural development.

Activity 4.3

Visit a library or use internet sources to read more on wind action in deserts and thereafter write a summary in your exercise book.

Water action in deserts and resulting landforms

Rainfall is very rare in deserts and when it rains may result into rushing torrents on steep slopes and cause sheet flood on gentle slopes. Thus, it is not only the wind that is responsible for shaping the deserts but also water plays a great role in eroding the desert surfaces and depositing the materials leading to a number of erosional and depositional features on the topography of a desert.

Water erosional features in the desert area

Water action in the desert area produces erosional features namely rills, gullies, wadis, pediment, mesas and buttes. The formed features are influenced by the relief, nature of rocks, land surface cover and amount of rainfall received in the area. These features are described in the section that follows.

Rills

Rills are small, shallow channels formed by surface runoff on a desert area (Figure 4.27). The desert surface is washed unevenly by running water through small channels called rills.

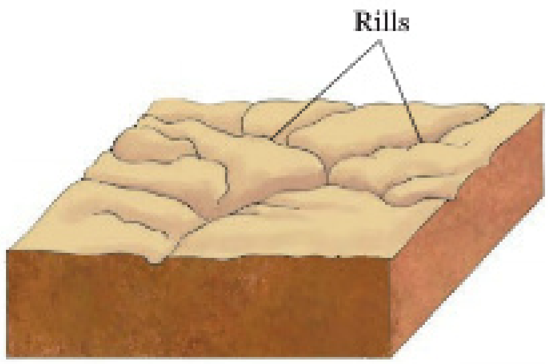


Figure 4.27: *Rills*

Gullies

Gullies are deep steep sided troughs produced when erosion in the rills becomes more concentrated into the ground. They occur when heavy rainfall opens and widens the rills into larger grooves (Figure 4.28).

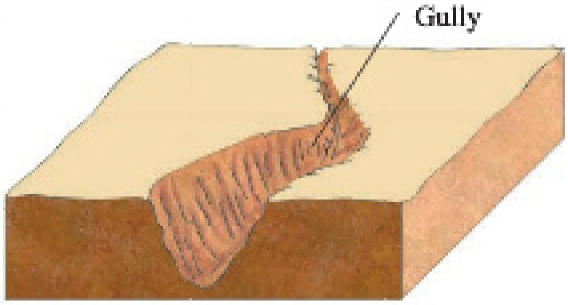


Figure 4.28: *Gully*

Wadis

A wadis is also known as chebka. These are deep cut valleys which have been formed by exotic river flow across the desert but have delivered the bulk of their water from outside of desert (Figure 4.29). Few wadis hold permanent streams, and may be flooded during the rainy storm. Wadis are common in Saharan desert, for example, Hamra, Talh Abd el Malik and El Bakht.

Figure 4.29: *Wadis*

Pediment

This is a gently sloping platform formed when the edges of the desert and semi-desert highlands get pushed back by erosion. They are covered with a thin veil of debris.

Mesas and buttes

Mesas are extensive flat-toped residual table lands which are generally capped with resistant rock stratum (Figure 4.30). Buttes are small residual flat-topped hills usually capped with resistant rock stratum which remains after denudation of mesas or a plateau. These features are common in the Northern areas of Turkana in Kenya.

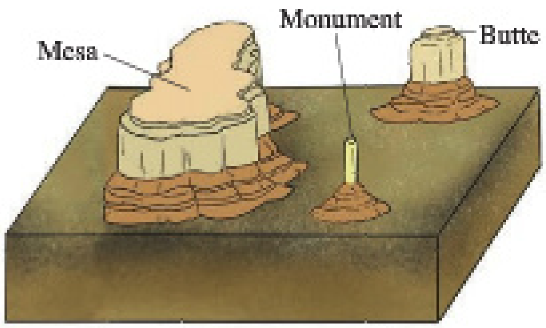


Figure 4.30: *Mesas and buttes*

Features formed by water deposition in desert area

Water action in the desert results into a different depositional features namely *alluvial fans*, *alluvial cones*, *bajada*, *peripediment* and *sebka* (Figure 4.31 and 3.32).

Alluvial fans

Alluvial fans are also known as cone. These are fan-shaped features formed when large quantities of sediments are deposited at the gullies. They are formed where sediments loaded streams exist steep floor to deposit their load on the flat desert floor.

Alluvial cones

Alluvial cones are formed when large quantities of coarse sediments are deposited at the foot of steep slopes. Alluvial cones are similar to fans but differ in the sense that they are composed of coarser materials and constitute steeper slopes.

Bajada

Bajada are sometimes known as bahada. Some basins are rimmed by uplands, and temporary rivers emerging from the uplands build up alluvial cones (similar to fans but made of coarse materials) at the foot of the upland. These eventually join together to form a continuous feature known as bajada. They are formed when several wadis cut through a highland close to each other.

Peripediment

Peripedment is a gentle slope, formed when alluvial deposits overlie the edge of the pediment surrounding the sebka. It is the area of accumulated sands and gravels peripheral to a pediment in desert basin.

Sebka or playa

There is no permanent drainage patterns in deserts, therefore any rain that falls either evaporates, or infiltrates into the surface, or runs off and drains into basins (depression). After a heavy fall of rain, temporary streams and rivers develop which may eventually drain into basin where they produce lakes. The lakes soon dry up through evaporation and turn into salt flats called sebka.

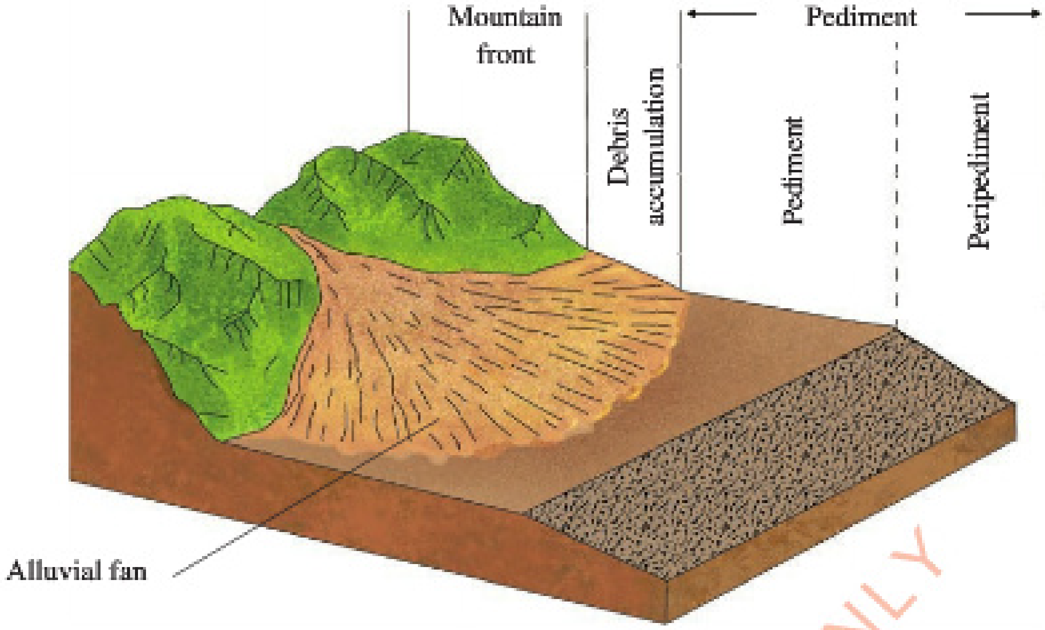


Figure 4.31: *Water erosional and depositional features in desert*

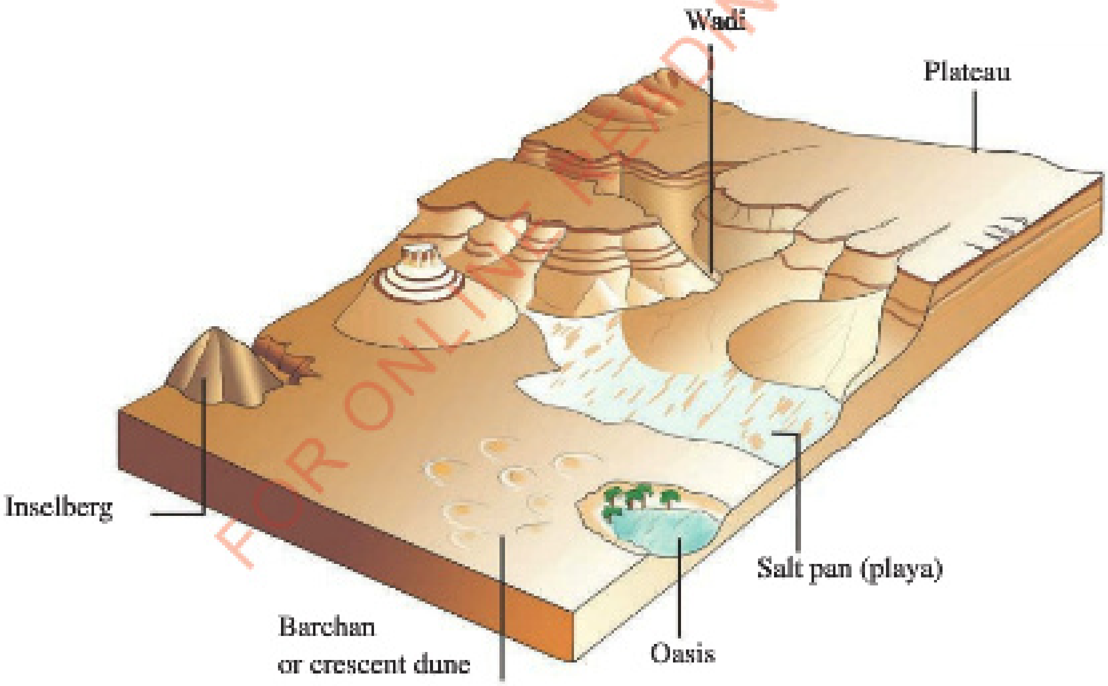


Figure 4. 32: *Water erosional and depositional features in the desert*

Activity 4.4

Read books and other materials about water and wind actions in desert areas. Write down the economic importance of the features formed due to those actions.

Water action in karst region and resulting landforms

The term *karst* is borrowed from Yugoslavia and it means features formed in the limestone regions mostly dominated by limestone rocks. It is formed when water react with soluble limestone or dolomite to form sinkholes, sinking streams, caves, springs, and other characteristic features. These features are characterised by materials that can assume different forms such as calcium carbonate, marble or gypsum. Calcium carbonate may exist in various forms of chalk, Jurassic and carboniferous limestones consisting mostly of fossils.

A typical karst landscape forms when much of the water falling on the earth's surface enters the cracks, fractures, and holes and eventually dissolves the bedrock to form solution. The formed solution can be discharged from springs that are often cave entrances. For example, some places in Tanzania are characterised with karst regions. It hosts significant composition of limestone rocks, such areas include Amboni in Tanga region and Nanyala in Songwe region respectively. Also, the karst region is found in Slovenia, Southern Europe.

Characteristics of the karst region

The karst region is characterized by scant vegetation such as scrubs and thickets. The region has rock outcrop with poor soil in some parts, however, this poor soil support the growth of grasses for livestock keeping. Its rocks are porous with well jointed structure that allows percolation of rain water through the cracks which is referred to as secondary permeability of rock.

Carbonation is the dominant weathering process in the region therefore, reaction between carbonic acid and limestone minerals takes place to form carbonates. However, surface drainage is limited due to the presence of underground rivers. The region is characterized by both surface and sub-surface landforms such as stalagmites, natural pillars, and helicities associated with evaporation and precipitation of calcium bicarbonate. Also, there are residual features like *scarps* and *hills* that consist of resistant rock as well as *gullies*, *rills*, *sink hole* and *grikes*.

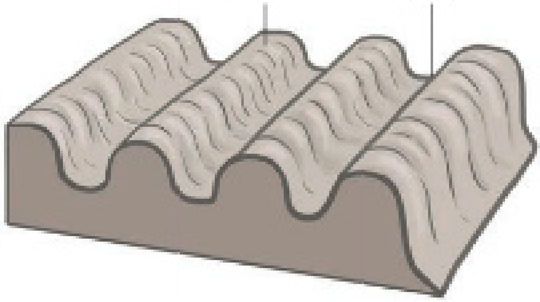
Landforms formed in the karst region

Features formed in the limestone region are classified based on the place of their occurrence. They are therefore classified into two types namely surface and sub-surface features.

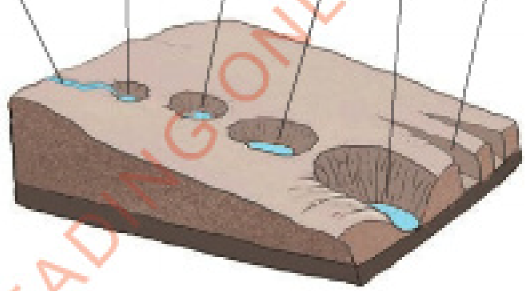
Surface features formed in the karst region

The surface features are landforms formed on the surface of the limestone region as a result of the influence of rain water (Figure 4.33). The features include: *Scarps, hills and mountains* which are pieces of hard rock that remain standing after the other top soil covering materials are worn away by the running rain water. *Grikes* which are depression-like landforms that are formed as a result of water eroding the cracks of the surface of the limestone region allowing water to disappear underground. *Clints* are flat-topped ridge or block like landforms that separate one grike and another. Their formation depends on the flow of water in the fractures of limestone rock.

Swallow hole/sink hole/ponor are vertical holes formed as a result of the enlargement of the rock cracks caused by the accumulation of water on the surface of the limestone region. *Doline* which is referred to as a shallow depression with gentle slopping sides and generally circular in plain is formed as a result of combining/merging several swallow holes. *Uvala* is a large depression formed when several dollies join together. The diameter of Uvala can extend to about one kilometer. *Polje* is a very large depression formed when several uvalas collapse and join together. The collapse may be due to dissolving associated with faulting. *Gorge* that refers to a steep sided trough lined by steep rock cliff is formed as the results of the collapse of the roof of the cave.



(a)



(b)

Figure 4.33: *Surface landforms in the karst region*

Sub-surface features formed in the karst region

Sub-surface features are also called subterranean features. These are landforms formed within the limestone region. Their development is a result of formation of solution and precipitation of calcium bicarbonate materials (Figure 4.34). Sub-surface landforms include *Cave or caverns* these are underground chambers or cavity like an opening formed as the results of dissolving of limestone rock underground. *Underground river* is a river stream formed when water sinks and flow underground through the sink hole. That river flow is also called subterranean river. *Stalagmites* are finger like structure of rock masses that grows from the floor of the cave upward. Their formation is a result of precipitation of calcium bicarbonate materials that accumulate on the floor of the cave. *Stalactites* are finger like structure of calcium bicarbonate (calcitic) materials that grows from the roof of the cave down ward. They are usually hanging vertically from the roof of the cave. *Natural pillar* is a pillar or column like landform formed as the results of the joining of stalagmite and stalactite. Also, it can be formed when stalagmite grows to the roof of the cave. *Anthodites* are flower-like structure that grows from the roof of the cave often lacks a well-defined shape as they are very small in size. *Helctites* which are crystalline formation that are of different shapes. They are as thin as threads arranged spirally, and they can rejoin the ceiling of the cave.

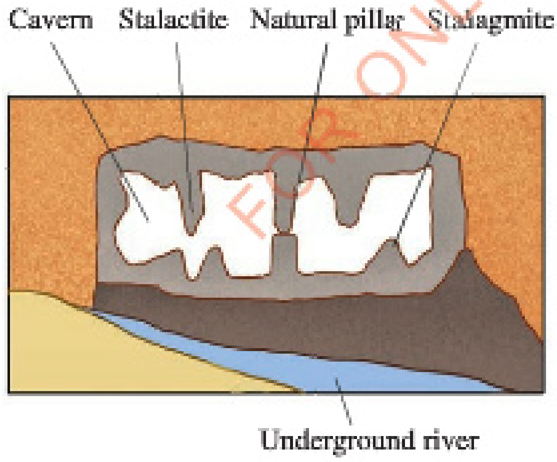


Figure 4.34: *Sub-surface landforms in the karst region*

Importance of karst region

The karst region has several values or importance, the major ones include: it supports livestock keeping as it provides grasses that are used by goats, sheep or cattle. For example, in Yugoslavia, karst region is used for sheep raring. In some areas, the regions provide fertile soil that can be used for crop production. Such soil includes *toreros soil*. The region also provides rocks that can be used for construction activities. Karst region provides raw materials that can be used in different industrial sectors. Such as limestone rocks which are essential materials for the manufacturing of cement. Moreover, underground features in the limestone region such as cave, stalagmite, stalactites, natural pillars attract tourism which in turn may provide foreign currencies. For example, Amboni Tanga in Tanzania. Karst region is a basic sources of water bodies such as underground river that provides water for different uses.

Exercise 4.3

1. For centuries, tourists from different parts of the world travel to the Sahara desert to view natural scenes of the Desert. As a desert tour guide, how would you describe the origin of wind related tourist attractions found in the area?
2. With the aid of a diagram, explain why wind is considered the major factor of erosion in desert areas.

3. With the aid of diagrams, clearly explain the distinctive features formed by fluvial action in the desert.
4. Despite karst region being characterised by scant vegetation and poor soil, it has socio-economic significance. Explain.

River action and resulting landforms

A river is a natural outflow of water from one point to another. It is among the major agents of denudation and deposition. As it flows it causes land sculpturing through erosion, transportation and deposition of materials. The eroded materials sometimes move hundreds of kilometres from its source to the plain stage. The materials transported by a river are known as *load* and can be in the forms of mud, silt, sand, gravel or suspension. Erosion caused by running water is known as *fluvial erosion*.

River erosion

Erosion is one of the main geological functions of a river. It involves physical removal of the soil materials by the influence of the moving mass of water. Its intensity varies from place to place depending on water supply, gradient and nature of the underlying rock. The erosive work of the running water along the river bed and banks performs four main processes which are; hydraulic action, abrasion or corrasion, attrition and solution. *Hydraulic action* is the force through which water hits river banks, and pushes water into cracks in the river. The air in the cracks is compressed, causing to high pressure which weakens and washes out weak materials, thus, with time the river banks collapse. Water itself is used as a tool to wear away the surface rocks. *Abrasion:* Abrasion is also known as corrasion. It refers to the wearing away of the beds and banks of the river by the load (rocks or pebbles) carried along by the river. The action involves grinding and plucking of loads against the bed and the banks of the river. The materials carried by water are used as a tool to wear the river banks. This process is most effective in rain season and it takes place mostly in the upper course and middle course of a long profile of the river. *Attrition:* Attrition is the rubbing away or wearing down by friction. It occurs when materials carried downstream are reduced in size by striking against each other and against the bed and banks of the channel. As they continue colliding, angular rocks become smaller and smaller to fine sizes, while others which are in irregular shape are increasingly rounded in appearance. *Solution:* Solution is also known as corrosion. It occurs in all stages of the river development. It is independent of the gradient, volume and amount of loads carried by the river and the erosive process. It is related to the chemical composition of the water and the rock. Acidic water acts as a solvent in calcareous rock like limestone and salt rocks. This acid helps to turn many insoluble minerals into soluble minerals that can be carried away in solution.

Effects of river erosion

These four processes of river erosion in their combination, enable the river to erode its channel in three ways; vertically, laterally and headward.

Headward erosion: It takes place at the origin of a stream channel, It occurs when the river cuts back at its source causing the origin to move backward away from the direction of the stream flow. This erosion causes the stream channel to lengthen. (Figure 4.35).

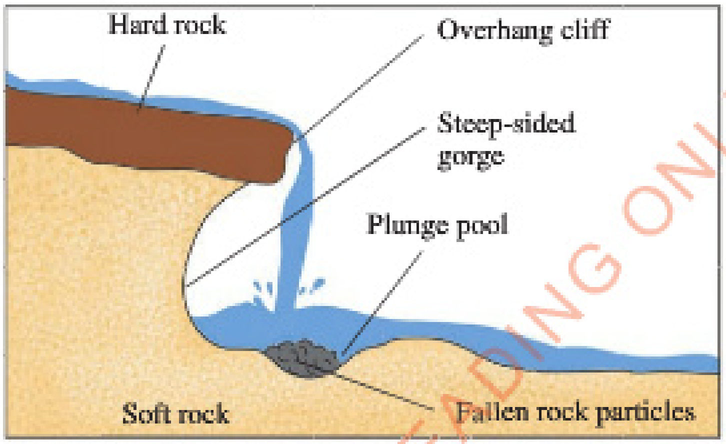


Figure 4.35: *Headward erosion*

Vertical erosion: Vertical erosion is a geological process whereby hydraulic action deepens the channel of a stream or valley by removing materials from the stream`s bed or valley floor. This happens more in the upper stage and middle stage of river development (Figure 4.36).

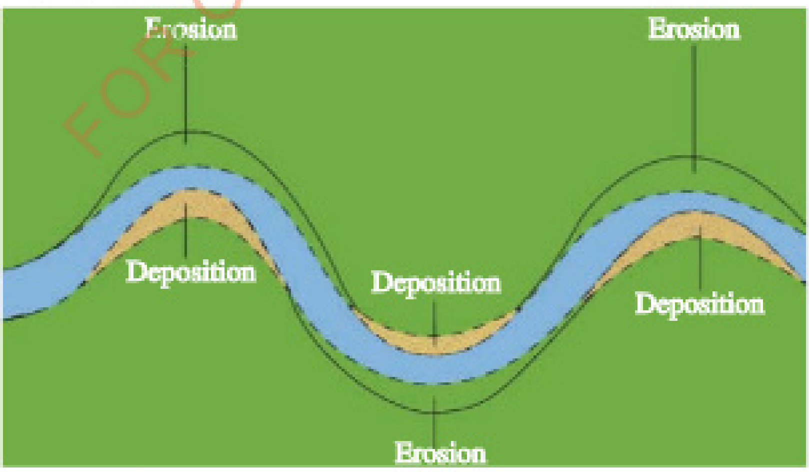


Figure 4.36*: River erosion*

Lateral erosion: It is the wearing away of the sides of a river channel. This is mostly effective along outside meanders (Figure 4.36). This form of erosion makes a river wider and it is most common in the middle and lower stages of a river.

River transportation

This process involves transportation of weathered debris from the valley sides, rock particles eroded from the bottom and sides of the channel from one place to the other. The larger the river volume the greater the amount of energy available for transporting the load. Too much load reduces the erosive power of the river which ultimately leads to deposition. As the load is carried downstream the materials are gradually reduced in size as they strike against one another or against the channel sides. In general, the load is transported through four main processes namely: suspension (grasses, leaves), solution (mud), saltation and traction (boulders which moves along the bed of the river). *Traction* involves the rolling and dragging of large particles such as boulders along the bed. The *saltation* process, involves bouncing of small particles along the river bed whereas *suspension* refers to the movement of very fine particles held up by the turbulence of the water. *Solution* occurs when dissolved materials are carried by a river. Minerals are dissolved in slightly acidic water and are carried along in solution. This typically occurs in areas where the underlying bedrock is limestone.

Factors influencing the rate of river transportation

There are different factors that influence the rate of river transportation. These include;

(a) The volume of water in the river; The energy of the river for transporting the load is affected by its volume. If the volume of water is high especially during flooding, the river has a higher ability to transport the load than when water volume is low.

(b) The larger the size of the load relative to the volume of water in a river, the lesser the ability to transport it.

(c) The relief of the river: A river flowing along steep slopes has greater ability to transport the load than a river flowing on a gentle slope. This is because along a steep slope the river moves swiftly than on a plain land.

(d) The larger the river, the greater its energy, and thus the higher its ability to transport its load. This means larger rivers have greater energy to transport loads compared to smaller rivers.

(e) Water speed (velocity): The higher the velocity of water flow the higher the chance to pick up larger materials, hence the higher the chances to transport them. Therefore, rivers with high speed can transport their loads more than low flowing rivers.

River deposition

Deposition occurs when stream's energy is insufficient to carry the entire load. Moreover, deposition is the function of a river which is determined by the failure of transportation. Large boulders and other heavy particles are deposited first, followed later by finer debris. Materials deposited by a river are called alluvium. Deposition is greater in the lower course, especially in the flood plains, such as inside the meanders. The channel is normally too small to hold all the loads hence water discharges out on the adjacent flood plain (Figure 4.37). Thus, together with limited gradient, speed is reduced and the river is no longer competent to carry all its load, thus deposition takes place.

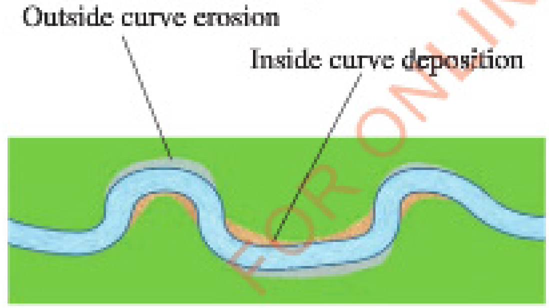


Figure 4.37: *River deposition*

Deposition is contributed by a decrease in water volume, velocity, and presence of obstacles when the river enters a lake or sea. Deposition occurs locally whenever speed is reduced, such as on the side of a meander or where there is a sudden decrease in gradient or where a narrow valley suddenly opens into a broad plain.

Cross profile of a river

This refers to the width of a river from one side of a bank to another. It usually varies from its source to the mouth as it is narrow in the youth stage where V-shaped valleys are formed and it widens at the middle because of lateral erosion and become wider at the lower course. Usually it is a function of lateral erosion.

Long profile of a river

This covers the total length of a river from the source to its mouth, forming a slope because of variation in vertical and lateral erosion. Like in cross profile, also long profile is sub divided into three sections; a steep at the youth stage, a gentle middle and almost a plain old stage (mouth) of the river (Figure 4.38).

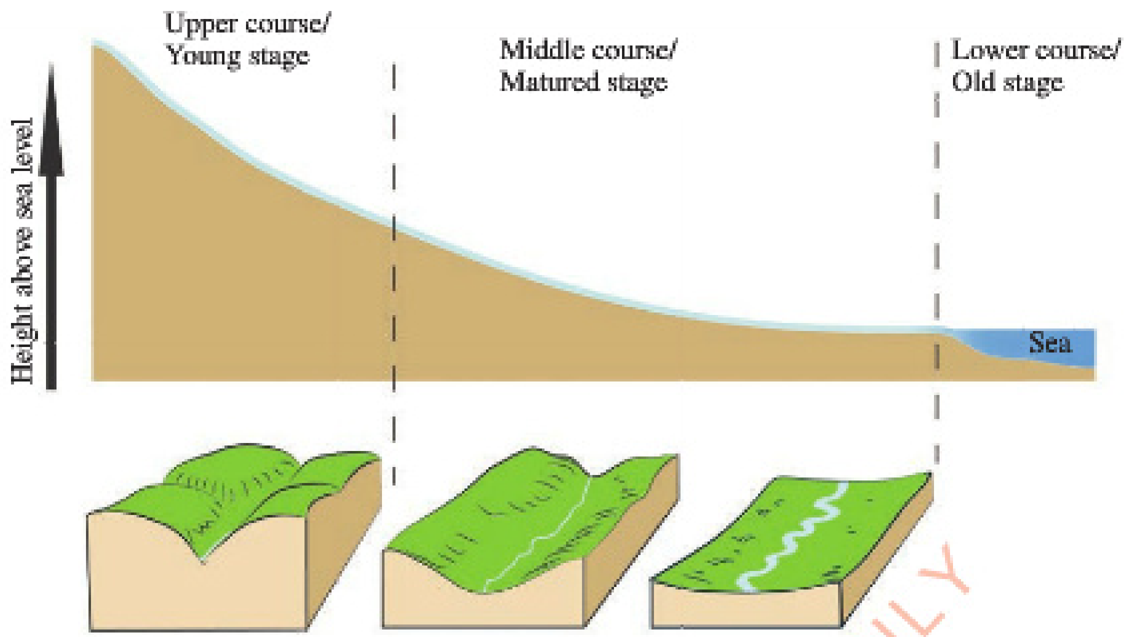


Figure 4.38: *Long profile and cross profile of the river*

Erosion and deposition in the river valley result to degradation and aggradations of materials respectively. As the process of erosion and deposition continue it reaches a point where the rate of erosion balances with that of deposition. This means, the amount of loads eroded by a river will be equal to the amount of loads deposited. This concept is known as graded river profile.

Graded river profile

The concept of graded river profile, explains the profile of a river which has attained a state of dynamic equilibrium between erosion and deposition rates. A graded river profile has a gently sloping land profile with the gradient decreasing towards its mouth. The graded profile has a concave shape due to the reason that, the rate of erosion is higher in the middle than in the upper and lower stages.

Critiques to the concept of the graded river profile

The concept has faced many challenges regarding its validity. Several critiques have been put forward to disprove the concept. *Climatic variation:* The climate which affects the amount of rainfall and temperature can affect the rate of erosion and deposition as the river crosses different climatic regions. There is a period of heavy rainfall likely to increase water volume in the river basin. As the volume of water raises velocity, erosion and load of the river increase as well. Ultimately, extra load carried by the river leads to extra deposition further down the valley or out at sea. The grade is mostly affected by changes in precipitation and glaciations but the effect cannot be on both, erosion and deposition at the same time. *Nature of rocks:* The type of rocks where a river flows is not uniform as soft rock can easily be eroded while hard rock can resist. Therefore, erosion and deposition rate will differ especially in the areas with minimal amount of rainfall and with alternate layers of hard and soft rocks. In hard rocks making adjustment is difficult as erosion is not effective to produce load for adjustment. *Vegetation:* Vegetation can reduce or increase the rate of erosion and deposition depending on the nature of vegetation in a given region. Thus, adjustment is not obvious in any place. *River rejuvenation:* The power of a river to renew its erosive power can also affect the adjustment due to the fact that instead of undergoing deposition to balance the rate of erosion and deposition, a river starts eroding the rock again hence the balance becomes impossible. The balance is mostly affected b the sea level changes (sea level fall), faulting and an abrupt increase in the amount of rainfall. In that way, the state of dynamic equilibrium is not easily attained. *Mass wasting.* The supply of materials down the slope by the gravitational pull such as landslide may affect the equilibrium especially on the rate of erosion and deposition. This is so because as deposition exceeds erosion no point of balance may be attained.

Stages of a river valley

A river, like an animal or a plant, has a life cycle. When it is at its youth stage, it flows turbulently in a narrow, steep sided valley, but as it moves down a slope denudation widens the valley and lowers its floor. The youth stage of a river takes place at an upper stage/course of a river, the stage is also konwn as upper stage. As the river continues moving down, the slope is reduced and the erosive energy is reduced too and it eventually enters the stage of maturity. This stage is also known as middle stage since it happens at the middle course of a river. At this stage the valley is opened out more and more, the gradient is further reduced and deposition becomes active. Layers of sediments are dropped by the river to the entire floor where a gently sloping plain known as flood plain is built. At this point, the river is now at the old stage also known as lower stage as it happens at the lower course of a river. Deposition within the mouth of an old river sometimes builds up a triangular shaped piece of land called a delta.

The youth stage of a river is often called a torrent stage; the mature stage is called a valley stage and the old stage is referred to as a plain stage (Figure 4.39).

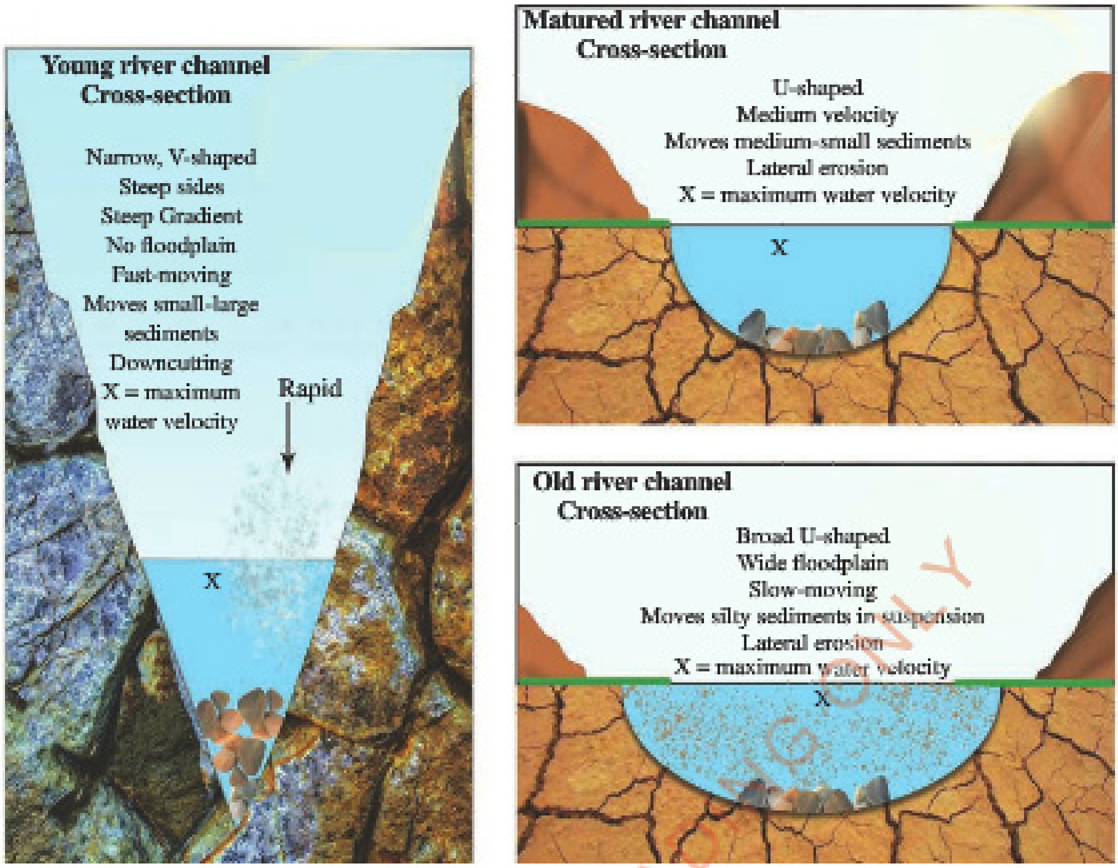


Figure 4.39: *Stages of river valley development*

Upper course of a river

In the upper course of a river, the cross profile of most river valleys are narrow and V-shaped while the gradient of the valley is usually steep and interrupted by waterfalls and rapids. Features formed in the upper course of a river valley are; pot holes, waterfalls, plunge pool, interlocking spurs, gorges, rapids and V-shaped valleys.

Pot holes: Are circular depressions (holes) formed on the bed of the river when pebbles carried by fast flowing river swirl and cut the bed of a river. These depressions gradually get deeper and wider respectively (Figure 4.40).

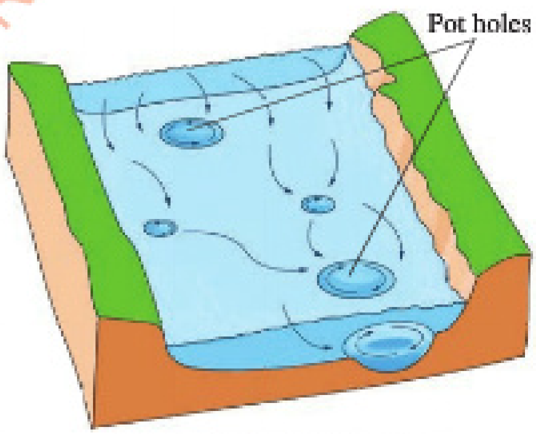


Figure 4.40: *Pot holes*

Waterfalls: A waterfall is a place where water flows over a vertical drop in the course of a river. Waterfalls can be formed in different ways, particularly when hard and soft rock stand opposite one another in a crossing river. Also, waterfalls can be formed when hard rock, lies horizontally over the soft rock, it can also occurs where a dyke has cuts across the bending plane. Moreover, waterfalls can occur when a hard rock dips gently upstream, and when it stands vertically. Areas associated with waterfalls are along the edges of steep sided plateau, along faults scarp or cliffs, along an overhanging valley and at the knick point of a rejuvenated river (see Figure 4.41).

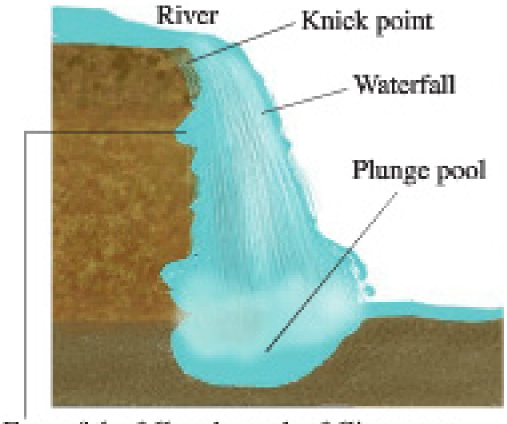


Figure 4.41: *Waterfalls*

Plunge pools: It is a depression formed at the base of waterfall created by the erosion force of falling water (Figure 4.43).

Interlocking spurs: Interlocking spurs are also known as overlapping spurs. They are projecting ridges that extend alternatively from the opposite sides of the wall of a young V-shaped valley down the river with a winding course flows. They are formed when river moves down slope through easiest path that is soft rocks. This often results in the river taking a winding course which undercut concave banks that often stand up as river cliffs (Figure 4.42).

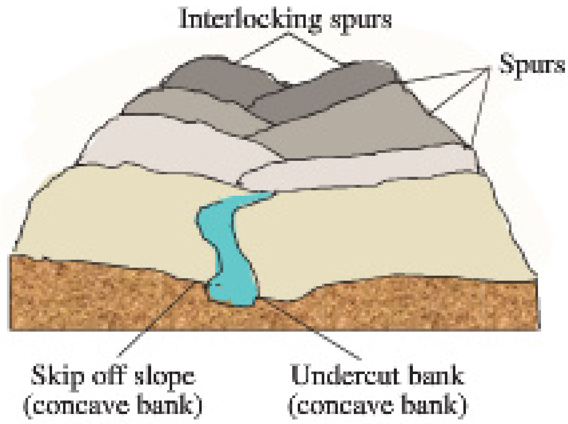


Figure 4.42: *Interlocking spurs*

Gorge: Gorge is a valley with narrow and deep walls often with a stream flowing through it. A gorge develops if a river follows a line of weakness such as a fault. The speed of water in the upper section, causes vertical erosion to become active and lateral erosion inactive because of resistant rocks (Figure 4.43).

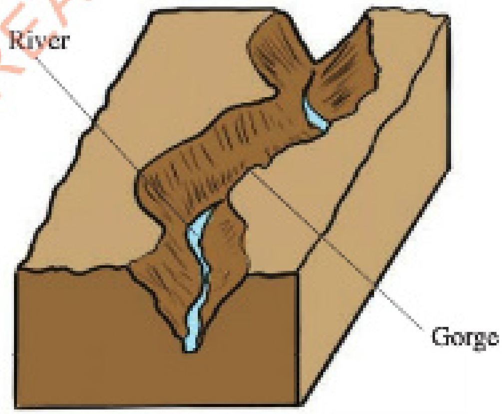


Figure 4.43: *Gorge*

Canyon: This is a deep and wider gorge with steep sided valley. The Yarlung Zangbo Grand Canyon in Tibet is the deepest in the world which extends to about 5300 meters deep. It is a gorge that looks more impressive in appearance such that it can even attract tourists (Figure 4.44).

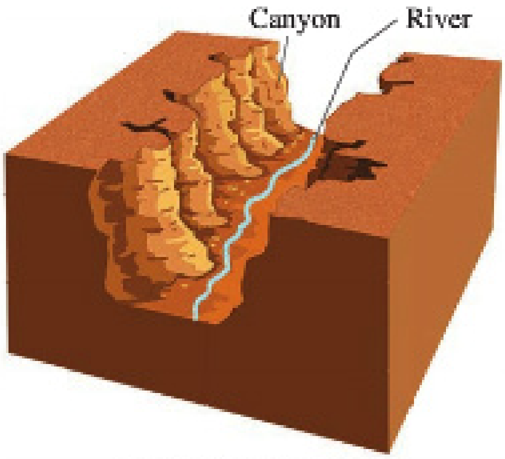


Figure 4.44: *Canyon*

V-shaped valley: This is a narrow steep sided valley with a V shape formed in the upper section of a river due to vertical erosion. The valley is formed when the river completely covers the whole floor of a valley in the upper course. The valley is deepened by vertical abrasion and widened by lateral erosion causing it to become V-shaped. The widening of a valley in the upper course is usually not as greater as the deepening (Figure 4.45).

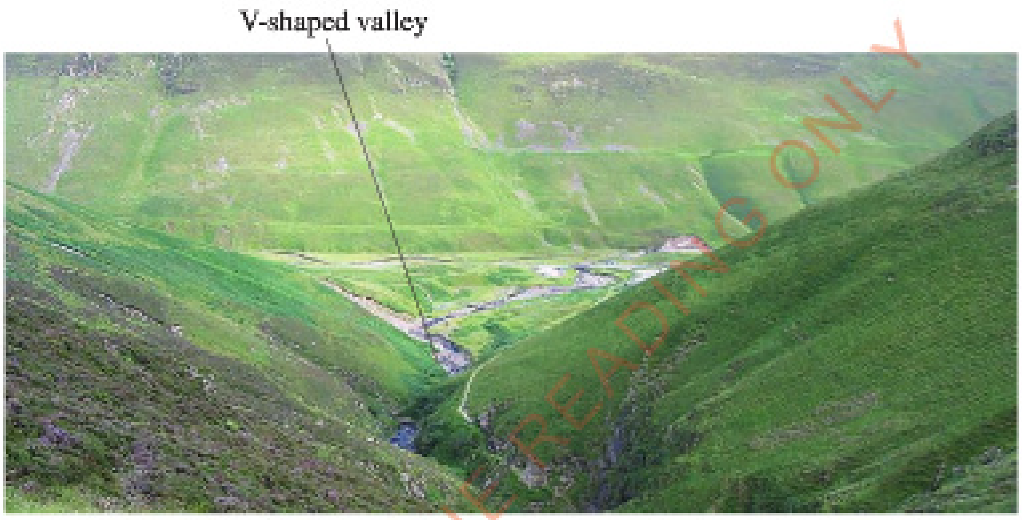


Figure 4.45: *V-shaped valley*

Rapids: These are formed when water flows on the steep slope area. The rapids develop if the face of a rock is steep but not vertical (Figure 4.46). It is the sudden descending of water without forming waterfalls.

Figure 4. 46: *Rapids*

Middle course of a river

At this stage, lateral erosion is more active than vertical erosion, hence the valley develops an open U-shaped valley. The volume of water increases as more tributaries join the main river. Moreover, the load carried by a river increases as gradient is gentler than in a young valley. Minimal deposition starts to take place at this course and river bends (meanders) are pronounced and spurs are removed to form bluffs.

Bluffs: These are features formed when interlocking spurs are removed by erosion. This often happens at the bed of a river where water is pushed against the outside bank leaving high steep banks.

Riffle and pool: Natural streams are never absolutely straight, even where they have steep gradients. They tend to develop bends. Erosion is greater on the outside of these bends, and the eroded material is carried downstream, where it is deposited as bars on the insides of the bends. These bars force the stream against the opposite bank, causing more erosion and deepening of the channel to form bluff. Eventually, the bends become pools and the gravel bars along the river to form "riffles," and the stream assumes an undulating profile (Figure 4.47). In straight a stream with bends of several sizes of course materials, the riffle-pool sequence commonly occurs at intervals. On the average, pools tend to be longer than riffles, and bend materials in riffles are noticeably coarser than in pools. For a stream that is in an equilibrium, the gravel bars remain in the same location (riffle) for years, although the materials composing them may change from year to year. Therefore, a riffle is a rock area in a shallow water or a ripple on water, caused by bars of sediment on the river bed. A pool is an area of deeper side banks of a river at slower flowing water.

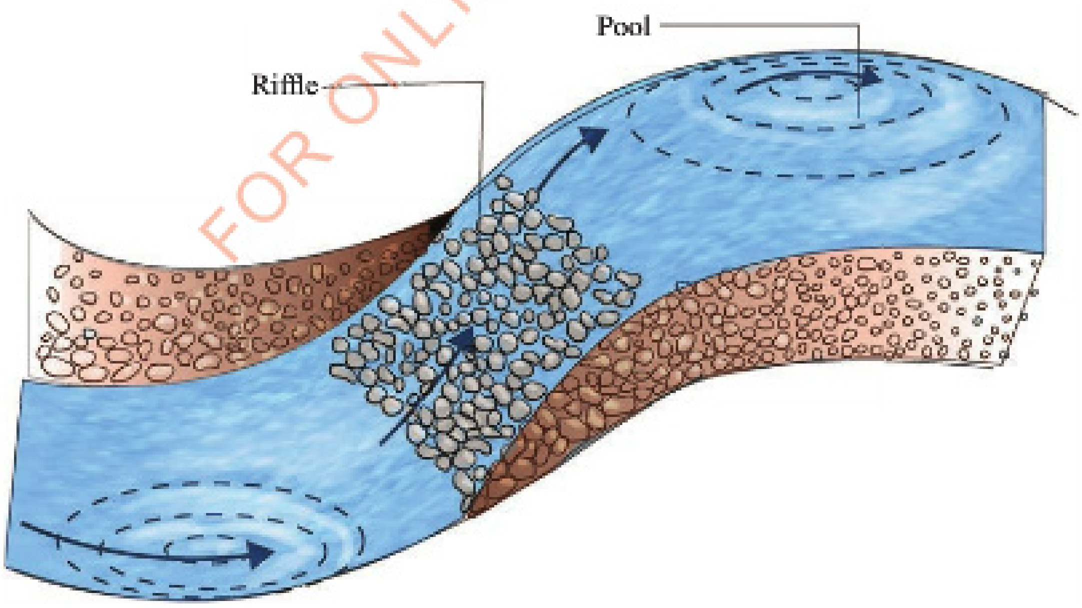


Figure 4.47: *Rocks along the river (riffle) and pool aside deep bank*

River cliff: This is a steep face of river bank of a considerable height. Sometimes it is referred to as an undercut concave bank often standing up as river cliff. It is formed on the outside of a meander bend by the erosive effect of fast flowing water.

Lower coarse of a river

At this stage, the river is closer to the sea and deposition becomes the dominant process. Lateral erosion continues eroding (pushing) back the banks of a river. Vertical erosion is almost negligible, but river volume is now at its maximum level because rivers are joined by many small rivers or stream known as tributaries. The main characteristics feature of the lower course of a river is that its gradient is lower than in the middle course and the speed of a river decreases, thus causing deposition to take place across the whole valley floor. The heavy material is dropped first while the very fine particle (silt) is transported until it reaches the mouth of the river. The deposited materials on the river valley sometimes cause the distributaries to spread into several channels called braided river. The gently plain (valley floor) where materials are deposited is called a flood plain.

Common features found at the plain stage or old stage are meanders, flood plains, braided channels, ox-bow lake, levees, deferred tributaries and deltas.

Meander: Is a winding path of water channel with curved bends of a river bank which occur in the flood plain when the speed of a river becomes very slow (Figure 4.48). Meanders are more common at the stage of a river, however they can be observed across the river profile.

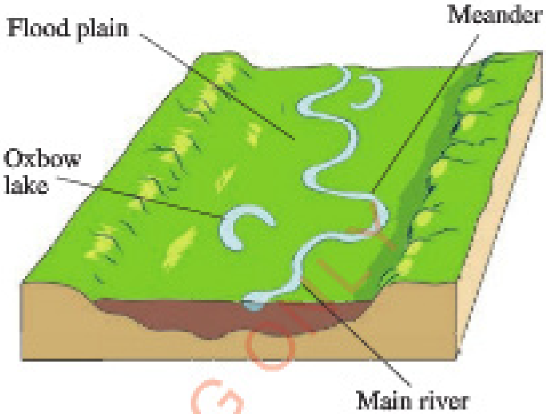


Figure 4.48: *Meanders*

Flood plain: This is a wide flat plain of alluvium on the floor of a river channel where the river flows in a meandering or braided channel (Figure 4.49). Most of the flood plains are marshy with several swamps and small lakes.

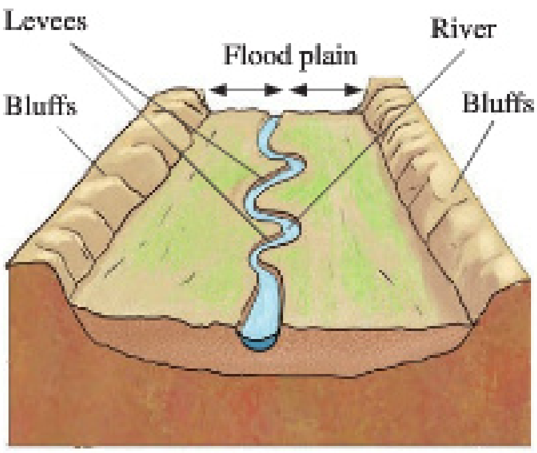


Figure 4.49: *A flood plain*

Braided river: Is a river stream which splits into several channels that rejoins and splits again as the river flows from one point to another. Braid channels are separated by sand bars or an island of alluvium (Figure 4.50).

Figure 4.50: *A braided river*

Oxbow lake: This is the crescent (curved) shaped lake formed on a river floodplain in an abandoned meander channel. It is a lake formed as a result of the cut-off of the loops of the neck of the river meanders. Sometimes it is referred to as a horse shoe shaped final section of a once very pronounced meander which is separated from the main stream (Figure 4.51).

Stages in the formation of an ox-bow lake

Stage 1: When a river flows over a flat land it develops large bends called meanders. At this stage the river erodes sideways of a river into its banks and not downwards.

Stage 2: Due to erosion taking place on the outside of the bend (meander) and deposition on the inside, the gap between two arms (neck of meanders) is narrowed by erosion.

Stage 3: At this stage the river takes the new shorter route. That is cut right through the neck and the ends of a meander are then sealed by deposition.

Stage 4: The meander now becomes an ox-bow lake.

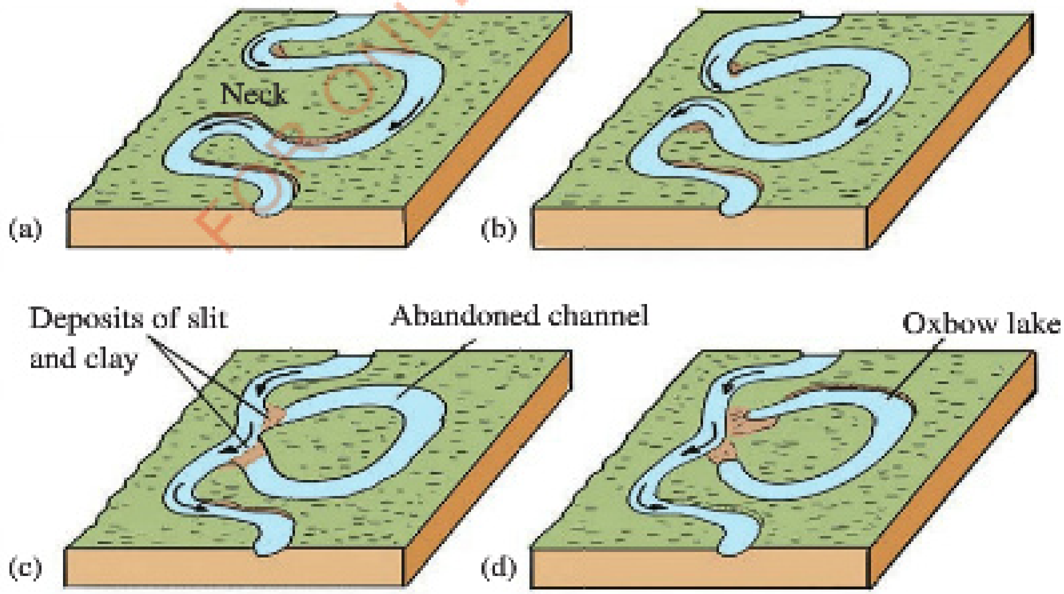


Figure 4.51: *Stages of the formation of an oxbow lake*

Levees: These are embankment or ridges built alongside the river channel. Most of the levees are not more than one or two metres high, but some are much higher. Levees are formed through successive flooding and deposition of sediments by the river.

Deferred tributaries: It is a deferred stream also known as a yazoo stream. It refers to a river or stream that is forced to flow alongside the main river for a long distance before joining the main river. The point at which the deferred stream joins the main river is called the deferred junction. This is caused by a levee across the original confluence of the two rivers which acts as a barrier (Figure 4.52).

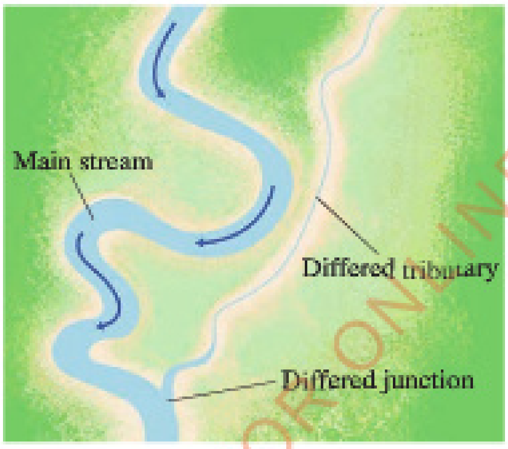


Figure 4.52: *Differed tributaries, oxbow lake and leeves*

Delta: Is a large flat, low-lying plain of river deposits laid down where a river flows into the lake, sea and ocean or another river. The decreasing velocity of the river and the build-up of sediment allows the river to break from its single channel as it reaches its mouth. Most of delta have a triangular shape and project beyond the shoreline. The mouth of the river flowing through a delta is dominated by several streams called distributaries. Under the right conditions, a river forms a deltaic part. A mature deltaic part includes a distributary network which is a series of smaller, shallower channels, called distributaries that branch off from the mainstream of the river. In a deltaic part, heavier, coarser material settles first. Smaller and finer sediments like alluvium or silt are carried further downstream and deposited beyond the river's mouth. A delta is divided into two parts, the subaqueous and subaerial. The subaqueous part of a delta is underwater. It is the most steeply sloping part of the delta, and contains the finest silt. The newest part of the subaqueous delta which is furthest from the mouth of the river is called the prodelta. On the other hand, the subaerial part of a delta is above the water. This part which is also known as lower delta is influenced by waves and tides while the upper delta is influenced by the river's flow.

Conditions for delta formation

There should be active erosion in the upper and middle course of the river so that the river can attain large load. The velocity of a river should also be sufficiently low to allow most of its load such as sediments and solid materials carried downstream by currents to be deposited at the river mouth. Moreover, the river's load must be deposited faster than it can be removed by waves, tides and currents. There should be a gently sloping land along the coast where the materials can be deposited.

Stages of delta development

There are four stages of the development of a delta, these include the following;

Firstly, accumulation of alluvium deposits. This occurs at the mouth of the river at the continental shelf that facilitates the formation of a delta.

Secondly, the formation of distributaries. These are small channels that divide the river leading their ways into a lake, sea or ocean that facilitate the formation of a delta. Spits and bars arise and lagoons are formed at this stage. The levées of a river extends into the sea via the distributaries (Figure 4.53).

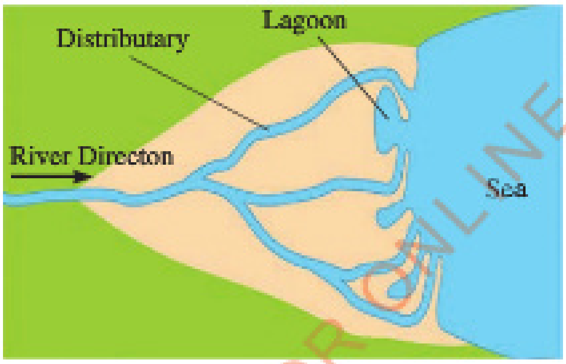


Figure 4.53: *Formation of distributaries*

Thirdly, formation of lagoons. These are areas with shallow or surrounded by shallow water, formed when areas of water are surrounded by tributaries as well as their associated deposits. The lagoons begin to get filled in with sediments and become swampy. At this stage, the delta begins to gain a more solid appearance (Figure 4.54).

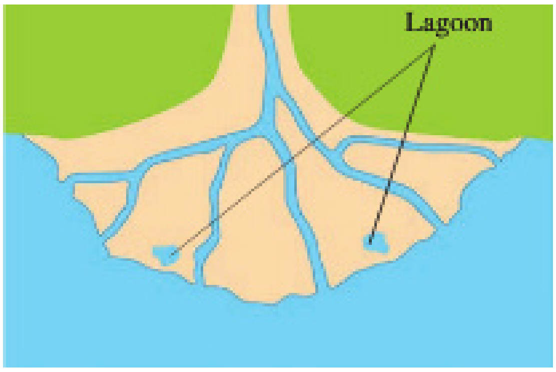


Figure 4.54: *Formation of lagoons*

Fourthly, extension of a delta after a lagoon is covered with alluvium deposits (silts). The filling of lagoon with silts causes further division of distributaries into smaller ones and completely covered by vegetation. This stage is considered the oldest part of a delta which is colonized by plants and its height is slowly raised. Swamps gradually disappear and this part of a delta becomes dry land (Figure 4.55).

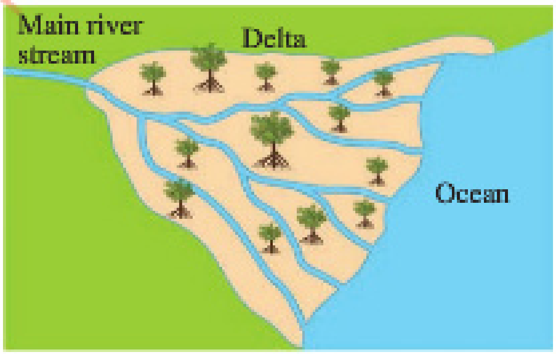


Figure 4.55: *Extension of a delta*

Types of delta

There are four main types of delta, namely arcuate, estuarine, digitate delta (bird's foot) and cuspate delta.

Arcuate delta: This type of delta consists of both coarse and fine sediments with the shape of an inverted cone. It is crossed by numerous distributaries (Figure 4.56). A good example includes the Rufiji delta in Tanzania, the Nile delta in Egypt, the delta of Niger, Ganges, Indus, Irrawaddy and Hwang Ho rivers.

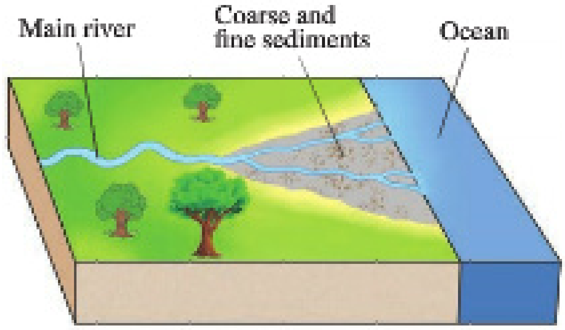


Figure 4.56: *An arcuate delta*

Digitate delta: It is the type of delta that looks like the foot of a bird with its claws and it is sometime called bird's foot delta. This delta consists of very fine materials called silt and it has a few long distributaries bordered by levees that cut out from the shore. It is usually formed when the power of waves and currents is low. A good example is the Mississippi delta in the USA (Figure 4.57).

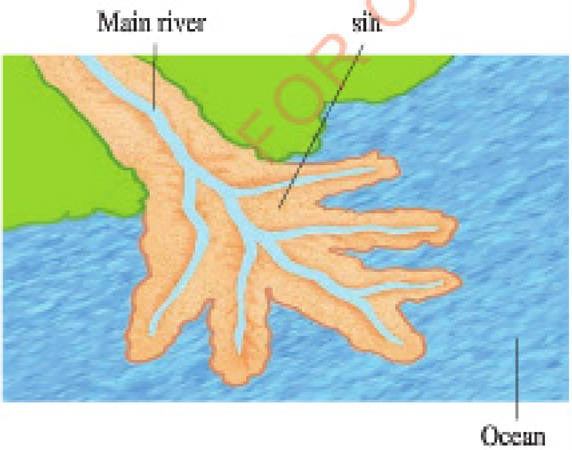


Figure 4.57: *The digitate delta*

Estuarine delta: It is a type of delta formed from materials deposited in the submerged mouth of a river. It takes the shape of an estuary. A good example is the estuarine delta of river Volta in Ghana, river Congo in the Democratic Republic of Congo, river Seine in France, Vistula in Poland and river Ob in Russia (Figure 4.58).

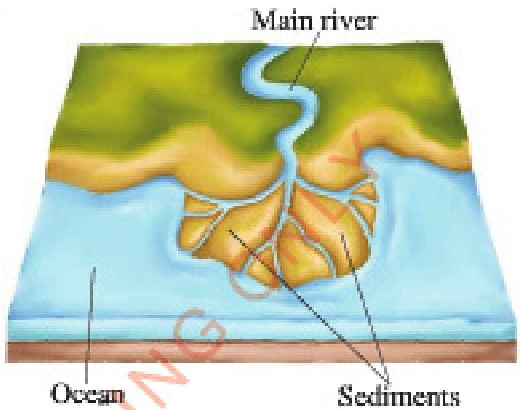


Figure 4.58: *Estuarine delta*

Cuspate delta: It is a delta with a tooth-like shape. It is formed where a river reaches a straight coastline along which wave action is strong. The materials spread equally on either side of a river's mouth, and it has no lagoons (Figure 4.59). This feature is found in Ebro River in Spain and Tiber river in Italy.

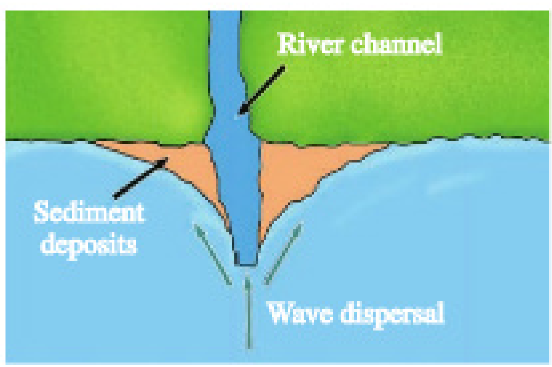


Figure 4.59: *Cuspate delta*

Importance of delta

Deltas are incredibly diverse and ecologically important ecosystems. Deltas absorb runoff from both floods (from rivers) and storms (from lakes or the ocean). Also, deltas filter water as it slowly makes its way through the delta's distributary network. This can reduce the impact of pollution flowing from upstream. It is home to many species of plants and wildlife as well as many species of fish. Plants such as lilies and hibiscus grow in deltas, as well as herbs such as wort, which are used in traditional medicines are habited in deltas. Many animals are indigenous to the shallow, shifting waters of a delta. Fish, crustaceans such as oysters, birds, insects, and even apex predators such as tigers and bears can be part of a delta's ecosystem.

Deltas have a rich accumulation of silt, so they are usually contain fertile agricultural land that provides food for worldwide distribution. Crops such as rice and tea are the leading agricultural products of the deltas. It is a world-class recreational destination that attracts millions visitors per year. Deltas are beneficial to the economy due to their well sorted sands and gravels. Sands and gravels are often quarried from these deltas and used in concrete for highways, buildings, sidewalks, and landscaping. Urban areas and human habitation tends to locate in lowlands near water access for transportation and sanitation. This make deltas a common location for civilizations to flourish due to access to flat land for farming, freshwater for sanitation and sea access for trade.

River rejuvenation

River rejuvenation refers to a renewed erosive activity in a river valley and it usually results from a negative movement of base level due to a fall in sea level or a regional uplift of a land. River rejuvenation is caused by several factors such as fall in sea level (Eustatic change) caused by diastrophic forces, such as, earth movements. Another cause is land uplifting and subsidence (Isotactic change), that occurs when the land is uplifted in the upper section or subsides in the lower section resulting to a new base level formation. Moreover, river rejuvenation is caused by an increase in the river volume; which may result from heavy rainfall.

Types of river rejuvenation

There are three types of river rejuvenation namely; dynamic, static and eustatic. *Dynamic river rejuvenation* occurs following the change of water flow gradient of a landscape as the river gets uplifted by tectonic activities. *Static river rejuvenation* occurs without any significant change of water flow gradient. It occurs due to an increase in water volume that can be contributed by heavy rains, ice melting and river capture. *Eustatic river rejuvenation* is the renewal of erosive activity following the fall of lake or sea level due to diastrophic forces.

Landforms caused by river rejuvenation

The effects of river rejuvenation may lead to the following landforms.

Knick point: It is a break of slope in the long profile of the river valley, where the river bed falls sharply, leading to the formation of a waterfall or a rapid. Examples can be seen in Congo River and Charlotte fall in Sierra Leone (Figure 4.60).

River terraces: River terraces are steps or bench like features on either side of the river valley. They are produced when the flood plain is rejuvenated. They are considered to be paired river terraces if they are equal on both sides of the river valley. If they are not equal, they are termed as unpaired river terraces (Figure 4.60).

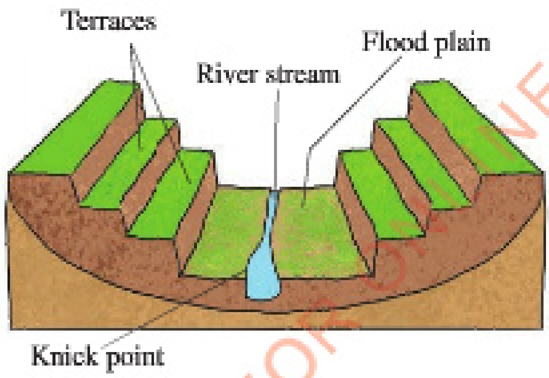


Figure 4.60: *Knick point and paired terraces*

Incised meanders: These are steep sided curved bends of a river valley produced as a result of the undercutting of river bed during the process of rejuvenation. There are two types of incised meanders namely *in-grown meanders and entrenched meanders: In-grown meanders* are the ones with an asymmetrical valley across a profile that has alternate steep sides with large slip off slopes. They usually develop on resistant rocks (Figure 4.61). An example of this feature is found on the river Mkomazi between Mgwasi and Kifungiro in Usambara mountain in Lushoto, Tanzania.

Figure 4.61: *In-grown incised meanders*

Entrenched meanders: These are meanders with a steep sided symmetrical cross profile. This type of meanders develops on weak rocks and where the base level fall quickly causing rapid vertical incisions (Figure 4.62). An example of this feature is found on River Tyne in Northern England.

Figure 4. 62: *Entrenched incised meanders*

Valley within a valley: It is a steep sided rejuvenation gorge formed within the former valley due to a fall in base level.

Waterfalls: Are usually formed due to sharp drop of river valley water from the knick point.

Canyon or Gorge: These are steep sided troughs formed when the undercutting becomes concentrated into the river bed.

River capture

River capture is also called river piracy. This is the diversion of part of a river course into the system of an adjacent powerful river that is able to erode its valley more rapidly than its weaker neighbour. The necessary conditions for river capture are; the capturing river should be stronger or must have greater energy for the vertical and head ward erosion. It should be also flowing at a lower level than its victim and should have greater power of headward erosion. Moreover, there should be a layer of less resistant rocks between the two rivers that allow easy erosion to take place. It should be able to erode its valley more rapidly than its weaker neighbour (Figure 4.63 a and b).

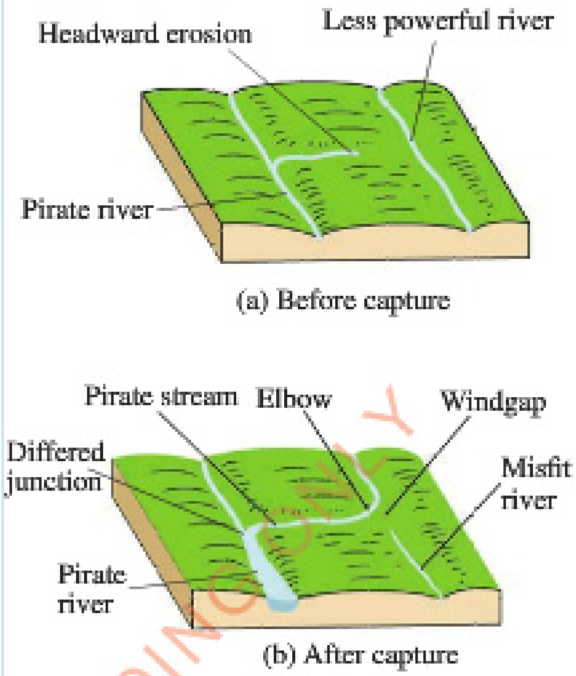


Figure 4. 63: *River Capture*

Landforms due to river capture

A river capture gives rise to the following landforms or features:

An elbow of capture which is a sharp change in the direction of a river course at the point of capture. Not all right angled bends in rivers are due to capture, others are results of structural control.

A wind gap which is the valley of the beheaded stream below the point of capture. It may be left as a dry valley.

A misfit which is the beheaded stream that has lost its headwaters. It may be reduced in volume causing it to appear too small, sometimes described as under fit stream.

Incision of pirate stream: This occurs when erosive power increases from its enlarged headwaters, the pirate stream may be rejuvenated and incise its valley. Several examples can be cited in relation to the river capture such as Tiva river capture in Kenya and Cunene river capture in West-central Angola.

Activity 4.5

Visit a river in your locality or watch videos and simulations from online sources about features produced in a long profile of a river, then, describe the features you have observed.

Exercise 4.4

1. Why is the construction of a dam for hydroelectric power production not ideal near the river mouth?
2. How do river functions affects its landscape?
3. "Geological differences and environmental dynamics along the river are the main factors affecting a river to reach a state of dynamic equilibrium". Justify this statement.
4. Describe the significance of an oxbow lakes.

Waves action and resulting landforms

Waves (wind waves) are the undulations that occur on the free surface of bodies of water, such as sea, ocean, lakes, and rivers. It should be noted that waves are actually the energy and not the water as such, which moves across the free surface of a water body. Wind driven waves (surface waves) are created by the friction between wind and the surface of the ocean. Therefore, wind acts as the source of energy for waves. Waves are created by energy passing through water, causing it to move in circular motion. An area of the sea or ocean over which the wind blows is called *fetch*. The length of the fetch and the speed of wind determines the size of the waves generated.

Elements of waves

As wind travels across the surface of the ocean, the continuous disturbance creates a wave *crest*. A wave crest is the highest water level of the wave while the lowest water level known as the *wave trough*. The vertical distance between the bottom of the trough and the top of the nearest crest is the *wave height (H)*. Also, *wave amplitude* the one-half of the wave height. The distance between two crests or troughs is the *wavelength (L)*. It explains the horizontal distance between two successive crests or troughs (Figure 4.64). The time it takes for the two crests or troughs to pass the same point is called a *wave period (T)*. This implies that longer waves move faster than shorter waves. Moreover, a wave is also characterised by *wave speed* which is about with the rate at which the wave moves through the water, and is measured in knots. Lastly, there is a *wave frequency* which is the number of waves passing through a given point during a one-second time interval.

The size and shape of a wave reveal its origin. Steep waves are young and are probably formed by local winds. Slow and steady waves originate from distant places, possibly from another hemisphere. The maximum wave height is determined by the strength of the wind, that is, how long it blows and the area over which it blows in a single direction. As waves move from deep to shallow water, they get closer together and slow down. Also, waves get higher as they travel into shallower water, making a process known as *shoaling*. They also change their shape from a more symmetrical wave shape to a shape with more peaked crests and flatter troughs. Slows and bends makes a process known as *wave refraction* which occur as the wave moves close to the shore. This is when the section of the wave in shallower water travels slower due to friction on the bed than the section of the wave in deeper water.

Waves travel because wind pushes the water body in its course while gravity pulls the crests of the waves downward. The falling water pushes the former troughs upward, and the wave moves to a new position. The actual motion of the water beneath the waves is circular. It indicates that things are carried up and forward as the wave approaches, and down and back as it passes.

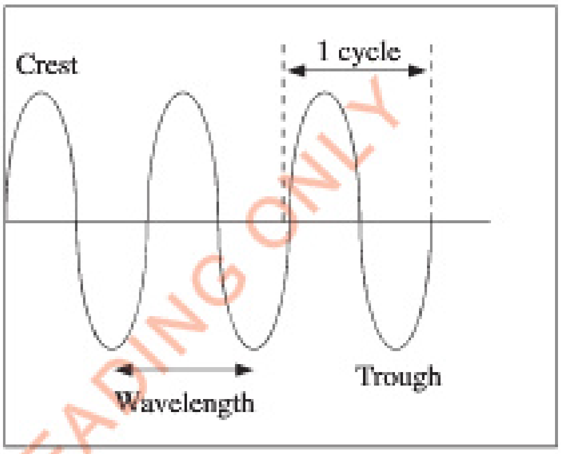


Figure 4.64: *Motion of waves*

Swash and backwash movements

There are two different movements associated with waves. These movements are swash and backwash (Figure 4.65). *Swash (Send)* is the mass of broken water which is thrown or rushed to the beach. This happens when waves pass into shallow water. *Backwash* is the returning water to the sea from the beaches or coast.

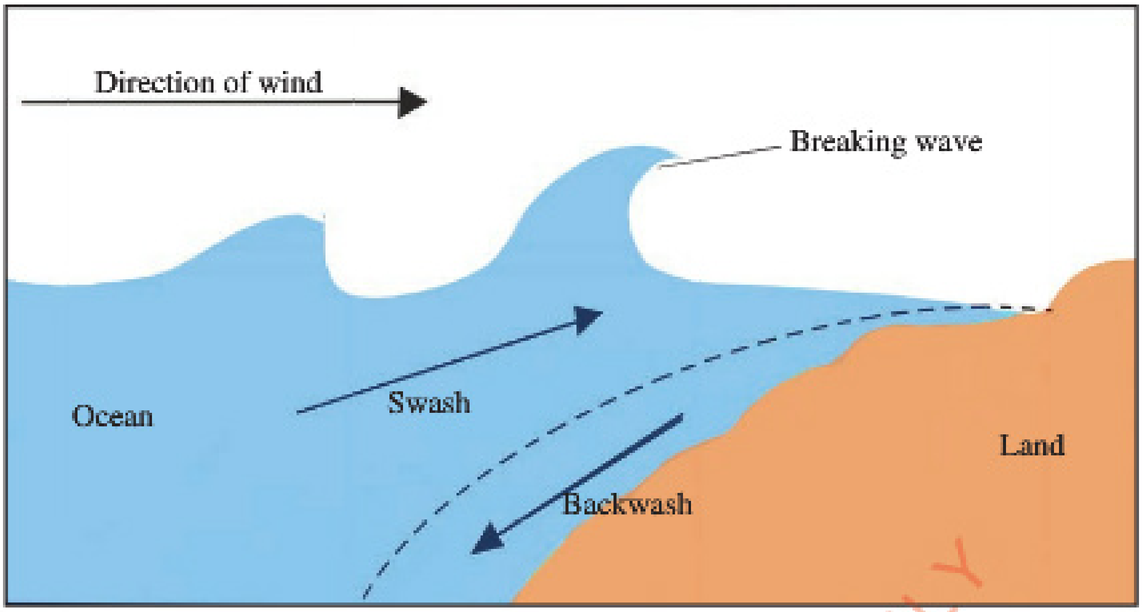


Figure 4.65: *Swash and backwash waves*

Types of waves

Basically, waves can be categorized as constructive and destructive waves.

Constructive wave

The constructive wave is the one whose swash is stronger than backwash. When the swash is stronger than the backwash deposition takes place leading to the formation of different marine depositional features. The formation or building up of features due to deposition has made this wave to be referred to as a constructive wave.

Destructive wave

It is the wave whose backwash is stronger than the swash. When the backwash is stronger than the swash the coastal area is eroded leading to the formation of different erosion features. The tendency of eroding or destroying the shore has made this wave to be referred to as a destructive wave.

The distructive waves are much bigger and more strong because they travel a long way and thus make them so powerful. They are mostly occur during a storm.

Causes of waves

For a wave to be created on the surface of the ocean, there must be a disturbing force. The type of force would determine the type of waves created, so that: wind stress over the oceanic surface which produces *surface waves (wind waves)*. The main forces that cause waves are *gravitation* pull of the moon and the sun on the Earth accompanied by centrifugal forces which produce *tidal waves*; and large earthquakes and underwater landslides which produce *Tsunami*.

Determinants of height and power of a wave

There are several factors that determine the height and power of waves. The factors include; *wind velocity or strength* and its *duration of operation*. The distance of open water (fetch) over which the wind can blow determines the height and power of the wave. That is where the fetch is long the waves is large and strong since it has enough time to develop into maturity and vice versa. Moreover, *depth of water* is another factor such that when a wave passes into shallow water, its crest steepens and then breaks, and mass of broken water rushes to the beach as a swash. In deep water there is a great possibility of having waves with high height and powerful depending on the strength of wind.

Waves are created by the transfer of wind energy blowing over the surface of the sea water. The waves play a triple function namely; erosion, transportation and deposition. The coastal lines of different regions of the world are dynamic. They are always under constant changes at different scales and magnitudes. Shorelines are being modified due to the action of waves which are determined by the speed, direction and consistency of the wind patterns. Waves are the major driving forces that break down or build up the line. As the waves move and strike the adjacent and the bottom of the oceanic rocks, they tend to a break, transport and deposit rock materials and send the materials of different scales and quantity into and off beaches or shorelines. The nature of the oceanic and coastal rocks, climatic conditions, the configuration of the coasts and fetch also determine the speed of erosion and types of features formed at a particular coastal region.

Wave erosion

Waves are energy passing through the water, causing it to move in a circular motion. In other words, waves are the outward manifestation of kinetic energy propagating through seawater. In reality, water in waves does **not** travel much at all. The only thing waves do is to transmit the energy across the sea. The rate and extent of wave erosion depends on factors that control the evolution of the coast. The operational mechanisms of the waves and their resulting features involve the following processes; hydraulic action, abrasion, attrition and solution.

Hydraulic action or hydraulic pressure

As waves move forward, they hit against a cliff directly and loosen the interior parts of joints and bedding planes. The compressed air expands with explosive violence. Such an action if repeated over and over enlarges the cracks and rock fragments break apart. The striking waves exert enormous pressure on the air trapped in crevices, cracks, holes and joined rocks. Such an alternate compression and decompression resulting from forewash and backwash of the breaking waves cause tremendous pressure which weaken the compaction of the rocks and eventually the rocks are shattered and break into huge fragments at the bottom of the cliffs or shoreline. Depending on the velocity of the waves and the nature of the rocks, the energy of the waves may dislodge a huge load of rock materials weighting several tones.

Abrasion (corrasion)

Abrasion occurs when the waves which contain large fragments hit and erode the cliff or the shoreline. It is the most effective method of erosion and is most rapid on coasts exposed to storm waves. The eroded materials may be carried outwards by the backwash or caught by next breaker and hurled against the shore. These materials are tools for abrasion. The amount of the fragmented materials (pebbles and sand) and speed at which those materials are hurled against the base of the cliff are the determining factors for erosive scale on the base of a cliff.

Attrition

This is the process whereby the carried materials such as sand and pebbles collide against each other and break into smaller particles carried by waves. The load and materials carried in the waves keep dashing against each other and crush as they are transported toward or away from the shoreline. The materials extracted from one geographical location may be transported hundreds of kilometers away from their original sources. In the process such transported load is reduced in size and structure, and may be deposited at other sides of the shoreline, at the bottom of the sea or dissolved through the process of solution.

Solution

This is the process through which the soluble rock such as limestone's or basalt rock dissolves in water mostly carbonic acid, and are removed from one point to another especially on a cliff forming beaches. The global shorelines and continentals are formed or characterized by different forms of rocks (soft and harder, easily dissolved and impermeable). When the seawater reacts with soluble rocks it tends to change the chemical composition of those oceanic rocks and eventually, the contacted rocks is weakened or dissolved forming different shorelines' landscapes such as beaches and cliffs.

Factors affecting the rate of wave erosion

The breaking point of the wave that occurs when waves break just after hitting the foot of a cliff and release most of its energy and causing maximum erosion. However, waves that break before hitting a cliff have minimum erosive effects. Moreover, depth of a sea also affects wave erosion because the deeper sea levels along the coast the higher and stronger are the waves than where the coastal sea levels are shallow. The length of the fetch also affects the wave strength. When the fetch is long the wave tends to be strong since it will have enough duration to collect the energy from the prevailing wind. The strength and the direction of prevailing wind are other factors that also affects wave erosion. In this case, the stronger the wind the more powerful the wave is, and vice versa. Moreover when the winds blows perpendicular to the coast, wave erosion becomes more effective than when it blows parallel to the coast alignment. Furthermore, the nature of rocks affects wave erosion because when the rock is hard, the rate of wave erosion is low but when the rock is soft, the rate of erosion is high. Furthermore, the rocks which are well-jointed or have been subjected to faulting undergo erosion at a faster rate due to an increased vulnerability. Lastly, human activities along the coast such as building on cliff tops and the removal of the beach materials contribute to more rapid coastal erosion. Human beings can reduce the rate of erosion by constructing walls (groyne) and planting trees. Groynes are walls built perpendicular to the coast line to prevent erosion by the influence of sea waves.

Wave erosion features

Features produced by wave erosion are; cliff and wave- cut platform, cave, arch, stack, stump, blow hole, geo, headland and bay (Figure 4.67 and 4.68).

Cliff

The first stage in the development of a cliff is the cutting of a notch at about high tide level. As erosion proceeds the notch is further developed and a defined cliff appears. The cliff steepens as its base is attacked by wave action. Therefore, a cliff is the steep face of rock of considerable height along the coast (Figure 4.66).

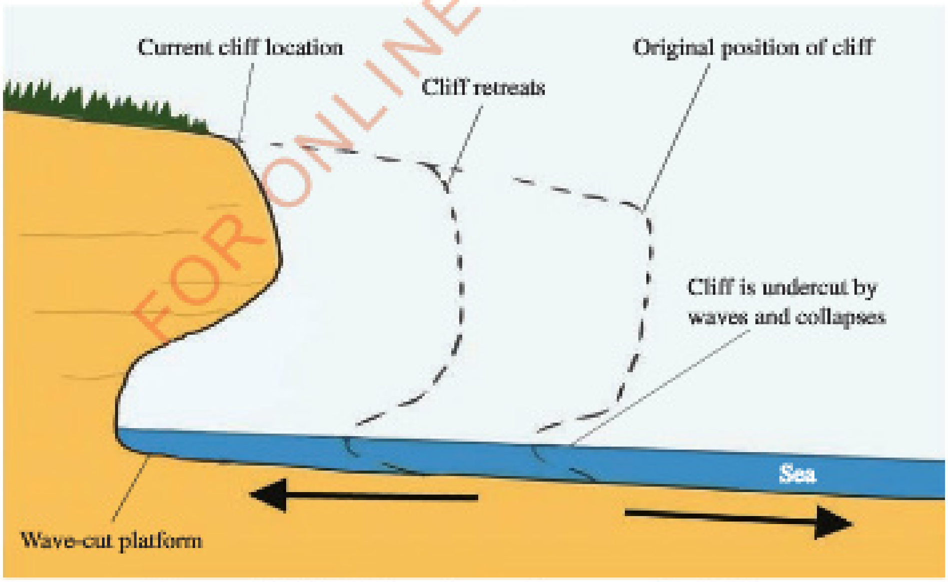


Figure 4.66: *Cliff erosion and wave-cut platforms*

Categories of cliffs

Cliff can be categorized into *vertical cliff* in which the wall is steep/vertical, and *overhanging cliff* which is formed in rocks whose bedding planes dip towards the sea (Figure 4.68). Another category is *straight cliff* which is formed along the coast composed of rocks with uniform resistance. Also, there is an *indented cliff* composed of headland and bay as a result of the presence of alternate bands of hard rocks and soft rocks.

Wave-cut platform

Wave-cut platform is a narrow flat area often found at the base of a sea cliff or along the shoreline of a lake, bay or sea that was created through erosion by waves (Figure 4.68). Normally, wave-cut platforms are formed as a results of excessive erosion of the surface of cliffs such that there is a bulk deposition of sediments and rock debris accumulated at the base of the cliff. The wave-cut platform may range from few to several meters depending on the configuration of the coast and the amount of the eroded materials to be deposited. The size and bulkiness of wave-cut platform may reduce the depth of the coastal water as it makes the water shallow hence increasing the speed and breaking power of the waves. This is due to the fact that as the waves approach the coast where the water is shallow they are steepened and get more colliding power to splash the adjacent and surface of the cliffs.

Caves

These are holes in the cliff face that develop from waves enlarging an initial weakness in the rock, especially along joints and faults. Abrasion and hydraulic force are both vital to cave formation. Caves are tunnel-like opening which may develop at the headland or cliff. A cave may be wide, narrow or rounded depending on the nature of the rocks, direction of the current, and the magnitude of erosive power. Caves may be developed into two sides of the headland and when two caves meet a feature called arch is formed. The size of the arch depends on the length of the headland and width of the caves. Also, it may extend to several meters as it gets enlarged by abrasives wave and the gravitational forces lead into collapse of the arch forming stack. When a cave is developed above the arch or headland as a result of alternate compression and expansion of the air in the cave is known as blowhole.

Arch

As the sea waves pound into caves, the water hits the back wall of the cave until it bends and joins another cave. When two caves join from either side of a headland they form an arch.

Stack

This is an isolated portion of a headland. Sometimes it can be formed from an isolate portion of a cliff. Some stacks are very large and could as well be called islands. It is an isolated mass of standing rock closer to the cliff. The size of a stack may range from a square meter to hundreds square meters. In fact, some of the stacks could be established as archipelago or islands. When this huge or minor stack is further attacked by waves and reduced into remnants it is called a stump.

Stump

They refer to the remains of eroded stack or rock pillars. A stump is formed when the base of the arch continuously becomes wider through further wave erosion, until its roof becomes too heavy and eventually collapses into the ocean or sea. This leaves an isolated column of rock called a stack. Under a continuous wave action, the stack is under cut at the base until it collapses to form a stump. Therefore, a stump refers to the remaining of eroded stack or rock pillars.

Blow hole

This is the hole formed at the top of the roof of a cave. It is a result of an alternate compression and expansion of air in the cave, in time the top of the roof breaks and produces a blow hole.

Geo

Is formed a wave cuts into a cliff, resulting into a narrow hole called geo. It is formed when a cave collapses. This feature is common in areas with strong waves.

Headland

Headland is the hard part of coast land extending into the ocean. The extension of the headland may be influenced by different rates of erosion and configuration of the coast itself. Some of the headlands are long and narrow while others are wider and extensive. When two or more separated headlands lay parallel to the coast, they produce an inland water called bay.

Bay

A bay is part of water extending into the land. Also, it can be described as an outward coastal land which is extended into the sea. The extension of the headland may be influenced by the different rates of erosion and configuration of the coast itself. A bay is a kind of recessed coastal body of the water and when it is extended further it is called a gulf which can extend hundreds of kilometers.

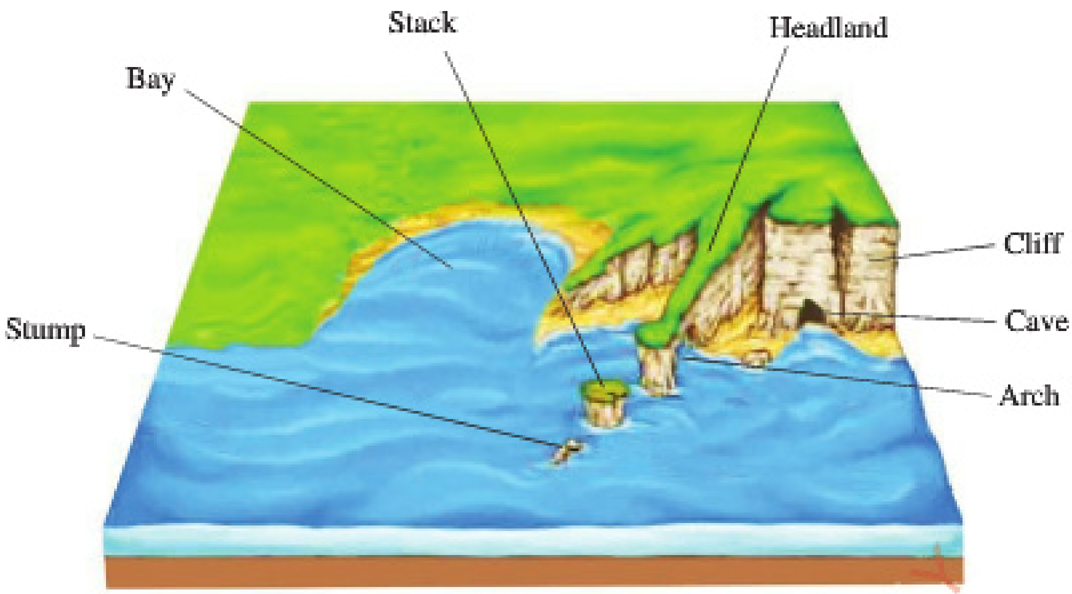


Figure 4.67: *Wave erosional features*

Wave deposition features

Wave deposition results to various features including barrier beach, spit, bay bar, tombolo and offshore bar.

Beach

A beach is a wider strip of sand or shingle deposits with water along the sea coast. It is the land bordering the sea coast between high and low tide. A beach is formed when materials carried by waves are accumulated along the coastline (Figure 4.69). Materials on the beach vary in size from fine sand, to pebbles. During deposition finer sand (silt) are deposited near the sea and the coarser materials further inland. A good example of beaches along East African coast include Coco, Bagamoyo, Mikadini, and Nungwi beaches in Tanzania.

Barrier beach

Barrier beach is a bar parallel to the shore, whose crest rises above high water, or it is the long ridge of sand, parallel to the coast and separated from it by a lagoon (Figure 4.69).

Spit

Spit is a long narrow ridge of pebbles or sand joined to the land (main land or island) at one end with the other end pointing in the seaward side. As a spit grows, it might become stable and fertile and even support habitation (Figure 4.68).

Bar

Bar is a ridge of material usually sand which lies parallel or almost parallel to the coast or across the estuary or bay. The commonly occur along the coast of northern Poland.

Tombolo

This is a feature formed as a result of a bar joining an island to the mainland. A good example is Checil beach which joins the Isle of Portland and the south of mainland Britain (Figure 4.68).

Bay bar

Bay bar is a bar that runs across a bay. A good example is a bay along the coast of Poland. Bay bar is associated with the occurrence of a lagoon.

Lagoon

Lagoon is a shallow body of water separated from the main body of water by a sand bar. A lagoon can either be coastal or atoll lagoon (Figure 4.68).

Offshore bar or long-shore bar

It is the bar which develops along the very gently sloping coast and runs parallel to it. An example of this feature can be seen in North America along the southern part of the Atlantic coast.

Cuspate foreland

A cuspate foreland is a triangular extension of the shoreline. The formation of a cuspate foreland is called a long-shore drift. When waves approach the coastline at an angle, it causes the movement of sand or sediments in the same direction toward the sea to the right or left.

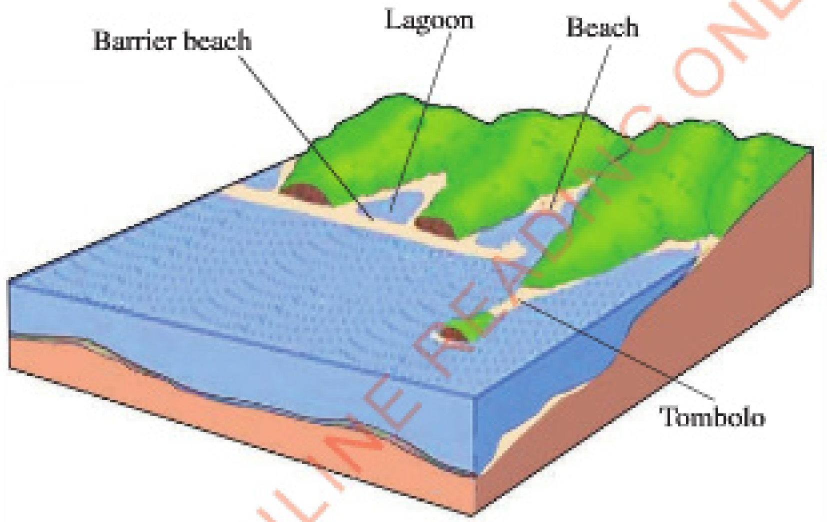


Figure 4.68: *Wave deposional features*

The importance of wave action and associated features

(a) Waves are potential for production of tidal power which is green energy as compared to thermal or nuclear energy sources;

(b) Most of the erosive and depositional features produce different marine features ideal for tourism and thus enhance economic development of the country;

(c) The coastal areas and shallow lagoons become the ideal places for fish breeding which in turn enhance the economy and the livelihoods of the millions of human population;

(d) The coastal areas are now among the most populated geographical locations in the world partly due to their access, supporting resources and natural beauty;

(e) They help in the distribution of nutrients in the ocean.

Tides

It periodical rise and fall of the sea level, once or twice a day, mainly due to gravitational attract between the moon and Earth. The Earth and moon exert a gravitational pull on each other, which is counterbalanced by forces associated with the earth's orbital rotation. Thus, while surface waves obtain their energy from wind, tidal waves derive their energy from the gravitational attraction of the moon and the sun towards the Earth.

Besides the gravitational pull by the moon and the sun, centrifugal forces that act to balance the gravitational force also contribute to tidal formation. Gravitational pull by the moon and the sun and the centrifugal force together act to create the two major tidal bulges on the Earth. A *tidal current* occurs when a tide rises and falls against the coastline, producing a flow of water.

However, movement of water caused by meteorological effects (winds and atmospheric pressure changes) are called *surges*. Surges are not regular like tides.

Types of tides

Usually,tides vary according to frequency, magnitude and height. Tides may be grouped into various types based on their *frequency* of occurrence in a day (24 hours) or based on their *height*.

Based on frequency: Based on frequency of occurance, tides are further subdivided into three categories. First; *semi-diurnal tide* which is the most common tidal pattern, featuring two high tides and two low tides each day. The successive high or low tides are approximately of the same height. Second; *diurnal tide* which has only one high tide and one low tide during each day. The successive high and low tides are approximately of the same height. Third; *mixed tide* that explain tides having variations in height. These tides generally occur along the west coast of North America and on many islands of the Pacific Ocean.

Based on height: Based on height or degree of tidal range, *spring tides* are formed when the moon, the Earth and the Sun are aligned in a straight line, causing the height of the tide to be higher. Spring tides occur twice a month, one on a full moon period and the other during the new moon period. The moon takes about 28 days to revolve around the Earth. Usually, the position of the moon relative to the sun changes in a lunar month. Therefore, in spring tide, the sun and the moon align in the same direction, causing the oceanic surface to bulge further, resulting in tides with higher magnitudes.

Neap tides occur when the sun and the moon are at right angles to each other and the forces of the sun and moon tend to counteract one another. The moon's attraction, though more than twice as strong as the sun's, is diminished by the counteracting force of the sun's gravitational pull. This results in subdued tidal bulges (neap tides). The time between the high tide and low tide, when the water level is falling, is called the *ebb*. The time between the low tide and high tide, when the tide is rising, is called the *flow* or *flood*.

Importance of tides

Tides are mainly useful for navigation purposes. The high tides are beneficial in raising water in shallow shores that often constrain harbouring or anchoring of the ships at the harbour. Therefore, due to heights of tides at the entrances enable easily arrival of boats and ships. *Ebb*- dominant estuaries tend to flush sediments seawards and by so doing provide more stable environments for shipping. Tides help in desilting the sediment and removing polluted water from estuaries. Also, tides are used for generation of electricity and this is found in Canada, France, Russia and China. Furthermore, high tides are good for bringing fish at the shore enabling the fishermen get plenty of fish.

Exercise 4.5

1. How constructive waves can enhance economic development of a country?
2. Discuss the importance of tidal waves on the livelihoods of communities living along the East Africa coasts.

Coast

A coast is a narrow zone where the land and the sea or ocean meet or overlap and directly interact. In studying the coast two concepts need to be understood. First is *coastline*, which is the border between the land and Sea. It can be a cliff line or gentle slopping. The second is the *shore*, this is the land between high tidal water level and low tidal water level. The *shoreline* is the line where the shore and the sea meet.

Factors influencing the shape of the coast

The coast keep on changing due to the following factors:

Marine deposition rate: It leads to the formation of coral reef and beaches.

Swash and backwash: Essentially, swash has deposition impact to the coastal landscape. Backwash is useful in clearing (erosion) the coast from deposited material, coral reef and formation of beaches.

Rock type and structure: In terms of rock type and structure, hard rock resist erosion, while soft rock is easily eroded hence influence changes to the coast line.

Topography: This is important since the gently sloping shoreline can influence deposition features while steep sloping shorelines can influence erosion features.

Geology: In areas whose geology appears in a form of rock with joints are vulnerable to erosion which may lead to the formation of caves, wave cut platform, and arch.

Plate movements and volcanic activities: These can lead to the upward or downward movement of the landmass along the coastline which may result from volcanic eruption.

Weathering through wave action: Weathering through wave action can lead to the formation of caves, bay, headland, and arch.

Solution: This process can dissolve some salt and limestone rocks along the coast.

Human factor: These involve building of walls/groynes to protect erosion and flood and through the extraction of stones and sand for construction of buildings, recreation centres thus affecting coastline in one way or another.

Global warming: It is another factor that leads to the melting of ice hence result into the formation of barrier beach and delta.

Glaciation: Glaciation influences the shape of the coast such that during the glacial era, when much of the oceans' water were frozen, the sea level slowly decreased as some water was stored on land as ice sheet, ice caps and ice bags. During the last ice age, the level of the sea was lower than it is today because large quantities of water were locked up in the ice masses which covered extensive parts of Europe and North America. Gradual return to warmer conditions melted ice sheets and their waters returned to the sea. This caused the level of the sea to rise and some coastal regions were submerged.

Earth movements: Earth movements can cause an uplift or a depression of the land for example, the coastal regions.

Organisms: Organisms especially coral polyps influence the change of the coast by develop coral reefs such as fringing reef, barrier reef and atoll.

Increased estuarine: This has an implication to the raising of tides that in turn reduces the drainage and prolong inundation of the low-lying coastal areas. This has an impact on agriculture, settlement and natural coastal systems.

Eustatic change: This is concerned with a change in sea level by either an increase or a decrease of the amount of water in the oceans. This is a result of either the melting of ice or freezing of water (Figure 4.69).

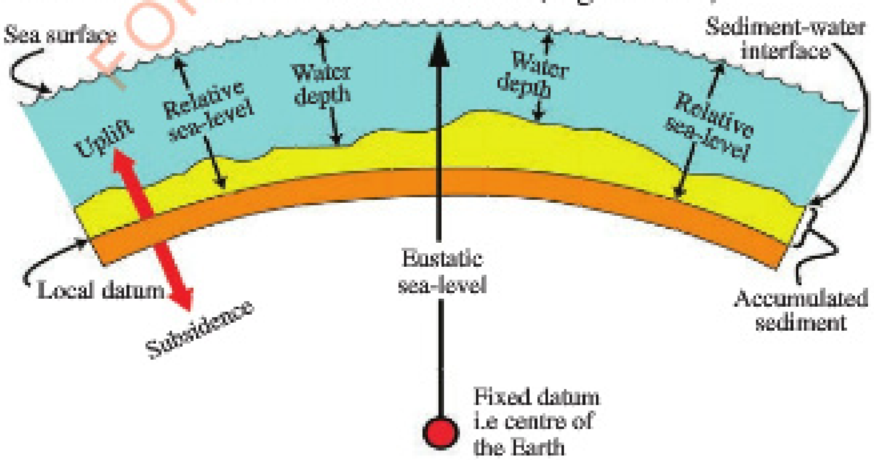


Figure 4.69: *Eustatic change*

Evidences of sea level changes

The main evidence of the sea level changes include: the formation of new features by increased erosion or deposition; balance between erosion and deposition at the river mouth; destruction of crops and vegetation buildings along the coast due to the rise of sea level; the formation of fiords, estuaries, ria and dalmatian coasts; the raised beaches along the coastal area; exposure of mud flats and the wave-cut platforms.

Sea level rise

Sea level rise is the functional role of an ocean surface, which is determined by the volume of ocean water, volume of ocean basins and the distribution of the ocean water. Globally, sea level has risen to approximately 120 metres ever since past glacial maximum approximately 20 000 years ago. It reached a near standstill about 2 000 to 3 000 years ago when the rate of sea level rise slowed to 0.1 to 0.2 per year. However, from 1 901 to 2 010 the global mean sea level has risen to about 1.5 to 1.9 milimetres per year. The change in sea level can be attributed to numerous factors namely glacial formation (freezing of water) leading to the fall of sea level; melting of ice as a result of the rise in temperature results into rising of sea level; and the rising and falling of coastal land, when land uplifts the sea level falls while when land sinks the sea level rises.

Other factors associated to the change in sea level are isostatic adjustment which refers to a local change in sea level caused by the change in the level of the land due to isostatic movement. The ever-increasing global warming is the primary cause of the current sea level rise. This is explained by the increasing human activities such as burning of coal, oil, forest and cutting down tropical forest that have resulted to increased atmospheric concentrations of heat-trapping gases that in turn results into rising of temperature, which leads to the melting of ice. Melting ice from highland areas ends up to the seas and oceans leading to the rise of sea level. The rise of sea level is associated with the formation of fiords, ria and estuaries. On the other hand rising temperature warms (heats) ocean water, as water gets heated expands leading to the sea level rise.

Classification of coasts

The length of the coastline is the main underlying reason for classifying the coasts. Coasts are divided into four categories based on sea level changes. These are emergent, submergence, stable or neutral, and compound coasts. Moreover, coasts can also be classified based on the nature, whereby there are indented coasts made of alternative layer of soft and hard rocks, and smooth coast which are made up of uniform rock structure. Besides, great variety of coastal classification that exist the coast can be divided into two basic types namely emerged coast and submerged coast.

Emerged Coast

These result from the fall in the sea level or uplift of the land. The emerged coast is also divided into two subtypes following their mode of formation and resultant features. These are emerged highland coast and emerged lowland coast.

Emerged highland coast: These are formed where the sea level has dropped or the land near the coastline has risen because of the uplifting of fractured land along the coast or folding of coastal land. The emerged coast therefore, is divided into highland coast and low land coast. The emerged coasts can also be a result of fall of the sea level caused by water being locked up in the ice masses or ice sheets or due to the high evaporation rate.

There are four main features associated with these coasts. The first feature is a *raised beach* which is the most prominent/dominant feature of raised beach is beyond the present shore line. It may still possess arches, stacks, caves and other coastal features which includes, notches and wave-cut platforms. The second feature is *notch* that is the V-shaped cut formed as a result of undercutting of a cliff by wave erosion during the high tides. An example of this feature is seen at Kilindini harbour's entrance in Mombasa, Kenya. The third feature is *wave-cut platform* which are platform like features standing above the present shoreline. The fourth feature is *old cliff* which refers to the cliff standing above the new cliff (Figure 4.70).

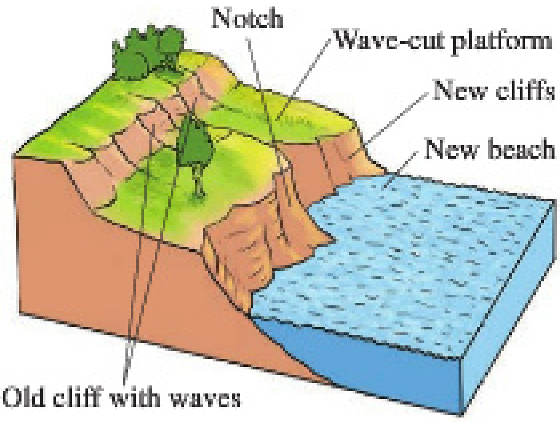


Figure 4.70: *Emerged highland coastline*

Emerged lowland coast: These are emerged continental shelves which become exposed as a result of relative fall in sea level along the lowland coast or rise of the lowland due to land uplift. The distinguishing feature include wave action in the shallow offshore water do deposit materials, thus resulting into the formation of features including beaches, mudflats, offshore bar and barrier beaches, various emergence of old coastline, river rejuvenation, and emergence of old beaches. Example of emerged lowland coast feature can be seen in the coastal plain of Mozambique, along the coast of the Gulf of Mexico, Tokoradi in Ghana and along the coast of Cameroon.

Submerged Coasts

These result from the rise of sea-level or the fall in the land surface along the coast and are mostly characterized by an indented coastline such as rias and fiords. The submerged coast is divided into upland coast and lowland coast. The submerged upland coasts are the coastlines formed due to the fall of the land or a rise in the sea level. They are less common and mostly characterized by peninsula (land almost completely surrounded by water) representing former upland also have inlets indicating the former valley, mostly separated by narrow headlands. Valleys near coastal areas that had been covered out by rivers become estuaries or arms of the sea that extend inland to meet the mouth of river. This can be seen along the coast of South west England, drowning many river valleys around the coast of Ireland, Devon and Corn wall and creating *rias* and *dalmatian* coast. In Scotland glacial valleys were drowned to create *fiord* and *estuary*.

Ria coasts: Ria coasts refer to the coast formed when the highland area with river valley is submerged and the lower part of its river valley becomes flooded by water from the sea. Therefore, the submerged river valley is called a ria. Ria coasts are characteristics of upland coastal regions where mountains run at right angle to the sea that is discordant to the coast. The rise in the sea level submerges or drawns the lower parts of the valley to form long narrow branching inlets separated by narrow headlands (Figure 4.71). They are not glaciated, that is the river does not originate from the glacial area and depth increases seaward. Example of Ria coast can be seen north-west France north-west Spain and South-West Ireland. Ria are useful in supporting few large commercial ports, used for setting fishing port.

Figure 4.71: *Ria coastline*

Dalmatian coast: The Dalmatian coast also called longitudinal coast refers to a coast formed where mountains or hills and valleys run parallel to the coast. The valleys become swallowed with water to give narrow inlet and the hills form islands. Example of this type of coast occurs in Yugoslavia and North and South America. They are characterized by mountain coastline, deep and lack distinguished ports. It is good for the allocation of ports. A good example is San Francisco Port in California (Figure 4.72).

Figure 4.72: *Dalmatian coast*

Fiord Coast: This is the coast formed when U-shaped glacial valleys are flooded with water. They are characterized by a valley with steep walls with several tributaries joining the main valley, that tend to have long valleys due to erosion and extends further inland. Good examples of this feature can be seen in Norway, Chile and New Zealand (Figure 4.73).

Figure 4.73: *Fiord coast*

Estuary Coasts: This is a coast formed when the mouths of rivers along low lying coast are drowned with water. The result of this is the formation of funnel-shaped estuaries (Figure 4.74).

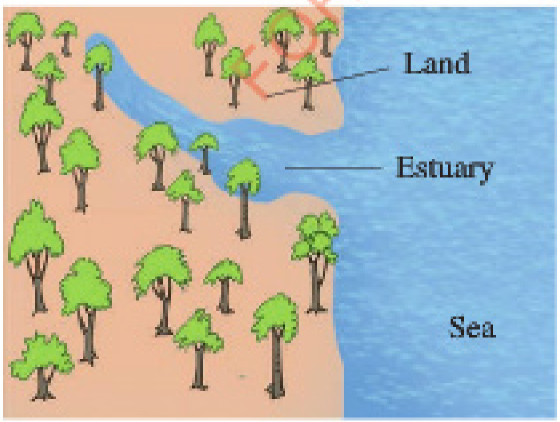


Figure 4.74: *Estuarine coast*

Stable coast: Stable or neutral coasts are coasts showing no signs of change in sea-level or in the land but influence coastal land slowly. In these coasts the incidental erosion process is a reversible one representing the condition in which the coastal profile is restored.

Compound coast: These are coasts produced due to the influence of a mixture of several emergences and submergences as well as other effects like accumulation of materials.

Coral coast

These are coasts formed or characterized by coral reefs. A coral reef is a limestone rock made up of skeletons of very small marine organisms called *coral polyps* which tend to live in coral reefs. Coral polyps are the small marine organisms created with hard skeleton. Coral is a general name for any of a large group of marine organisms with calcareous skeleton. Coral coasts differ from other coasts since they are largely organic in origin. When polyps die, their skeletons, which are made of calcium carbonate, accumulate with other organisms to form coral limestone under favourable conditions. In this way, large banks of rock called *coral reefs* are gradually built up along the coast to form a coral coast.

Conditions necessary for the growth of coral polyps

Sea temperature which ranges between 20 °C and 30 °C is a necessary condition for growth of coral polyps. Sunlight that penetrates to a depth of at least 50 m is another requirement. Beyond this depth, sunlight is too weak for photosynthesis to take place and this is essential for the survival of the microscopic algae on which the coral polyps depend. Coral reefs require salt water which is free from sediment. They do not occur at river mouths where the salinity is neutralized. Growth of coral reefs requires plentiful supply of plant food (plankton) and enough oxygen.

Distribution of coral reefs

Most of the coral reefs are found on the eastern coasts between 20° and 30° North and South with warm and clear salt water and in the tropical area with plentiful supply of sunlight. The Eastern coasts of the continents favour coral formation because they are washed by warm ocean currents. Coral coasts are widespread in East African coasts, especially in Zanzibar and Bagamoyo. They do not develop on the western coast of land masses because of the cool currents which flow along these areas.

Types of coral reefs

There are three types of coral reefs, namely; fringing reefs, barrier reefs, and atoll reef.

Fringing reef: This is a coral reef attached to the coast with shallow narrow lagoon separating it from the mainland. The platform surface is usually flat up to one kilometre wide and its outer edge falls steeply to the seafloor (Figure 4.75). The Lagoon may disappear at low water. Good examples of fringing reefs are observed along the coast of East Africa, specifically in Kenya and Tanzania.

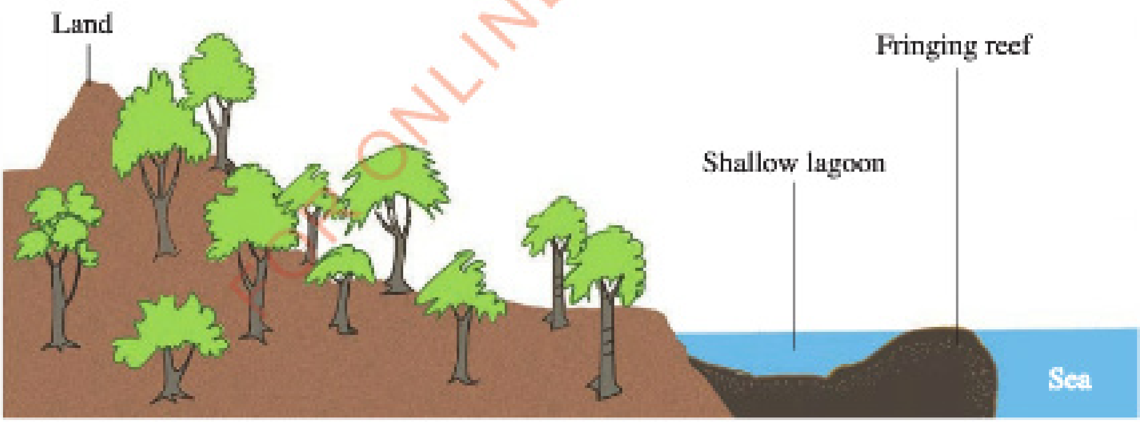


Figure 4.75: *A fringing reef*

Barrier reef

A barrier reef is similar to a fringing reef except that the barrier is located far away from the coast and is therefore separated from the mainland by deep water lagoon which is wider (Figure 4.76). Barrier reefs occur along parts of the east coast of

Africa, notably around Mayotte, an island between Madagascar and Mozambique. They are also found along the coast of Queensland, Australia.

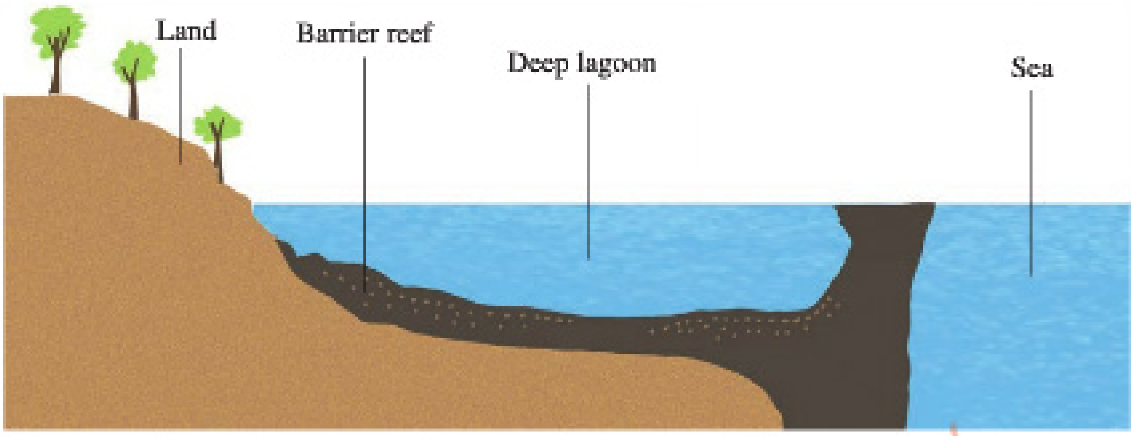


Figure 4.76: *Barrier reef*

Atoll reef: This type of coral reef is circular in shape, enclosing a fairly deep lagoon without any land in the centre. The encircling ring is usually broken at a few places to allow free flow of water (Figure 4.77). On the inside of the reefs, sand and limestone debris collect, and palm trees may grow. Also in calm water atolls are useful for fish breeding. The best example of atoll reef in Africa is the Aldabra Atoll that lies between Zanzibar and Madagascar.

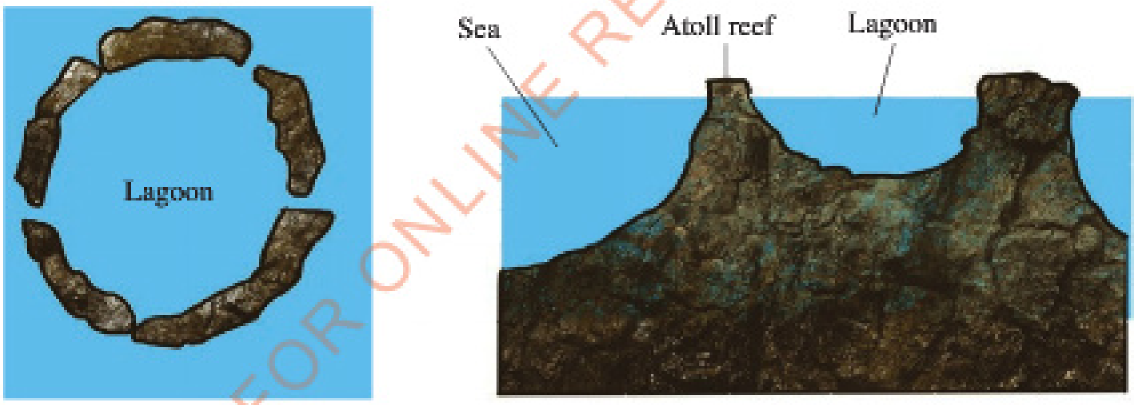


Figure 4.77: *Atoll reef*

Formation of coral reefs

The origin of the coral reefs especially barrier and atoll reefs has been debatable for more than half a century. Several theories have been suggested to explain formation of coral reefs but none is self- satisfactory and universally accepted. The most widely accepted theory was put forward by one of the great scientist Charles Darwin after his voyage to the Pacific Island in 1842.

Darwin's theory

Darwin's theory also known as subsidence theory relies on the subsidence of land masses. According to this theory, all coral reefs began as fringing reefs around an island. Due to a general down warping of the earth's crust, corals continue to grow upwards to keep pace with the subsidence. Later on they form a barrier reef. Eventually, when the land is completely submerged, the atoll is formed (Figure 4.78). Thus, according to Darwin, it is the subsidence of the land mass that caused the deepening and widening of lagoon, the foundation of a barrier reef and an atoll.

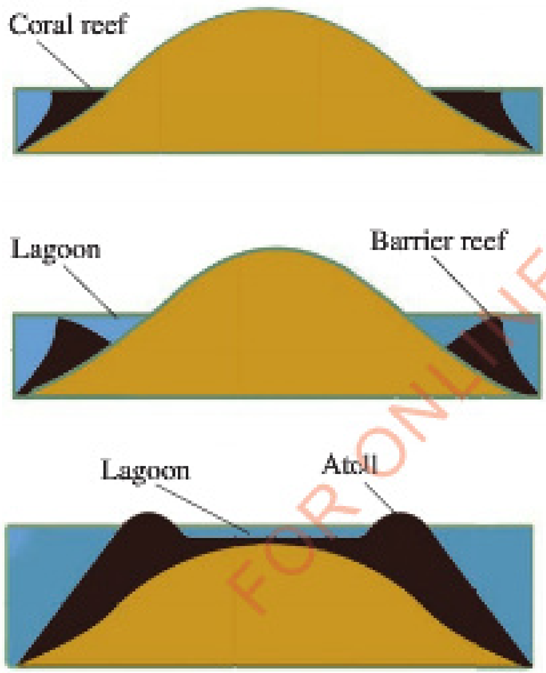


Figure 4.78: *Illustration of Darwin's theory on the origin of fringing reef, barrier reef and atoll*

Daly's theory

This is also known as glacial control theory. The theory is based on the changing level of the sea during and after the ice age. This theory holds that the formation of barrier reefs and atolls was due to the rise in the sea level caused by the melting of ice (Figure 4.79).

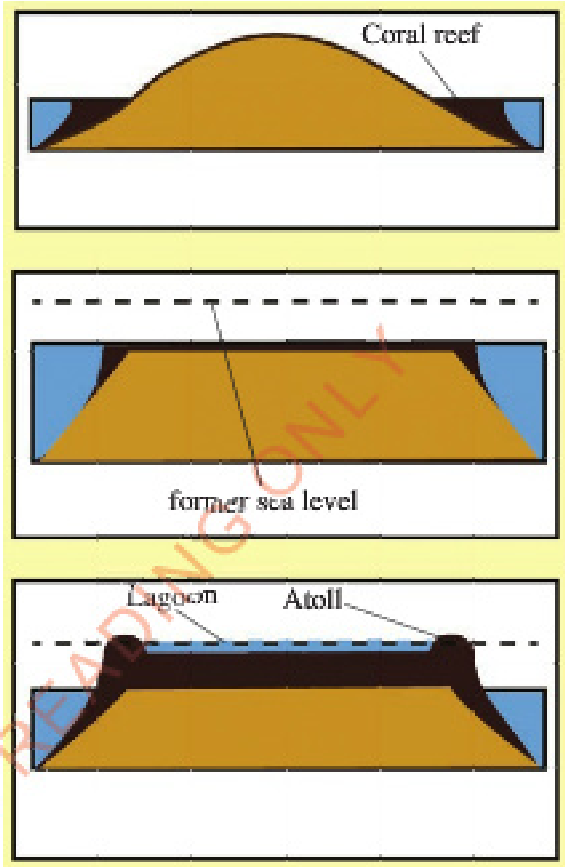


Figure 4.79: *Illustration of Daly's theory on the origin of fringing reef, barrier reef and atoll*

Murray's theory

This is also known as stand still theory. According to Murray's theory, the formation of barrier reefs does not involve subsidence. Murray argues that coral reefs might have grown as a result of deposition of the coral debris on the seaward side of the fringing reef. The deposited materials eventually form base for further growth of polyps.

Five most famous coral reef areas of the world

The most famous coral reef areas of the world include the following:

The Great Barrier Reef: This is the largest coral reef system commonly found in the Queensland and parts of the coast of Australia. The Belize Barrier Reef: This is the world's second largest coral reef that covers the area along the western Atlantic coast such as Bermuda, the Bahamas, Florida and Caribbean islands. The Andros Bahamas Barrier Reef: This is the third largest coral reef of the world that covers the eastern coast of Andros Island, and the Bahamas in Burma. The New Caledonia Barrier Reef: It is the fourth world largest coral reef that covers almost the length of 1500 km around New Caledonia islands. The Indo-Pacific coral reefs: These coral reefs cover the vast area from the coast of east Africa to the Persian Gulf through the Indian and Pacific Oceans.

Problems facing the development and growth of coral reefs

Due to the benefits provided by coral reefs and their geomorphic importance, it is vital to explore the problems facing their development and growth. The main problems are: strong winds which lead to the formation of strong and destructive waves resulting from strong waves. The waves which hinder the development of coral reefs; oil spills, acid rain, poor fishing methods (using chemicals) in the ocean which lead to the destruction of coral rock and death of coral polyps; and the breaking of coral rock in order to get raw materials for cement and stones for construction. All these poses a great challenge to the growth of corals. Furthermore, deposition of mud along the coast brought by rivers hinders growth of coral reefs; and poor or absence of coastal management policies and laws hinder the growth and development of coral coasts as people conduct different activities along the coast. Also, fall of the sea level affects the development of coral reefs; and improper conduct tourist activities endanger the existence of coral reefs. Furthermore, an increase of temperature due to global warming is attributed to coral bleaching.

Significance of coastal features

Coastal features are valuable in numerous ways. Firstly, deep, well-sheltered harbours have been developed from submerged coastlines, for example include Kilindini in Mombasa, Kenya, and Lagos in Nigeria. Both harbours have been formed along submerged coasts. Secondly, coastal features like cliffs, caves, beaches and beach hotels are tourist attractions. Thirdly, the submerged glaciated coasts (fiord coasts) are good breeding areas for fish. Fourthly, depositional features like mudflats and silt/sand provide fertile soil which is very good for agricultural activities. Lastly, coral reefs features protect the coast against strong waves which can cause coastal land degradation and destruction of property.

Problems facing coastal areas

Coastal areas are subjected to many problems including; water pollution caused by disposal of untreated waters like sewage and water containing chemicals from industries and agricultural areas; oil spills from tanks; excavation of sand and rock; as well as dangerous fishing methods (dynamites fishing). Land degradation caused by wave erosion, which affects the coastal lands as well as erosion by rejuvenated river discourage formation of coral reefs. Floods caused by the occurrence of storms, tsunamis and a change in sea level due to the melting of ice or land subsidence may affect properties and livelihood activities. Unpleasant smell from the sea due to water pollution makes some coastal areas unfriendly to users, as it is the case of Kivukoni area in Dar es Salaam. Occurrence of volcanic activities along the coast due to earth movements may alter existing coastal features, destroy properties and pollute the water.

Exercise 4.6

1. Explain the influence of human activities on the development and distribution of coral reefs.
2. The shape of the coast of Indian Ocean has never remained the same; it gradually changes due to anthropogenic forces. Explain.
3. With the aid of a world map, illustrate the geographical distribution of areas with high and low salinity.

Revision exercise

1. (a) With vivid examples show how mass wasting and downwash can occur at global, regional and local scales.
   (b) Appraise the contribution of mass wasting to the socio-economic development.
2. What are the main types of sand dunes?
3. What are the major factors affecting the morphology of sand dunes?
4. Chemical and mechanical weathering are dependent to one another. Substantiate the statement.
5. 'Inspite the low humidity and low rainfall in desert areas, water is nevertheless the dominant agent of erosion and deposition'. Discuss.
6. Explain how chemical or solution erosion can act as one of the processes of river erosion.
7. Deposition is the function of a river which is determined by the failure of transportation. Justify.

8. Describe the mechanism for the occurrence of river piracy.
9. Illustrate the four main processes involved in river erosion.
10. 'The coastal zone is undergoing constant changes' Justify the statement with vivid evidences.
11. As a geographer, explain how waves action modify geomorphology of coastal region.
12. "Coastal landforms can induce economic prosperity along coastal area". Justify the statement.
13. Appraise the contribution of the rise and fall of the sea-level and land surface to the formation of coasts.
14. Discuss the view that the origin of coral reefs is debatable.

Chapter Five

Rocks

Introduction

Rocks are composed of various minerals, each fulfilling essential roles necessary for life. In this chapter, you will learn about the meaning, characteristics and types of rocks, and rock cycle; how to determine age of rocks and how rocks are transformed into soil. The competences developed will enable you to demonstrate an understanding of rocks and the rock cycle. It will also enable you to use rocks sustainably for various economic activities for self and national development.

Think about

Rocks as an important Earth material for life existence

Meaning of rocks

Activity 5.1

Explore different types of rocks through observing local environment or watching pictures or video through online sources. Write down all necessary details from your exploration.

Rocks are natural occurring solid cohesive aggregates of one or more mineral materials. They are often made up of the combination of several chemical elements which are oxygen, silicon, iron, aluminium, calcium, potassium, sodium and magnesium (Table 5.1). Rocks vary in degree of hardness, coherence, and permeability.

Table 5.1: *Rocks formed by a combination of minerals*

Rocks	Minerals
Limestone	Quartz, mica, feldspar, calcite, dolomite, iron ore
Granite	Felspar, Quartz, mica and some iron ore
Basalt	Calcite, dolomite
Sandstone	Quartz, Calcite, feldspar and iron ore
Shale	Quartz, mica, feldspar, chlorite, calcite and dolomite.

Types and characteristics of rocks

Rocks are of different types and varying characteristics. Some rocks are hard and compact, for example, granite and sandstone. Other rocks are made up of loose particles such as, gravels and mud. Similarly, there are rocks made up of organic matters like limestone and coal. Generally, rocks can be classified based on their mode of formation (origin), chemical composition and age.

Types of rocks according to mode of formation

Based on their mode of formation or origin, rocks can be categorized into three main types namely Igneous, sedimentary and metamorphic rocks.

Igneous rocks

The term igneous is derived from a Latin word "ignis" meaning fire. It is a rock formed from cooling and solidification (crystallization) of molten rock materials (magma). Magma can be derived from partial melts of pre-existing rocks in either a planet mantle or crust. The melting of rocks is influenced by one or more of the three processes that are; an increase in temperature, a decrease in pressure as well as a change in its composition. Igneous rocks are also called primary rocks because other types of rocks such as sedimentary and metamorphic owe their origin from igneous rocks. It forms the basis for soil formation (pedogenesis) and lastly, it constitutes the largest proportion of the earth's crust as it covers almost 99% of all rocks. Thus, indirectly or directly all other rocks were formed from igneous rocks. Examples of igneous rocks include basalt, granite, gabbros, rhyolite and dolerite.

Characteristics of igneous rocks

Igneous rocks have several characteristics as follows: The rocks are hard and water percolates with great difficulty along the joints. Sometimes the rocks can be soft when exposed to environmental factors for longer time that can be easily dug-out by spade. Igneous rocks also consist of granular or crystalline rocks but there are much variations in the size, form and texture of grains because these properties largely depend upon the rate and place of cooling and solidification of magma or lavas. They lack strata-like sedimentary rocks. Lava can cool down and solidify phase after phase to form layers but these layers are not strata-like sedimentary rocks. Moreover, igneous rocks do not contain fossils, rather they contain acidic or basic nature, because the rocks are formed due to the cooling down and solidification of magma, which is free of fossils. Naturally, magma is hot, such that it can easily destroy any fossils that come into contact. Igneous rocks are classified based on various characteristics of the rocks such as texture, mode of formation and chemical composition.

Classification of igneous rocks according to the mode of formation

Under this classification there are two types of igneous rocks; intrusive and extrusive igneous rocks.

Intrusive igneous rocks also known as *plutonic* rocks, occur when magma cools down, solidifies and crystallizes slowly within the earth's crust. A good example of intrusive igneous rock is granite. Intrusive igneous rocks are also sub-dived into plutonic and hypabyssal intrusive igneous rocks. The classification is based on the depth of the place of cooling and solidification of magma. When magma cools and solidifies very deep within the earth, it forms plutonic but when magma is cooled just below the earth's surface, the rocks are hypabyssal.

Extrusive igneous rocks which are also known as volcanic igneous rocks occur when magma reaches the earth's surface either as lava or fragmental ejecta and form rocks such as pumice or basalt. Generally, extrusive igneous rocks are formed mostly by fissure eruption of volcanoes resulting into flood basalts.

Classification of igneous rocks based on texture

Texture describes the physical characteristics of the minerals forming a rock, such as grain size. It relates to the cooling down and solidification history of the molten magma from which it comes from. The texture of an igneous rock includes phaneritic, aphanitic, porphyritic, glassy, vesicular and fragmented textures.

Phaneritic texture: Rocks are comprised of large crystals of 0.5 milimetres to several centimetres in size that are clearly visible to the eye with or without a hand lens or binocular microscope and it has no fine matrix material present. This texture is formed by the slow cooling down and solidification of magma beneath the earth's surface in the plutonic environment.

Aphanitic texture: This is comprised of small crystals which are generally less than 0.5 milimetres in size and they cannot be seen by the eye or hand lens. This texture results from a rapid cooling down in volcanic or hypabyssal (shallow subsurface) environments.

Porphyritic texture: This is comprised of at least two minerals having a visible (large) difference in grain size. The larger grains are called phenocrysts and the finer grains are either called matrix or groundmass. Porphyritic rocks have usually undergone two stages of cooling; one at depth where the larger phenocrysts are formed and the second one near the surface where the matrix grains are crystallized.

Glassy texture: This is non-crystalline, whereby the rock does not contain mineral grains. Glass results from a very fast cooling down process through which minerals do not get a chance to crystallize. This happens when magma or lava comes into quick contact with much cooler materials near the earth's surface. Pure volcanic glass is known as obsidian.

Vesicular texture: This term refers to vesicles (cracks) within the igneous rock. Vesicles are a result of gas (bubbles) expansion which often occurs during volcanic eruptions. Pumice and scoria are common types of vesicular rocks.

Fragmental (pyroclastic) texture: During an intensive volcanic eruption rocks are usually blown out in the atmosphere. These rocks are comprised of numerous grains or fragments that have been joined together by the heat of volcanic eruption.

Classification of igneous rocks based on chemical composition

This classification refers to rock's specific mineralogy and chemical composition. It is associated with the cooling down and solidification history which influences the composition of that igneous rocks. Most of the igneous rocks are extremely compacted in their chemical composition. Based on chemical composition igneous rocks are classified as either acidic, basic or ultra basic.

Acidic (felsic) igneous rocks: These are types of igneous rocks that consist of great amount of silica (more than 50%) and feldspar. They have very little or no iron (metallic minerals) and they are also low in density. For example, granite has 2.7 g/cm^3, and their colour varies from white to pink. Granite is good for construction purposes and building stone and it is acidic in nature.

Basic (mafic) igneous rocks: These rocks are also called Ferro magnesium minerals. They are igneous rocks that consist of large amount of magnesium, iron and aluminum. The word *"Ma"* comes from Magnesium and "fic" from ferric (iron) such as gabbro, basalt. These rocks are also dark in colour and rich in iron and magnesium because of the presence of metallic minerals, such as basalt, gabbro and dolerite. They are of high density of 3.0g/cm^3.

Ultra basic (mafic) igneous rocks: These rocks consist of a very large amount of metallic minerals like iron and magnesium. They also have little amount of silica accounting to less than 45%. A good example is peridotite, which lacks aluminum and it is high in density of about 3.3g/cm^3. The ultra basic (mafic) igneous rocks are very rare on the earth's surface and they normally comprise great bulk of materials found below the earth's crust. Figure 5.1 summarizes the chemical composition of igneous rock.

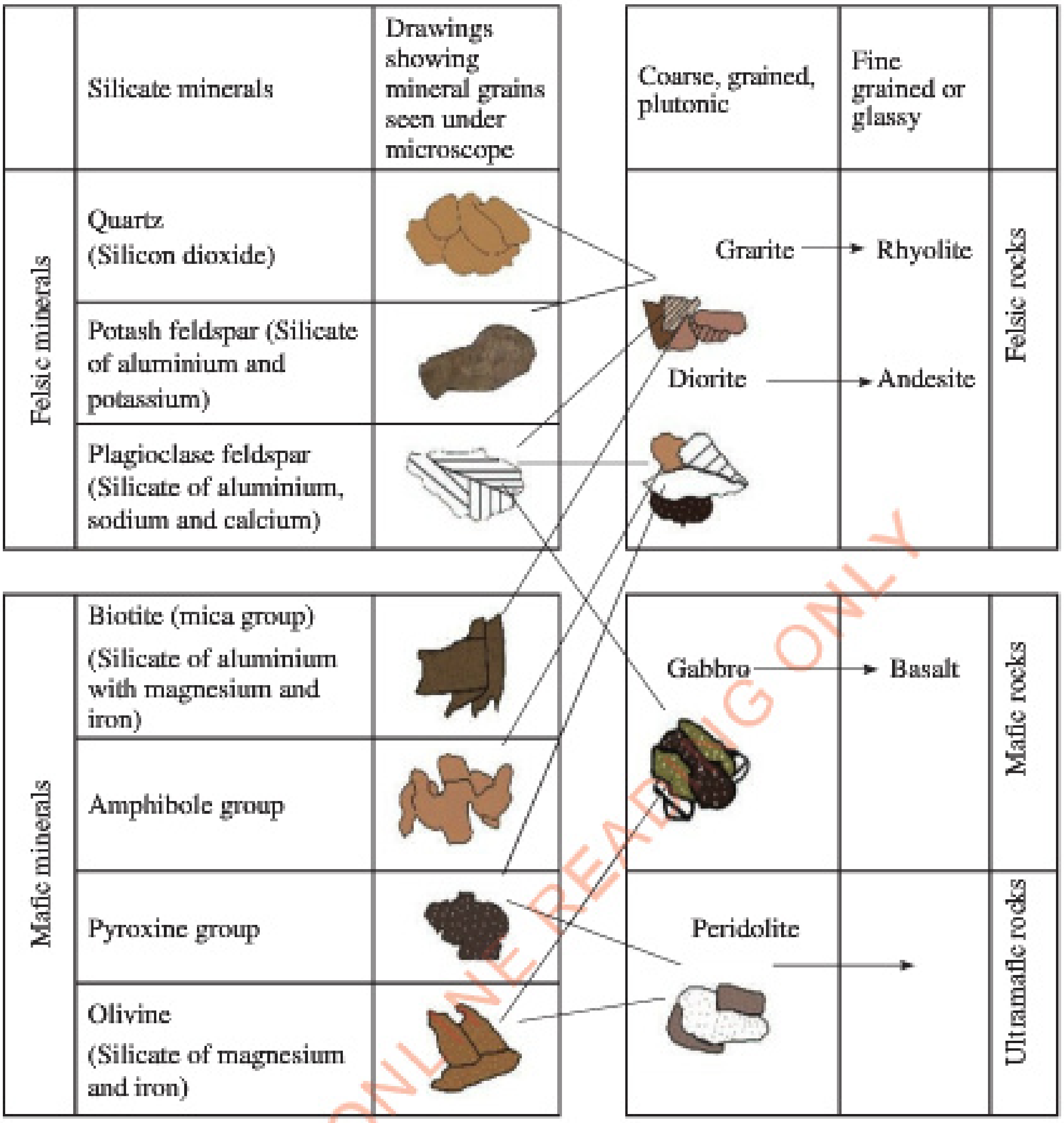


Figure 5.1: *Chemical composition of igneous rocks*

Sedimentary rocks

The word sedimentary comes from the Latin word *"sedere"* meaning 'sit" or *"settle"* referring to the types of rocks which have been formed either from sediments or the remains of once living organisms. Sedimentary rocks are rocks formed at or near the earth's surface by the accumulation and lithification of sediments or by the precipitation from solution at normal surface temperatures. They are formed from the remains of former rocks which have been weathered, eroded, transported and deposited elsewhere by wind, water or ice. The deposited sediments are consolidated, compacted and cemented in a number of ways to form sedimentary rocks. Sediments can be detrital, chemical or organic. Detrital sediments are mechanically eroded from pre-existing rocks. Chemical sediments on the other hand are fluid precipitates or evaporites deposited in the environments. Sedimentary rocks are important with respect to resources like limestone deposits, coal and oil.

Characteristics of sedimentary rocks

Sedimentary rocks consist of fossils of plants and animals since they are formed by sediments derived from old rocks as well as from plant and animal remains. They contain several layers or strata but are seldom crystalline rocks. The sedimentary rocks are mostly formed from the deposition of sediments of various types and size which takes place in sequence and system. Most of the sedimentary rocks are soft permeable and porous, but few are non-porous and impermeable. They can change to other types of rocks by the influence of heat/pressure or weathering process. Furthermore, they are formed by accumulation, compaction, cementation, and lithification of sediments. Sedimentary rocks are found over the largest surface area of the globe. It is estimated that about 75% of the surface cover of the earth is of sedimentary rocks.

Types of sedimentary rocks

Sedimentary rocks are grouped into two types based on the size of the rock or mineral grain and mode of formation. Based on the size of mineral grain, sedimentary rocks are classified as *clastic*. Clastic sedimentary rocks are formed as bits of weathered rock are cemented together. All kinds of rocks are subjected to weathering, hence many different minerals can make up this group of rocks but clay and quartz are the most common. Classification of clastic sedimentary rocks is done according to the size of the sediments that make up the rock. It consists of rock and mineral grains or clasts of varying size ranging from clay, silt, and sand to pebble, cobble, and boulder-size materials. These clasts are transported by gravity, mudflows, running water, glaciers, and wind and are eventually deposited in various settings such as desert dunes, on alluvial fans, across continental shelves, and in river deltas. Based on their mode of formation sedimentary rocks are categorized into three types which are mechanically, organically and chemically formed sedimentary rocks (Table 5.2).

Table 5.2: *Types of sedimentary rocks and their characteristics*

Rock name	Description
 Limestone	This type of rock is classified as chemical or organic sediment depending on how it is formed. It is composed primarily of calcium carbonate. The rock can be formed in two ways, either organically from the accumulation of shell, coral, algal and fecal debris or chemically from the precipitation of calcium carbonate from lake or ocean water. Limestone is used in many ways. Some of the most common uses are to produce cement, and crushed stones and for acid neutralization.

 Conglomerate	This is a clastic sedimentary rock that contains large (greater than 2 millimetre diameter) weathered debris. Large amount of sand can accumulate in places like beaches, deserts, flood plains and deltas.
 Sandstone	This is primarily a clastic sedimentary rock made up mainly of sand-size (1 to 2 millimetre diameter) weathered debris. Large amount of sand can accumulate in places such as beaches, deserts, flood plains and deltas.
 Coal	This is purely an organic sedimentary rock that forms mainly from plant debris. Plant debris usually accumulates in a swamp environment. Coal is combustible and is often mined for use as a source of fuel.

Mechanically formed sedimentary rocks

Mechanically formed sedimentary (Clastic) rocks are formed from the mechanical break up of other rocks and are classified based on particle size. It includes a variety of either coarse or fine texture rocks formed by lithification, desiccation and cementation of detrital sediments, such as sand. Mechanically formed sedimentary rocks can be classified into three sub-categories, namely; argillaceous rocks, arenaceous rocks and rudaceous rocks. The *argillaceous rocks* are composed of very small and fine particles like clay, silt and mudstone. These can be formed through wind deposited - loess (mudstone), river and sea deposited - clays, gravels and alluvium, and glacier deposited - Moraines, sand and boulder clay. Its mineral size particles range between 0.02 – 0.003 milimitres. They are characterized by having visible layers, containing fossils, being tough for those cemented with silicate solution contents and being weaker for those cemented with calcium solution, joint may develop at 90° to the bedding plane to form lines of weakness. The *arenaceous rocks (arenites)* include all clastic sedimentary rocks whose medium particle sizes range from 2 to 0.06 milimitres, or if silt is included, to 0.004 milimitres. Some arenites are composed primarily of carbonate particles, in which case they are called calcarenites and are grouped with the limestones. *Rudaceous rocks* consist chiefly of large sized particles such as gravel, pebbles, cobbles, or boulders. Loose materials of this class are gravels, pebble-beds, shingle, boulder beds, scree and talus. When these particles are cemented, they form conglomerates and breccias.

Organically formed sedimentary rocks

These are the rocks formed from the remains of once living organisms either animals or plants and they accumulate over a long period of time. Organically sedimentary rocks can be further sub-divided into four (4) sub categories namely; Calcareous, Siliceous, Carbonaceous and Ferruginous.

Calcareous rocks: These are formed from the shells and skeletons of once living animals for example, limestone and chalk or coral reefs.

Siliceous rocks: These are formed as a result of remains of organisms like diatoms and radiolarians whose skeletons are rich in silica. An example of this is diatomite rocks.

Carbonaceous rocks: These are formed from plant remains buried thousands of years ago, under heat and overlying pressure resulting to plants changing into rocks. Coal like lignite, bituminous, anthracite, and brown coal are examples of this category of rocks.

Ferruginous rocks: These are formed from precipitation of hydrated iron oxide by some small bacterial organism produced by decomposing vegetable matter composed of high concentration of iron. Example are ironstone and ferric rocks.

Chemically formed sedimentary rocks

These are type of rocks that are formed when rocks undergo chemical changes, and the original minerals are substituted by another type to form sedimentary rocks. Most of these are formed from either precipitated or evaporated salt solution which have been formed due to the dissolving of original minerals. However, not all sedimentary rocks are formed from rock pieces. Chemically formed sedimentary rocks include the following:

Gypsum and rock salt: These rocks are formed when water containing a large amount of dissolved minerals evaporates, and the dissolved mineral matter remains as deposit. For example, if water supply to a lake is cut-off, the water in the lake will eventually disappear and the lake will turn to a salt lake. If the water in the lake containing calcium sulphate dissolved minerals dries, it usually form gypsum as one of the sedimentary rocks. On the other hand, rock salt will form if the water contains chloride as dissolved minerals.

Carbonate rocks: Occurs when weak carbonic acid is formed through dissolving rain water as it falls from the atmosphere. When it reaches the rocks rich in calcium carbonate like limestone it tends to be transformed into calcium bicarbonate which is easily removed in solution. Limestone landscape, is one of the most noticeable feature and it has very low to almost no vegetation. Reasons for poor vegetation or absence of vegetation is that the permeability of limestone permits rain to soak into it very easily. Rivers from non-limestone region sometimes flow to limestone regions, and when this happens, the river disappears into vertical holes in the surface and continues to flow as underground rivers inside the limestone.

Metamorphic rocks

These are rocks formed either from sedimentary or igneous rocks after being subjected to high pressure or high temperature below the zone of diagenesis or both. Metamorphic rocks are formed through the process known as *metamorphism*. Metamorphism refers to the change of minerals or geological texture of the existing rock to new form without melting to liquid form (magma). The change occurs due to pressure, heat or both. Any rock can be altered by great heat and pressure including the earlier formed metamorphic rocks. In fact, a metamorphic rock means a complete alteration in the appearance of pre-existing rocks due to a change in mineral composition and texture through temperature and pressure.

Agents of metamorphism

Metamorphism consists of three agents. These are heat, compression and solution. Heat is the most important factor for the development of metamorphic rocks from the pre-existing parent rock. The heat changes the mineral composition of the pre-existing rocks. Compression is another agent. Compression from convergent horizontal movements from the endogenic forces put strain and change the form and composition of the parent rocks. With this agent when active chemically hot gases and water pass through the rocks, they change the chemical composition. For example, magmatic water and water contained in the bed of sedimentary rock helps in introducing chemical changes in the rocks. Metamorphic rocks are classified based on their degree of metamorphism and texture. Therefore, there are four types of metamorphism, namely; dynamic (pressure force), thermal (heat force), thermos – dynamic (combination of heat and pressure) and metasomatic.

Dynamic metamorphism: This is the type of metamorphism which is influenced by pressure caused by compressional forces. The movement subjects the rocks to great pressure resulting to wide scale changes of rocks, which is also referred to as regional metamorphism. This occurs to rocks placed under tremendous stress, for example at a collision plate boundary like at Alps Mountains, Himalayan Mountains, and Atlas Mountains.

Thermal metamorphism: This is the type of rocks formed only by the influence of heat. It involves rocks which are deeply buried and those which come into contact with magma. Metamorphism occurs at the temperature between 100°C and 800°C. At these temperature levels rocks are still solid but softened. In the softened state, minerals may rearrange themselves and crystals may change their shape or size. The rocks can change their appearance and character and become, sandstone – quartzite, limestone – marble. Two processes under thermal metamorphism are involved. The first one is *buried metamorphism*, which takes place to deeply buried rocks with the temperature reaching 300°C to cause metamorphism. The second one is, *contact metamorphism* or *aureole metamorphism* which occurs to rocks which are adjacent to bodies of hot magma intruded into the cold crust.

Thermo-dynamic metamorphism: Thermo-dynamic metamorphism is the process which takes place as a combination of heat and pressure. It is caused by earth movement on wide scale thus, causing high pressure and high temperature.

Metasomatic metamorphism: This is a process of metamorphism coupled with the introduction of ions from an eternal source. The ions are brought in by water from outside the immediate environment and are incorporated into the newly crystalline minerals. At the same time, hot water may dissolve minerals that were part of the rock and carry them away. For example, during contact metamorphism, metasomatic may cause schist minerals to crystallize ions (K^+, Na^+, Si^{+4}) that are carried away by the water and participate in metamorphic reactions.

Metamorphic textures: This describes the shape and the orientation of grains found in metamorphic rocks. The main metamorphic textures are either *foliated*, *non- foliated* or *lineate*. A foliated rock is a metamorphic rock whose minerals are arranged in parallel layers. This happens when minerals are crystallized or are flattened under pressure. They also, occur when minerals of different densities divide into layers behaving like a mixture of oil and water and which result into alternating light and dark bands. Many foliated rocks break into thin sheets, for example, slate and schist. Non-foliated rocks are metamorphic rocks without layers and sometimes they may contain long crystals. These rocks do not break up into sheets, such as, marble and quartzite. Moreover, metamorphic rocks are very hard and resistant than igneous and sedimentary rocks and they are formed under high pressure and temperature.

Characteristics of metamorphic rocks

Metamorphic rocks are very hard and more resistant to erosion and weathering. They do not contain fossil and they are formed by metamorphism process. They can also undergo weathering to form sediments that in turn form sedimentary rock. Most of them have wavy like structure.

Exercise 5.1

1. Mr. Chapakazi informed his students that while igneous and metamorphic rocks are both types of rocks, they process distinct characteristics. What are the key differences referred to?
2. With examples, elaborate socio-economic importance of rocks to human development.

The rock cycle

Rock cycle is the transition and transformation among rocks (igneous, sedimentary, and metamorphic rocks). The rock cycle is driven by two forces which are earth's internal heat which causes material to move around in the core and mantle, and the hydrological cycle which is a movement of water, ice, and air at the surface. Generally, rock cycle can be seen as an endless and revisable process by which rocks change from one type to another.

Stages of rock cycle

The first stage of rock cycle is determined by the presence of magma. When magma are forced outside via vents, fissures, and cracks, may cool down and solidify to form igneous rock. The second stage is the formation of igneous rocks. This occurs when molten material called magma or lava cools and solidifies beneath or on the earth's surface forming intrusive and extrusive igneous rocks under the process known as *crystallization*. The third stage is the formation of sedimentary rock. This occurs when igneous rocks become exposed to external agents of weathering and erosion. The weathered material is transported and deposited in oceans, lakes basins and lowlands. The sediments are compacted by the pressure of overlying layers of sediments to form sedimentary rocks. The process of compacting sediments by the pressure of overlying layers of sediments is called *lithification* or *sedimentation*. The fourth stage is the formation of metamorphic rocks. This occurs when sedimentary rocks which are deeply buried, and rocks at collision zones of plates are subjected to pressure and heat turning them into metamorphic rocks through the process of metamorphism. The fifth stage is the completion stage of the circle where the metamorphic rocks are subject to greater heat and pressure and become molten and then be converted into magma. However, the rock cycle is not neccessarily linear. For example, an igneous rock may change, without becoming a sedimentary rock, and get transformed into a metamorphic rock by heat and pressure. Equally, sedimentary and metamorphic rocks may be converted to materials to form new sedimentary rock. The rock cycle as described above has been related to the theory of plate tectonics. The cycle starts with the erosion of a continental land, where the materials from that continent accumulates on the continental margin and become compacted by lithification into sedimentary rock.

If the continental margin is a convergent plate zone, the sedimentary rocks may be transformed by high pressure to belts of metamorphic rock. Progressively, those sediments that were not crumpled up into mountains may be carried down by subduction deeper into the crust. They will undergo greater metamorphism and eventually temperatures and pressures may be so great that melting takes place to generate magma. Later on, magma is converted into igneous rocks which may eventually appear on the earth's surface, either as extrusive igneous rocks from volcanoes or by the exposure of intrusive igneous rocks through erosion. The igneous rocks are attacked by weathering and erosion, and get transported to the continental margin where the cycle starts again. Generally speaking, rock cycle has neither the beginning nor the end, ever since the earth's crust was once made up of molten material (magma), thus we can conclude that the first rock to form on rock cycle is an igneous rock (Figure 5.2).

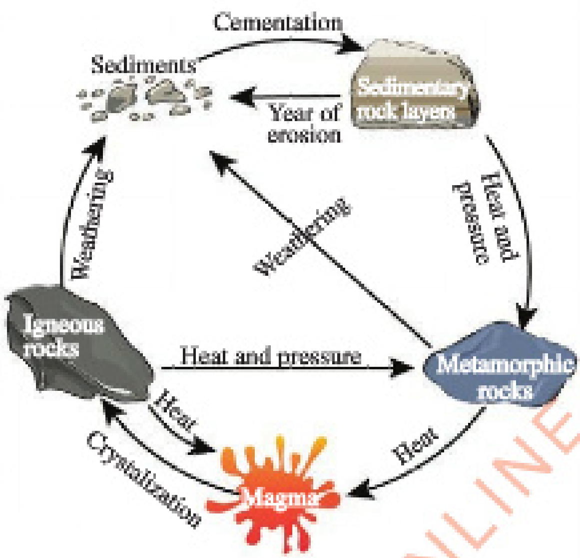


Figure 5.2: *The rock cycle*

Importance of rock cycle

Rock cycle is a good model of explaining the essence, source and origin of rocks. It supports diagramatically the transformation of one type of rock to another. It helps in explaining soil formation by the process known as *pedology*.

Classification of rocks according to age

Rocks are classified based on the age that is influenced by time. As time goes on rocks develop and get matured or change from one type to another. This is caused by various factors. The interrelationship between rocks gives out a physical cycle of the rocks.

Determining age of rocks

It is believed that the lowest rocks (rock layers closest to the bottom of sequence) are the oldest rocks and those existing above (rock layers that are closer to or up the surface) ones are younger. There are two methods of determining age of rocks. One method is to look at any *fossils* the rock may contain. If any of the fossils are unique to one of the geologic time periods, then it would mean that the rock was formed during that particular period of time. Another method is to use the *'What's on top?' rule.* When you find layers of rocks on a cliff or hillside, younger rocks are on top of older rocks. The age of a rock in years is called absolute age. Geologists find absolute ages by measuring the amount of certain radioactive elements in the rock. Scientists express the ages of rocks in two ways which are relative age and absolute age.

Relative ages of rocks

Relative ages of rocks are established by comparing the ages of rocks with each other. The determination of the relative age of a rock is based on; the law of original horizontality of the sediments, law of superposition, law of original lateral continuity, law of cross-cutting relationships, principle of inclusions, principle of fossil succession and the principle lithology of a rock.

The law of original horizontality: This is based on the assumption that most of the sedimentary rocks are usually deposited under the action of gravity in approximately horizontal layers which lie parallel to the surface to which they are deposited.

The law of superimposition: It is also, known as the stratigraphy method. The law holds that the older layers of the sediments are arranged in a sequence whereas the younger layers are overlying older layer as influenced with the force of earth's gravity. In that case, the oldest layer will be at the bottom while the younger layer will be on top of the sequence. Generally, the vertical arrangement of the layers downward determines the age of the rock especially when one knows the rate at which deposition has been taking place in forming each layer.

The law of original lateral continuity: It is based on the fact that the layers of sediments will extend laterally continuously over some distance until they are interrupted by the obstacles or they become thinner.

Law of cross - cutting relationships: Under this law the younger features cut across the older features. Usually faults, dykes, and erosional angular unconformity, are considered to be younger than the materials that are faulted, intruded, or eroded. For example, the mudstone, sandstone and shale are cut by the basalt dyke and it is obvious that mudstone, sandstone, and shale had to be present before the intrusion of the basalt dyke. That makes the dyke younger than the mudstone, sandstone, and shale (Figure 5.3).

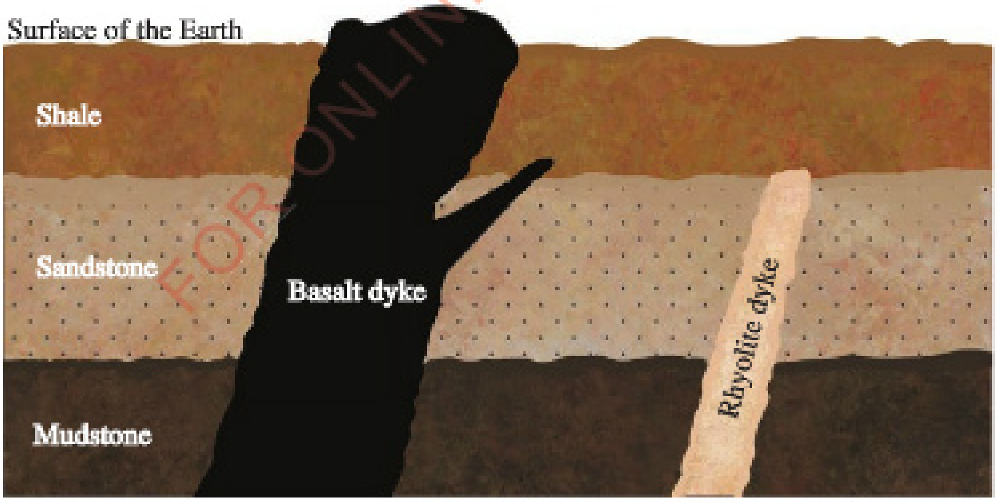


Figure 5.3: *Low of cross- cutting*

The principle of inclusion: This principle suggests that when the fragmented rock is surrounded by another rock. For example, if the surrounding rock is igneous rock then the inclusion is called xenoliths. Generally, the inclusion represents the fragments of the older rock.

The principle of fossil succession: Justification for the age of a rock occurs when evolution has produced a succession of unique fossils that correlate with the units of the geologic time scale. By fossil succession, assemblages of fossils contained in strata are unique to the time they lived, and can be used to correlate rocks of the same age across a wide geographic distribution.

The principle of lithology of a rock: This is the basis of subdividing rock sequences into individual units for the purposes of mapping and correlation between areas. It is the description of its physical characteristics visible at outcrop, in hand or core samples, or with low magnification microscopy.

In relative age of rocks, *relative dating* method is used. This method involves determining the age of a rock in comparison with another rock. It is mostly used in the classification of sedimentary rocks. There are three ways to be used in this classification which include principles of superimposition, mineral relativity and fossil relativity. The *principle of superimposition* is based on the law of superposition which states that "the rock layers are arranged in a sequence such that young layers are overlying the older rock layers". Therefore, as one goes down beyond the earth's surface, the rock layers become older and older. In other words, vertical arrangement of layers downward determines the rock ages. Based on such arrangement, it is easy to estimate the relative age of rocks, especially when one knows the rate at which deposition has been taking place in forming each layer. This helps to know the *unconformity* which is the contact between two rock units in which the upper unit is usually much younger than the lower unit. Unconformities are typically buried erosional surfaces that can represent a break in the geologic record of hundreds of millions of years or more. There are three basic types of unconformities that helps to determine relative ages of rock layers. These are *non conformity*, *disconformity* and *angular unconformity*.

Non conformity occurs when the sediments are deposited on top of an eroded volcanic or metamorphic rock (Figure 5.4). This is the gap that occurs where the sedimentary rock overlies the eroded surface of the rock. Generally, it represents a buried erosional surface which can represent a break in the geological records of hundreds of millions of years.

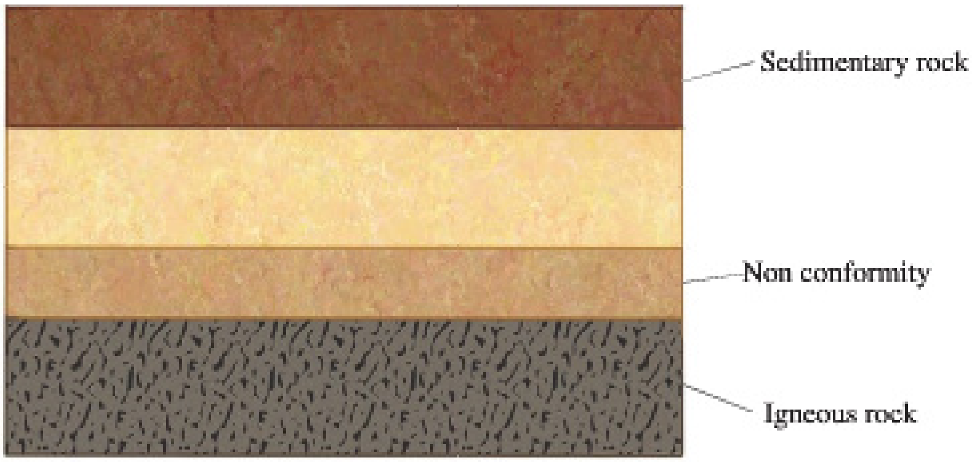


Figure 5.4: *Non conformity*

A disconformity occurs where one layer or several layers of sedimentary rocks have been removed due to erosion by water moving underground or as surface runs off. Disconformities are much harder to recognize in the field because often there is no angular relationship between sets of layers (Figure 5.5). Disconformities are usually recognized by correlating it from one area to another and finding that some strata is missing in one of the areas.

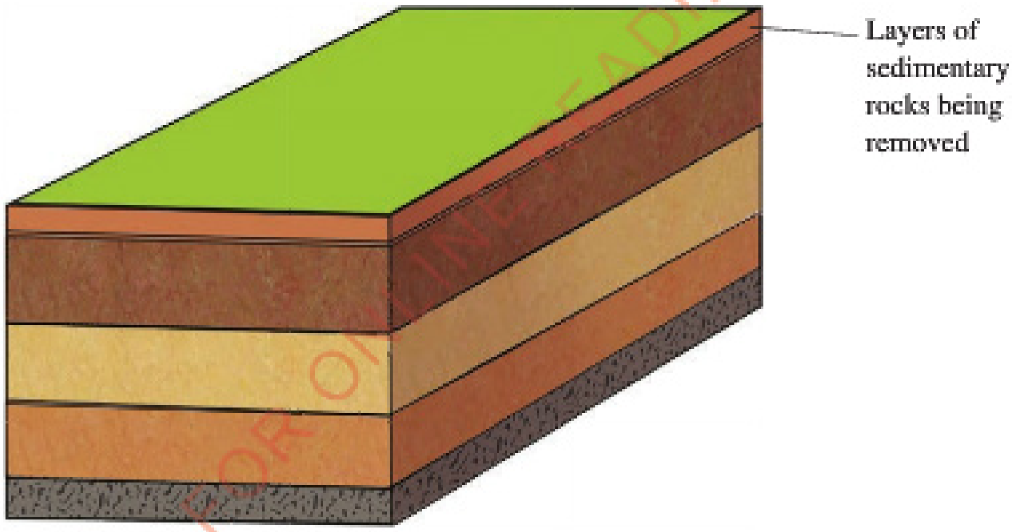


Figure 5.5: *Disconformity.*

An angular unconformity occurs where horizontally parallel strata of a sedimentary rock are deposited on tilted and eroded layers producing an angular discordance with the overlying horizontal layers (Figure 5.6). It occurs when the folded rock strata (layers) have been eroded and then covered by younger horizontal layers of sedimentary rocks.

Figure 5.6: *Angular unconformity*

The mineral relativity: This is based on the relativity of mineral rocks. By this principle any rock is new or old than the fragments of which it is composed of.

Fossils relativity: This method uses fossils found in rocks which lived in a definite order of period. These are remnants or remains of once living organisms which were buried and intermingled with old rocks. Some fossils found in sedimentary rocks imply that such living organisms lived in a definite order of period. For example, graptolites are normally found in dark mudstones and shales. They lived 350 to 450 million years ago. Thus rocks containing these fossils were formed in that period. Trilobites are the earliest marine organisms that flourished about 500 to 600 million years ago. According to fossils relativity, therefore, rocks containing graptolites are younger than those containing Trilobites.

Absolute age of rocks

Absolute dating is the process of determining the age of a rock on a specified time scale in archaeology and geology. Some scientists prefer the terms chronometric or calendar dating, since the use of the word "absolute" implies an unwarranted certainty of accuracy. Absolute dating provides the numerical age or range in contrast with relative dating which places events in order without any measure of the age between events. This is the method that determines the actual age of rocks by using scientific methods. It involves determining the age of a rock by using the breakdown of certain elements of nuclei atoms such as uranium atoms and carbon 14 atoms. With this method, two ways namely, radioactive dating (radioactive breakdown of uranium) and radioactive substance (radio carbon dating or carbon 14) are described.

Radioactive dating: This is also referred to as radioactive breakdown of uranium. Scientists can measure ages of some rocks in more exact terms. They do this with the help of radioactive substances found in some of the rocks. A radioactive substance is the one that changes over a period of time. All matters are made of tiny units called atoms. A radioactive substance has atoms that break apart, a process called *radioactive decay*. For example, uranium is an unstable element which breaks down in a known rate of time. Uranium elements break down gradually into lead which becomes a stable isotope. The half-life of uranium decay is 4.5 billion years (Table 5.3). Supposing a rock had 100 gram of uranium, half of it, that is 50 gram would decay after 4.5 billion years to form lead. At this time the amount of lead would double and that of uranium would decrease by half. On the basis of this, a very long Half-life Radioactive uranium is used to date very old rocks (Table 5.4).

Table 5.3: *Elements used for radiometric dating*

Radioactive Elements	Half-life	Decay elements	Materials that can be dated by radioactive element
Uranium - 238	4.5billion years	Lead - 206	Igneous, and Metamorphic
Uranium - 235	713million years	Lead - 207	Igneous, Metamorphic and Sedimentary rocks
Potassium - 40	135million years	Argon - 40	Igneous, Metamorphic and sedimentary
Rubidium - 87	47 million years	Strontium - 87	Igneous, Metamorphic and sedimentary
Carbon - 14	5 730 years	Nitrogen - 14	Charcoal, wood and shells.

Table 5.4: *Dating ranges of five radioactive elements*

Radioactive Elements	Dating Range	
	From	**To**
Carbon - 14	from 100 years ago	to 70 000 years ago
Potassium- 40	from 100 000 years ago	to the earth's beginning
Uranium - 238	from 10 million years ago	to the earth's beginning
Uranium - 235	from 10 years ago	to the earth's beginning
Rubidium- 87	from 10 years ago	to the earth's beginning

Usefulness of radioactive dating method

The radioactive dating of meteorites (rock from the space) has helped to determine the age of the Earth because these meteorites are made of the same material from which the Earth was first formed about 4.5 billion years ago.

Radio substance dating: Radiocarbon dating (also referred to as carbon dating or carbon-14 dating) is a method of determining the age of an object containing organic material by using the properties of radiocarbon (14C), a radioactive isotope of carbon. Scientists may be interested in the age of a fossil shell or a piece of wood. These once-living materials can be dated by measuring radioactive carbon. All living things contain a radioactive form of carbon. As long as a plant or an animal is alive, the amount of Carbon 14 in its body remains the same, but when the plant or animal dies, the amount of Carbon-14 starts to decrease at a known rate. This method is used to determine the age of younger rocks of between 60 000 to 70 000 years. For example, Carbon dioxide has a half-life of 5 730 years. By noting the amount of carbon 14 which is still present you can determine its age in a fossil. The fossil's age is found by measuring the amount of Carbon -14 in the fossil and comparing to the amount found in modern living things. For example, the amount of carbon – 14 in an ancient piece of wood found to be one half of the amount of carbn-14 found in wood from a tree still living. This would mean that one-half life of carbon-14 had passed since the old wood stopped taking in the radioactive carbon.

Usefulness of carbon-14 dating method

Carbon-14 is useful in dating fossils in young rocks that are between 1 000-70 000 years old. Carbon-14 dating has provided a record of fairly recent events in the earth's history. The amount of carbon-14 in fossil wood found in Europe and North America enables scientists to estimate that these areas were covered by ice as recently as 11 000 years ago.

Geological time scale

The geological time scale divides the history of the Earth in time unit and lists these units in the order they occurred. It is a scheme or chart that indicates age classification of rocks and the associated geomorphological and biological events. Geological time scale is divided into Eons, Eras, Periods, Epochs and ages (Table 5.5). Eons consists all that span of time from which fossil remains were then known.

Table 5.5: *The geological time scale*

Era	Period or system	Epochs or series	Important physical events and fauna	Time in millions of years
CENOZOIC	Quaternary	Holocene alluvium pleistocene	Glaciers melted, many mammals disappeared in warmer climates, emergence of human beings, alluvial deposits and a period of early civilization	1
		Diluvium	Glaciation, invertebrates, large mammals and man	
		Pliocene	Mountain building like Alps, large mammals	10
		Miocene	Uplift of rockies, grazing animals	25
	Tertiary	Oligocene	Lands generally low, Alps and Himalayan system developed, Rockies area had volcanoes sabre toothed cats appeared	40
		Eocene	Erosion, lakes in North America Tropical/ mild climate. All modern mammals	60
		Paleocene	High mountains, cool climates, birds and primitive mammals,	70
MESOZOIC SECONDARY	Cretaceous		Lowlands' widespread, mild climates, flowering plants and insects, extinction of grand reptiles and coal deposits	135
	Jurassic		Lowlands widespread, Europe under seas, mild climates, mountains rose in Western North America and widespread eruptions, disappearance of dinosaurs and Pangaea breaks up	180

	Triassic		Continents, mountainous, desert, widespread eruption in Weastern North America.	220
PALEOZOIC PRIMARY	Permian		First mammal-like reptiles, Hercynian Orogenesis	270
	Carboniferous		Pennyyanian Mississippi Lowlands emerged from seas, tropical coast swamps formed, large reptiles and amphibians, Hercynian Orogenesis begins	350
	Devonian		End of Caledonian Orogenesis, fish dominant, warm deserts and sandstones, first land animals	395
	Silurian		Mild climates, fish being dominant	440
	Ordovician		Beginning of Caledonian orogenesis, invertebrates dominated.	500
	Cambrian		Seas in Geosynclines, mild climate invertebrates, Algae and trilobites. Associated with igneous and sedimentary rocks	570
PRE-CAMBRIAN	Proterozoic (Algonician)		Sial in Geosynclines mild cold climates invertebrates	600
	Archafo- Zoic (Primitive life)		Extensive mountain building, Laurentian Orogenesis, earliest life known (Life dawn)	
	Azoic (without life)		Formation of the earth's crust, no rocks have been found	

Geological eras

This is the smallest time interval that occurs when the eons are divided. Basically, there are three eras namely Cenozoic (new life) Mesozoic (middle life), and Paleozoic (ancient life).

Cenozoic era

Cenozoic which means *'recent life'* is popularly known as the age of mammals. The era is referred so because mammals were dominant in life forms. It is the third major era of the earth's history which began about 70 million years ago and has not yet ended. Many of today's mountains and plateaus were lifted up during this era. At this era ice affected much of the land. Many mammals resembling the modern ones such as dogs, cats and horses had appeared by the middle of Cenozoic era. Moreover, most of the human life fossils have been found in this era (Figure 5.7). Recently, the Cenozoic era is internationally accepted as the youngest of the three subdivisions of the fossil ferrous part of earth's history. Cenozoic era is divided into three periods which are Paleogene (66 million to 23 million years ago), Neogene (23 million years to 2.6 million years ago) and Quaternary (2.6 million years to present). Traditionally the era is divided into Tertiary and Quaternary periods. Furthermore, periods are divided into epochs. For example, we are living in Cenozoic Era, Quatenary period in the Holocene Epoch.

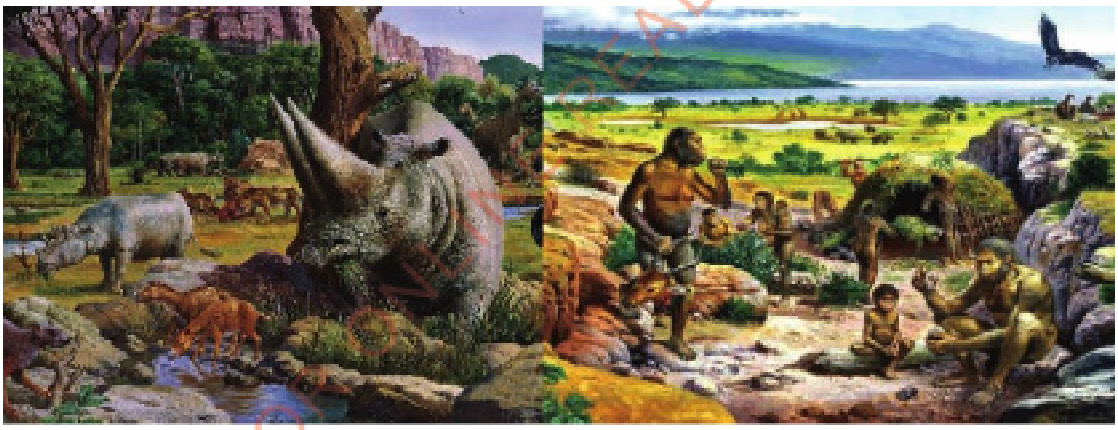


Figure 5.7: *Cenozoic era*

Mesozoic era

Mesozoic means *middle life* but it is also known as the age of reptiles. This was due to wide spread of reptiles. The climate of this time favored the reptiles to flourish and spread. A good example is the giant reptiles like dinosaurs meaning 'terrible lizard' (Figure 5.8). This is the second era in earth's history which began about 230 million years ago and it ended about 70 million years ago. This era lasted for about 160 million years. During a this era the continents began to move to their present configuration and shallow seas began to spread across them. Also, at this era great changes occurred on plants and animals. During this era there was an appearance of flowering plants such as the family of maple and oak. With time, birds and mammals eventually replaced reptiles that could not adopt the cnew condition. Thus, at the end of the period dinosaurs disappeared. Mesozoic era is divided into; Triassic, Jurassic and Cretaceous periods.

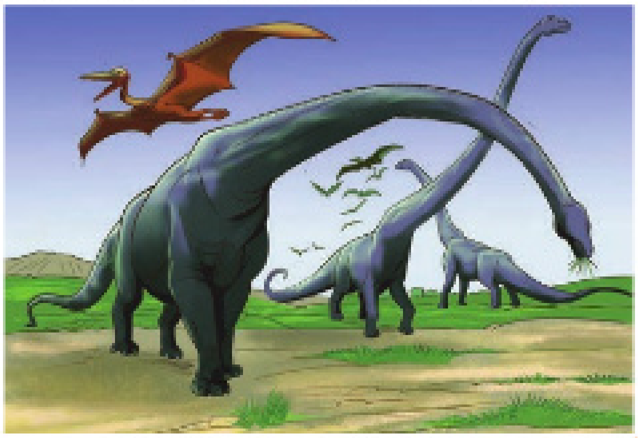


Figure 5.8: *Mesozoic era*

The Paleozoic era:

Paleozoic means 'ancient life'. This era began about 600 million year ago and it ended about 230 million years ago. In this era continents collided, climate changed and different types of life forms appeared. This age is called the age of invertebrates. Its beginning is marked by sudden appearance of abundant fossils. The early Paleozoic was a quiet time, continents were much closer and many types of Invertebrates evolved and multiplied. At the late Paleozoic era the first forest appeared (Figure 5.9). The bulk of today's coal formed at this time too. Furthermore, insects, amphibian and reptiles appeared and up to its end, life had been established on land.

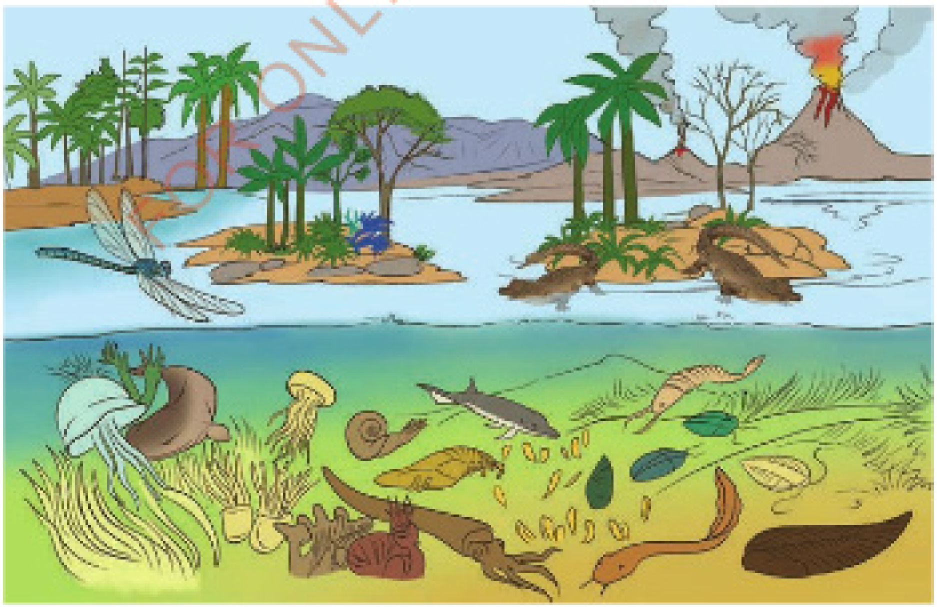


Figure 5.9: *Paleozoic era*

Pre Cambrian era:

This era began with the formation of the Earth and it ended about 600 million years ago. During that era very few fossils were found in those rocks and very few of those rocks still exist as they were worn away or changed by crustal movement.

How geological time scale was named

Some of the names of rocks were given on the basis of their localities i.e., where they were either formed or studied. For example, Cambrian rocks (Wales) Jurassic (Jura Mountains) Nyanza and Kavirondian (Kenya). Other names of rocks were given with reference to rock family, for example, cretaceous-chalk rock.

Importance of geological time scale

The geological time scale depicts ages of rocks by showing the time when and how certain types of rocks were formed. For example, some rocks were formed by glacial deposition and volcanic eruption. It also, helps in understanding when and how different landforms were formed. For example, mountains of different types like fold or volcanic mountains. Moreover, it helps to learn about different mountain buildings (orogenic) like Laurentian Caledonian, Hercynian and Alpine, Himalaya orogenic. For example, Alps were formed during Miocene 26 million years ago and the Himalayans are said to be formed during Oligocene about 38 million years ago. Furthermore, the time scale helps to predict the occurrence of crustal deformation. For example, areas of old rocks, can be subjected to faulting anytime in case of disturbance or stress. Records of the life of plants and animals help in understanding the relationship existing between living things and the geological processes. For example, plants, animals and man emerged when the conditions became conducive. Plants emerged when soils had developed and animals came into existence when plants had already existed. Man emerged at the later stage. This helps to show the life record of plants and animals and depict climatic changes which had occurred on the earth's surface.

Weaknesses of the methods used to determine the age of rocks

(a) Some of the methods used in determining the age of rocks like relative methods are largely based on estimation (extrapolation).

(b) Instruments like Carbon-14, cannot be used to determine the age of a rock over 75 000 years ago.

Exercise 5.2

1. On their field trip to Mwanza (rock city), form five students heard the geologist saying that "An igneous rock is the mother rock". Explain what the geologist mean by that statement?
2. Geological time scale has given a clear picture on the geomorphological and biological history of the earth. Comment on this statement.
3. The Tanzania Geological Survey Department wanted to update the geological map. They carried out a field study in all parts of the country. Analyse the criteria which would be used to identify mineral deposits.

Transformation of rocks into soil

The transformation of rocks into soil is designated as soil formation. Soil formation is the genesis of the soil from parent rock materials (rocks), adopting both its physical and chemical characteristics. Soil formation or *pedogenesis* is principally initiated by the weathering of the parent rock. After weathering, the layer of loose, broken and unconsolidated parent rock materials known as *regolith* are accumulated. However, regolith does not only originate from weathering but may also be derived from the deposition of alluvium, drift, loess and volcanic materials.

Parent rock materials

The mineral material from which soil forms is called parent rock material or soil materials. Moreover, the parent rock as a geological factor is a source of rock fragments which make up soil. The parent rock materials are chemically and physically weathered, transported, deposited and precipitated and at the end transformed into soil. A rock, whether igneous, sedimentary or metamorphic, is the source of all soil mineral materials and the origin of all plant nutrients with the exception of nitrogen, hydrogen and carbon.

There is a greater relationship between soil formed and its parent rock materials. For example, soils formed from mafic rocks are usually more fertile, with higher contents of calcium, magnesium, and phosphorus than soils formed from felsic rocks which contain more clay and have a more reddish-brown colour. Quartzite, a metamorphic rock of pure quartz (SiO_2) rock, is essentially infertile and resistant to soil formation, and most soils formed are shallow. Granite gneiss rocks average about 25% quartz, 65% feldspar (dominantly alkali feldspar), with lesser amounts of mica (muscovite and biotite), and small amounts of hornblende. Weathering patterns follow rock fabric, from isotropic in granite to banded in gneiss, but the resulting soils are very similar. In well leached environments, the soils formed are acidic, and have low contents of base cations and low mineral nutrient reserves. Kaolinite and hydroxy interlayered minerals (HIM) are abundant clay minerals formed in surface and subsoil horizons.

Sandstones (quartzose sandstones and orthoquartzites) contain more than 50% sand-size particles predominantly of quartz, the rest being impurities such as feldspar and mica, and cementing material usually silica, iron, or carbonates. In well-leached environments, most of the soils derived from such rocks are coarse-textured and deep. Limestone and dolomites are by definition composed of more than 50% carbonates, the remainder being 'contaminants' deposited on the sea bottom, including silt, clay, and particles of quartz and iron glacial deposits. Glacial deposits are unique among the many parent rock materials. They are the only parent rock materials which are physically pulverized into small particles and then abruptly deposited on the land surface in the zone of soil formation. These previously unweathered materials, except where sedimentary rocks have been incorporated, become *in situ* site of mineralogical alteration and they release ions in soils formed as the glaciers retreat. As a parent rock materials, the physically pulverized and previously unweathered materials differ from the weathered saprolite materials formed over crystalline bedrock.

Lacustrine deposits consist of thin alternating layers, usually of silt and clay-sized particles. Soils formed in lacustrine deposits are often quite impermeable in saturated conditions. They often have acquired and preserved thick organic matter residues, thus forming organic soils called histosols.

How volcanic ash material enters the soil as periodic deposits on the surface of existing soil is unique. This combination of periodic additions of rapidly weathering minerals to the soil surface has given rise to fertile soils. In areas with favorable temperature and moisture, conditions support the growth of food crops resulting in high human population densities. Good examples are in Java, Japan, Central America, and the rift valley in East Africa, specifically in Rungwe and Kilimanjaro Mountains. Most of the soils formed from volcanic ash are now classified as Andisols.

Although parent rock materials largely contribute to the development of soil and determine its properties, it is not the only factor involved in soil formation. Soil formation is the outcome of a combination of several non-rock factors mainly climate, topography, organisms, and time. Thus, soil formation is the product of parental rock materials and non-rock factors working together.

There are five main factors that influence the process of soil formation. These factors include parent rock materials, topography and age of the land (time), climate and organisms. Since these factors are closely interconnected and interdependent, their relationship may be summarized as follows;

Soil = f (parent rock material + climate + topography + organisms + time)

Where:

f = function of

Climate

Climate is the dominant factor for soil formation as it operates through elements such as temperature, humidity, precipitation, wind, and clouds in soil formation, and shows the distinctive characteristic of the climate zones in which they form. The principal climatic variables influencing soil formation are precipitation and temperature, which affect the rates of chemical, physical and biological processes.

The temperature and moisture both influence the organic matter content of soil through their effects on the balance between plant growth and microbial decomposition. Water is essential for the entire major chemical weathering reactions, thus the greater the depth of water penetration, the greater the depth of weathering of the soil and its development. Excess water percolating through the soil profile transports soluble and suspended materials from the upper to the lower layers, the process known as leaching. Moreover, in desert, semi desert and tropics, temperature variation has a significant role of disintegrating rocks into screes and even very fine particles which are eventually transported by the influence of gravity, water or wind action. Therefore, climate influences directly and indirectly the soil formation process.

Topography

Topography or relief is characterized by inclination (slope), elevation, and orientation of the terrain (Figure 5.10). Topography influences the rate of precipitation, run off erosion and the rate of formation of the surface soil profile. Steep slopes encourage rapid soil loss by erosion and mass wasting on one hand, and on the other allow less rainwater to enter the soil before changing into runoff, hence little mineral deposition in lower profiles. Therefore, soils on steep slopes are likely to be thin, poorly developed and relatively dry. The gentle slope slows the lateral movement of water as surface runoff instead increase the likelihood of water logging and formation of peat.

In gentle slopes there is a low rate of soil erosion but high rate of deposition, because materials moved downward the slope tend to produce deep soils. In semi-arid regions, low rainfall on steep slopes results in incomplete vegetation cover. Therefore, in such areas, there is little plant contribution to soil formation.

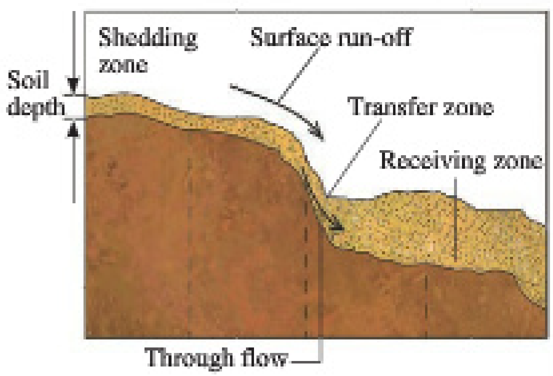


Figure. 5.10: *Influence of topography on* soil formation

Living organisms

Living organisms or biota as a factor of soil formation includes both plants and animals ranging from macro-organisms to micro-organisms. The biological factor in particular gives life to the soil. For example, when plants die, leaves fall onto the soil surface where microorganisms can act upon and decay plant tissues. The organic matter is used as an energy source for microorganisms, increasing their population in the soil. These organisms easily utilize digestible materials like simple sugars and carbohydrates found in the plant material, leaving more resistant materials such as fats and waxes behind. The materials left behind are not easily decomposed; they comprise the humus found in the soil. Humus acts as a gluing agent, essentially holding primary soil particles (sand, silt and clay) together to form secondary aggregates or peds. The organisms and the humus aid in the soil development and the formation of soil horizons.

Human activities widely influence soil formation through addition of organic manure, liming and tilling by using tractors, draining or irrigation, addition of fertilizers and the deliberately control of soil erosion. These activities help to improve soil stability and development. Large animals such as gophers, moles, and prairie dogs bore into the lower soil horizons, bringing materials to the surface. Their tunnels are open to the surface, encouraging the movement of water and air into the subsurface layers. In their localized areas, they enhance mixing of the lower and upper horizons by creating and later refilling underground tunnels.

Time

Time is a factor in the interaction of other soil forming factors. With time, soil evolves features that depend on the interplay of the soil forming factors listed earlier. It takes several millions of years for soil to develop a profile. Such period depends strongly on climate, parent rock materials, relief and biotic activity. Over time, the soil develops a profile that depends on the functions of biota and climate. Soil forming factors continue to affect soils during their existence, even on stable landscapes that are long-enduring, for millions of years. Materials are deposited on top or are blown or washed from the surface. Soil usually take a long time to form, perhaps up to 400 years for 10 milimetres and under extreme conditions up to 1 000 years for 1 milimetre. It can take 3 000 to 12 000 years to produce a sufficient depth of mature soil for farming.

The estimation of relative age or degree of maturity of soils is universally based on horizon differentiation. In practice, it is generally maintained that the larger the number of horizons and the greater their thickness and intensity the more mature is the soil. Soil forming process is a generally very slow and long period of time is required for a thin layer of soil to form on a newly exposed surface. Warm moist environment is conducive to soil development than cold and dry environment. For instance, soil develops relatively quickly from sediments as compared to that develop relatively slow on bedrocks.

Activity 5.2

Read books and internet sources about factors affecting rocks as a parent material for soil formation. Write down your findings.

Processes of soil formation

The process of soil formation is also known as *pedogenesis*. Numerous processes are involved in the formation of soil and eventually, the creation of the soil profiles, structure, and texture. There are four basic processes occurring during soil formation namely; addition, losing, translocation and transformation. The addition process involves the accumulation of materials either from deposition or rising from below with raising ground such as addition of leaves. Losing occurs when the materials are moved from the soil, for instance, when materials are removed due to soil erosion. Translocation occurs when materials are not removed from the soil, instead they move from one location to another. Examples of translocation are eluviation and illuviation. Transformation process involves changes of soil materials. A good example of transformation is weathering process, and when leaves decompose to form humus. The four soil forming processes can be grouped into two major categories, which are simple processes and complex processes.

Simple processes

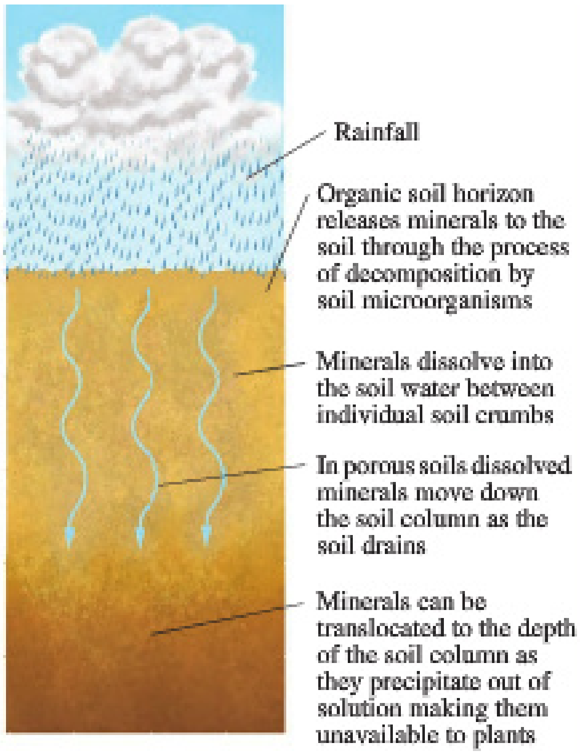
These include processes like weathering, leaching, eluviation, illuviation, humification, cheluviation, organic sorting and mineralization.

Weathering

This is the processes by which rocks are decomposed or disintegrated by chemical, biological or mechanical means, respectively, due to exposure at or near the earth's surface. Weathering leaves primary minerals as residues and produces secondary minerals. It also determines the rates of release the of nutrients, the soil depth, texture and drainage. In the system, this means that minerals are released as inputs into soil system from bedrock store and transfer into soil store.

Leaching

This is the removal of soluble materials in solution from top soil to sub-soil. This is common where precipitation exceeds evapotranspiration and there is soil drainage, rainwater containing oxygen, carbonic acid and organic acids collected as it passes through surface vegetation causing chemical weathering leading to the breakdown of clays and the dissolving of soluble salts (bases). Calcium and magnesium are eluviated from the A-horizon, making them increasingly acidic as they are replaced by hydrogen ions. Calcium and magnesium are subsequently illuviated to the underlying B- Horizon, or are leached out of the system (Figure 5.11).



eachin in soils

Eluviation

Eluviation is the downward movement of organic soil material and mineral matter from the A-horizon to the lower horizon in solution or in colloidal suspension. It differs from leaching as it involves the total loss of materials and can either be vertical or lateral. Another difference is that eluviation involves the movement of colloids while leaching involves the movement of materials in solution form only.

Illuviation

Illuviation is the process of washing and re-deposition of organic and mineral matter in the B-horizon. Illuviation can lead to the formation of a layer in the B-horizon called **hard pan**. B horizons often go through significant changes through the deposition of clays, organics, carbonates, and other materials. The particles that are deposited by illuviation include clay minerals, iron, humus, and calcium carbonate which are carried by percolating fluid, usually from precipitation.

Humification

This is the process through which organic matter is decomposed to form humus. Humus may be mixed throughout the depth of the soil or it may form a distinct layer. The process of humification is the most active of all in the A-horizon of the soil profile. Humus is incorporated within the soil to give a crumbly, black, nutrient-rich layer known as **mull**. In places where humus is slow to decompose, such as in the cold, and wet upland areas, humus produces a fibrous acidic and a nutrient deficient surface horizon known as **mor.**

Cheluviation

This is a downward movement of soluble **chelates** through the soil profile. Cheluviation occurs through the influence of organic agents. When organic matter decomposes, it releases nutrients and organic acids. These nutrients and acids are known as chelating agents which attack clays and other minerals, mainly in the A-horizon. The chelating agents then combine with the cations of the iron and aluminium to form organic-metal compounds known as **chelates,** which are readily transported downward through the soil profile.

Organic sorting

These are processes operating within the soil to re-organize minerals and organic matter into horizons, and contribute to the aggregation of particles and the formation of peds. Earth worm activity is a significant factor in sorting materials into different particles.

Mineralization

This is the conversion of the elements from organic compounds to other available form as a result of microbial activities in the soil. It is a process whereby the organic matters are further decomposed into mineral compounds forming important nutrients for the plant growth.

Complex processes

These processes involve a combination of several simple processes involved in soil formation. They include, podsolization, calcification, salinization, gleying and laterization.

Podsolization

This is a more intense form of leaching. This is a soil forming process which normally takes place in cool climates where precipitation is greatly in excess of evapotranspiration and where soils are well drained or sandy. Podsolization is defined as the removal of iron and aluminium oxides together with humus. As the surface vegetation is often coniferous forest, more rain percolating through it becomes progressively more acidic and may reach a pH of 5.0 or less. This in turn dissolves an increasing amount of bases such as calcium, magnesium, sodium and potassium silica and ultimately the sesquioxides of iron and aluminium. The resultant podsol soil therefore has two distinct horizons: the bleached A-horizon drained of coloured minerals by leaching, and the reddish-brown B-horizon where the sesquioxides have been illuviated. Often the iron deposits form an iron pan which is a characteristic of a podsol.

Laterization

This is a soil forming process taking place in tropical humid and sub-tropical regions. Latosols are the typical products of the process. They are characterized by the presence of little or no humus, the removal of soluble and finest soil components, and heavy accumulation of iron and aluminium. The type of soil formed is called laterite soil, which is sometimes impervious.

Calcification

This is a soil formation process in which the surface soil is supplied with calcium in such a way that the soil colloids are always close to saturation. It is a soil forming process of sub humid and semi-arid climates. Although there may be some leaching, it is insufficient to remove all the calcium which then accumulates in relatively small amounts, in the B- horizon. Soils formed through this process include chernozems, prairies and sierozems. The collective name for these calcium accumulating soils is pedocals.

Salinization

This occurs when potential evapotranspiration is greater than precipitation in places where the water table is near the surface. It therefore happens locally in dry climates, and it is a characteristic of desert soils. When moisture evaporates from the surface, salts are drawn upwards in solution by capillary action. Further evaporation results in the deposition of salt as hard crust, thus making salinization a critical problem in many irrigated areas.

Greying

This is a soil forming process taking place in poorly drained areas in cold, and wet climates. Due to poor drainage condition, there is an incomplete decomposition of organic matter causing anaerobic or water-logged condition. This is most likely to occur on gentle slopes, in depressions where the underlying rock is impermeable, where the water table is high enough to enter the soil profile, and in areas with very heavy rainfall and poor drainage. The reddish coloured oxidised iron, iron III (Fe^{+++} or ferric iron), is chemically reduced to form iron II (Fe^{++} or ferrous iron) which is grey-blue in colour.

Revision exercise

1. Using your community as a referrence, discuss how rocks can be utilised sustainably for economic development.
2. Give an account on the usefulness of the geological time scale.
3. Igneous rocks are common in our environment. Explain how you can distinguish them with other types of rocks?
4. Physical geography teacher was quoted saying, "rock formation is an endless process". Comment on the teacher's statement.
5. Soils were once rocks. Substantiate this view.

Chapter Six

Hydrology

Introduction

Hydrology describes the occurrence and circulation of water which is among the most valuable natural resources on the planet Earth. Without water, there would be no life on Earth. In this chapter you will learn about the meaning and branches of hydrology, hydrological cycle and processes, as well as groundwater and surface water. The competences developed will enable you to demonstrate an understanding of the basics of hydrology and the hydrological cycle. It will also enable you to develop skills for protecting and improving water quality as well as using it sustainably for social and economic development.

Think about

Occurrence and distribution of water on Earth

The concept of hydrology

Activity 6.1

Read from different sources about the concept of hydrology.

The term hydrology is formed of two Greek words: '*hydōr*' meaning 'water' and '*logos*' meaning 'study', thus the study of water. However, as a complex real-world systems, hydrology is defined as the science that deals with the occurrence, distribution and circulation or movement of waters on the Earth. It is also concerned with physical and chemical properties of water, and their interaction with the physical and biological environment that include the effect of man. As a study of water, hydrology is concerned with an input of precipitation on the ground surface, processes of water operating on ground surface and into the ground, storage of water over the land, in rivers, lakes, oceans, and below the earth's surface in the pores of the soil and rocks, and through plants, as well as outputs such as evaporation and transpiration (evapotranspiration).

Branches of hydrology

The development of hydrology over time and its wide range of application in society have led to the emergence of different branches. The following are some of the major branches of hydrology;

Surface hydrology

Surface hydrology is concerned with hydrological processes that operate at or near the earth's surface. Surface hydrology focuses on the study of streams, rivers, dams, lakes, wetlands, seas, oceans and other water bodies found on the surface of the Earth. It is also concerned with measuring, estimating and analysing surface water availability and their dynamics.

Groundwater hydrology

Groundwater hydrology, also known as *hydrogeology* or *geohydrology* is the study of occurrence, distribution and movement of water in aquifers and porous layers of rocks, sands, silts, and gravels below the earth's surface. This branch of hydrology focuses on groundwater resources and their interactions with surface water and the surrounding environment. It involves the analysis aquifer properties, groundwater level, its exploration and extraction.

Isotope hydrology

Isotope hydrology is the study of the isotopic signatures of water. This branch of hydrology makes use of isotopic dating to determine the origin and age of water throughout its circulation within the hydrological cycle. Isotopic dating involves measuring the levels of deviation in the isotopes of oxygen and hydrogen in water, as well as aquifers mapping, conservation of water supplies and assessment of water pollution levels.

Hydrometeorology

Hydrometeorology is the study of the transfer of water and energy between land, surface water bodies and the lower atmosphere. Hydrometeorology incorporates meteorology to understand and solve hydrological problems such as floods and drought forecasting, and determine the dynamics of water in the atmosphere and its effect on levels of precipitation reaching the ground.

Ecohydrology

Ecohydrology is the study of ecological processes in the hydrologic cycle. It is concerned with the hydrological processes occurring in the soil and plant foliage. It is also concerned with the hydrological system and its effects on plant physiology, soil moisture, and plant diversity and spatial distribution in a given period of time.

Hydrological cycle

Hydrological cycle also known as water cycle is the continuous movement of water in the air, on the surface and below the earth's surface, to the ocean and back to the air through transpiration and evaporation. The driving force of the hydrological cycle is the Sun, which provides the energy needed for evaporation. The hydrological cycle consist of physical processes that create a continuous water movement on the Earth that has neither a beginning nor an end. The processes include *evaporation, transpiration,condensation, precipitation, interception, infiltration, runoff*, and *groundwater flow* (Figure 6.1).

Although the total amount of water within the cycle remains essentially constant, its distribution among the various pathways is continually changing. Just because Antarctica is frozen, it does not mean that evaporation is not taking place. Ice can turn directly to water vapour by *sublimation*. Again, it should not be taken for granted that deserts like Sahara often lack precipitation. The fact is, it rains but rain water evaporates before making it to the ground.

Hydrological cycle as an endless natural process can best be understood by considering the process in which water evaporates from water bodies, plants leaves (vegetation) and the land surface into the atmosphere as water vapour. Thereafter, water vapour condenses to form clouds which precipitates in the forms of rain, snow, sleet, or hail back to the earth's surface. The precipitation falls on open bodies of water and land surface. Part of precipitation is intercepted by vegetation while some evaporates into atmosphere before dropping as it is the case in desert. Part of precipitation that reaches the earth's surface seeps into the ground through the process called infiltration. Part of precipitation that reaches the surface of the Earth but does not infiltrate the soil is called runoff. Runoff can also come from melted snow and ice.

When there is excessive amount of precipitation, soils become saturated, thus rainwater can no longer infiltrate. Runoff will eventually drain into creeks, streams, rivers, lakes and oceans. Along the way, a portion of runoff evaporates and percolates into the ground until it reaches the water table and the zone of saturation, or is used for agricultural, residential, or industrial purposes. The physical state of water in the hydrological cycle has three phases, namely; solid (glaciers and ice sheets), liquid (ponds, streams, rivers, lakes, and oceans), and gas (water vapour).

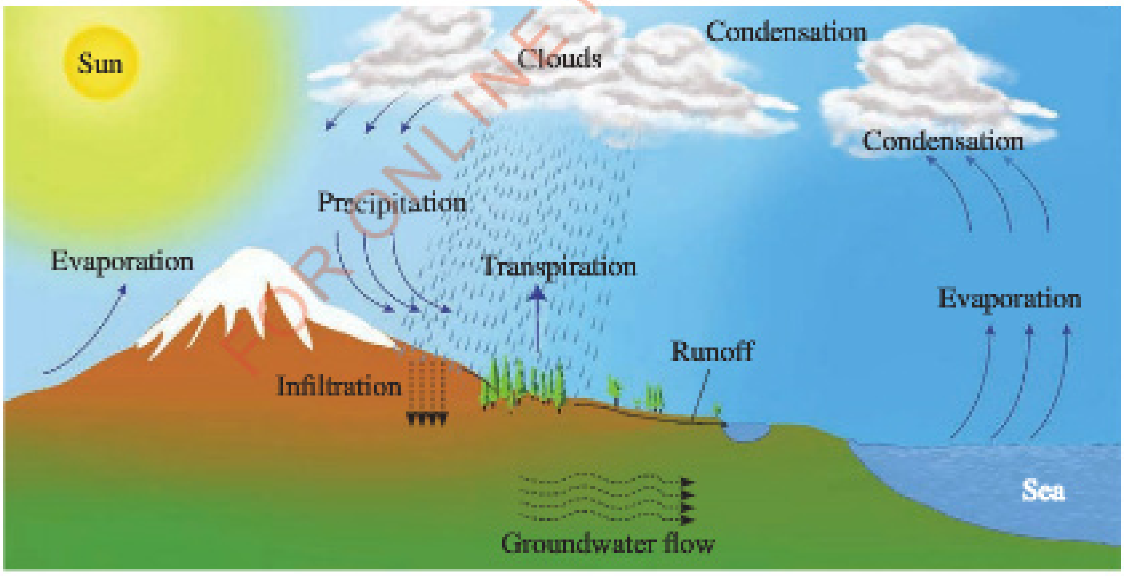


Figure 6.1: *The hydrologic cycle*

Processes of hydrological cycle

The hydrological cycle has five major processes which are; evaporation, precipitation, infiltration, runoff, and groundwater. However, there are other processes complementing the major the processes of hydrological cycle. These include; condensation, interception, transpiration, depression storage, moisture storage and percolation.

Evaporation

Evaporation is the process whereby liquid water is converted to into water vapour (vaporization) and removed from the evaporating surface. Water evaporates from a variety of surfaces such as rivers, lakes, pavements, soils, rocks, and wet vegetation. Evaporation occurs when radiant energy from the sun activates water molecules through heating process such that some of water molecules rise into the atmosphere as *vapour*.

Factors affecting evaporation

The rate of evaporation can be low or high depending on a number of factors such as solar radiation, temperature, humidity, wind, water quality, shape and size of the evaporating surface.

Solar radiation: Evaporation process is determined by the amount of solar energy available to vaporize water. Solar radiation is the main source of energy and which change large quantities of liquid water into water vapour. The potential amount of solar radiation that can reach the evaporating surface is determined by location of evaporating surface in relation to the position of the sun in terms of latitudes, and time of the year such as winter and summer. Again, turbidity of the atmosphere and the presence of clouds which reflect and absorb large proportion of the solar radiation, reduce rate and amount of evaporation.

Air temperature: Air temperature is a measure of how cold or hot the air is and it is determined by solar radiation. The solar radiation absorbed and later emitted by the atmosphere and the heat energy emitted by the earth increases the air temperature in the surrounding area. The more the liquid is exposed to the solar radiation, the higher the temperature. High temperature implies that there is kinetic energy available for evaporation. As kinetic energy increases, the liquid is converted into vapour, thus accelerating the evaporation process.

Humidity: This is the amount of water vapour in the air. High humidity means there is a lot of water vapour in the air while low humidity means there is little water vapour in the air. On a humid day when there is already a lot of water vapour in the surrounding air, evaporation takes place more slowly. As humidity of air decreases, the ability of the surrounding air to absorb more water vapor increases, and the rate of evaporation becomes higher. Therefore, evaporation is greater in warm and dry atmospheric conditions, and least in cold and humid conditions.

Wind speed: Wind is air in motion. Air movement is needed to remove the lowest moist layers in contact with the water surface and to mix them with the upper drier layers. Wind speed influences evaporation rate only when its movement is turbulent since vapour removal is effected by turbulent diffusion and spreading. If the movement of wind is laminar it is likely to have insignificant amount of evaporation, especially on large water surface. The stronger the wind, the greater will the turbulence be, so there will be more convection and more evaporation.

Water characteristics: The physical characteristics of water such as salinity, depth and size of water bodies influence the rate of evaporation. Evaporation decreases by about 1% for each 1% increase in salinity. Therefore, evaporation from sea water is less than evaporation from fresh water. Again, water depth has an effect on the seasonal distribution of evaporation. Shallow water bodies like ponds have a similar seasonal temperature regime to the air temperature above them while deep water bodies such as lakes and oceans have greater capacity for heat storage and may exhibit thermal stratification which also influences high evaporation. However, the total volume of evaporation is larger in large water bodies than in small water bodies.

Soil characteristics: Some of the soil characteristics like moisture, capillary, colour and temperature have significant effect on evaporation. Evaporation from the soil increases if the soil surface contains high moisture and is re-wetted by frequent and intermittent showers than from a soil surface which is thoroughly dry. Also, where rainfall is infrequent, evaporation opportunity can depend on the capillary rise of moisture from deep soil. Soil colour affects albedo as darker soils tend to absorb more heat thus increase soil temperature. Warmer soils may have higher rates of evaporation as they have more energy available for evaporation.

Vegetation cover: Vegetation cover promotes canopy interception. Usually, about 10% to 20% of the precipitation falling on plant which is at mature stage is intercepted and returned to the atmosphere through evaporation than during the early stage of planting and harvesting periods. Under very dense forest conditions, interception maybe even as high as 25% of the total precipitation, thus more water are intercepted and become readily available and exposed to evaporation. Precipitation is intercepted when it falls on sheltering surface of vegetation. Interception is dominant in woodland or grown trees and crops compared to arable and glass land.

Evapotranspiration

Evapotranspiration is the combination effects of two separate processes whereby, water is lost on one hand from the land surface by evaporation and on the other hand from the crop or vegetation by transpiration (Figure 6.2). Transpiration is a process through which water is transported through a plant from its roots to tiny pores on the underside of its leaves (stomata) where it evaporates into the atmosphere as a water vapour. Evaporation and transpiration occur simultaneously, and there is no easy way of distinguishing between the two processes.

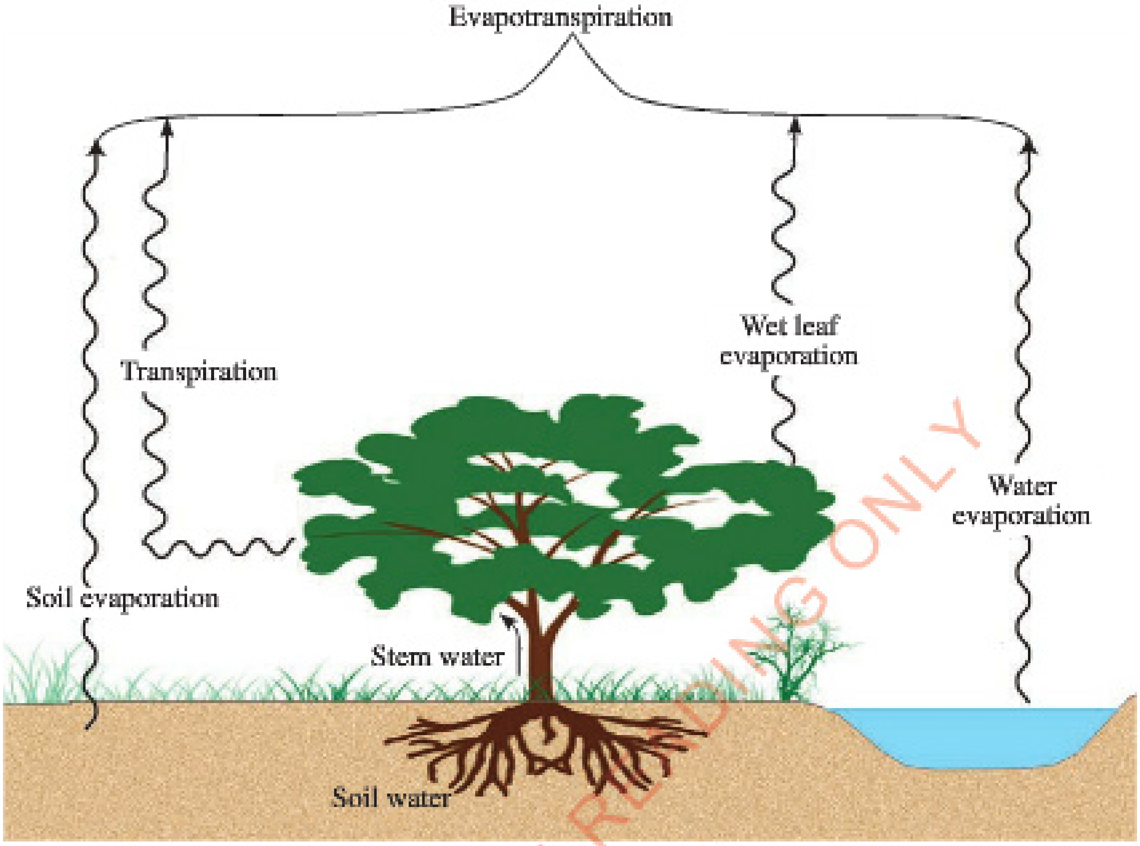


Figure 6.2: The process of evapotranspiration

Types of evapotranspiration

There are two main types of evapotranspiration, namely; potential evapotranspiration and actual evapotranspiration. **Potential evapotranspiration** is the amount of evaporation from soils and transpiration by plants that will occur if an unlimited amount of water is available under good atmospheric or weather conditions. This is the maximum evapotranspiration assuming that there is a sufficient supply of soil water to meet the highest demand by plants. **Actual evapotranspiration** occurs when water is limited or under natural field conditions. This is the amount of water that is used for the proper growth of plants. This may occur if water content in the soil is low, causing stomata openings to be reduced in size and hence, lowering water loss through transpiration.

Factors affecting evapotranspiration

Air temperature: The solar radiation absorbed and later emitted by the atmosphere and the heat emitted by the Earth increase the air temperature in form of sensible heat. The sensible heat of the surrounding air transfers energy to the crop and exerts as such a controlling influence on the rate of evapotranspiration. In sunny and warm weather, the loss of water by evapotranspiration is greater than in cloudy and cool weather.

Humidity: High humidity of the air reduces evapotranspiration demand. This is common in humid tropical regions. In such environments, the air is already close to saturation, therefore, less additional water can be stored, and in that case evapotranspiration rate is lower than in arid regions. Moreover, under humid weather conditions, high humidity of the air and presence of clouds cause the rate of the evapotranspiration to be lower.

Wind speed: The process of vapour removal from plant leaves or vegetation canopy depends to a large extent on wind turbulence which transfers large quantities of air over the vegetation surface. As moving wind keeps on vaporizing water, the air above the vegetated surface becomes gradually saturated with water vapour. If the saturated air is not continuously replaced by drier air as a result of turbulent wind, water vapour removal on air above the vegetation surface decreases and the evapotranspiration rate decreases as well.

Vegetation characteristics: Vegetation or crop characteristics like crop type, rooting system, leaf structure and density, and development stage may determine the rate of evapotranspiration. Some vegetation or crop types require more water for growth and survival while others require less water as a result of high and low evapotranspiration respectively. Some plants have long and many roots that absorb more water from the soil thus causing high evapotranspiration. Some plant species have many, large and wide leaves containing large number of stomata per unit area (the stomatal density) and large size of the stomatal openings which influences high evapotranspiration. It should be noted that plants regulate transpiration through adjustment of stomata. As stomata close, the resistance of the leaf to lose water vapor increases, decreasing diffusion of water vapour from plant to the atmosphere, thus low evapotranspiration.

Land management: Land management encompasses types of irrigation, farming, and fertilization. Evapotranspiration is high when a vegetated or cropped land is under flood irrigation while in the sprinkler and drip irrigation the evapotranspiration is medium and low, respectively. That is so because with flood irrigation, much water is supplied to the soil and spread over a large area of the land surface. Again, the type of farming activities practiced in a certain area affect the evapotranspiration. With mulching, for example, a land surface is covered with grasses, thus reduces direct solar radiation from reaching and heating the land, and thus reduces excessive water losses in the form of evapotranspiration. Furthermore, when high content of fertilizers is used on the cropped or vegetated land, it leads to high evapotranspiration simply because plants become healthier and their capacity of trapping or absorbing water and losing water is high as well.

Condensation

This is the process by which water vapour in the atmosphere is changed into liquid after being cooled to and beyond dew point. Condensation is determined by conditions such as presence of water vapour, presence of hygroscopic nuclei (particles) and cooling process. Therefore, condensation occurs in the following ways:

Radiation cooling occurs when the ground loses heat rapidly through terrestrial radiation and the air in contact with it is then cooled by conduction. If the air is moist, some vapour condenses to form radiation fog and dew. If the temperature is below freezing point, frost is formed.

Advection cooling occurs when warm and moist air moves over a cooler land or sea surface. Whereas, advection involves horizontal movement of air mass from one region to another, thus, the amount of condensation created is limited.

Orographic uplift occurs when warm, moist air is forced to rise as it crosses a mountain barrier. As warm air rises it quickly cools down thus raising relative humidity and causing clouds formation.

Convective or adiabatic cooling occurs when air is warmed during daytime and rises in pockets as thermals. The solar radiation on heating the earth's surface causes it to emit energy which warms the adjacent air above it. The warm air is forced to rise due to its low density, while rising it loses heat, and consequently, the temperature drops. Since air is cooled down by the reduction of pressure with height rather than through loss of heat to the surrounding air, it is said to be adiabatically cooled. Since both orographic and adiabatic cooling involves vertical movement of air, they are more effective mechanism of condensation.

Frontal cooling occurs when two air masses with contrasting characteristics of humidity and temperature meet. Normally, the cold dry air is forced to pass below the warm humid air and exchange of heat occurs whereby the warm air mass loses heat and cools.

Condensation manifestation

Condensation manifests itself as dew, frost, fog or as clouds.

Dew is water in the form of droplets that appear on thin, exposed objects in the morning or evening due to condensation. It constitutes tiny drops of water that form on cool surfaces at night, when atmospheric vapour condenses. Dew forms when the temperature of the surfaces falls below the dew point of the surrounding air, usually due to radiation cooling.

Dew point is the temperature at which the water vapour in the air at a constant pressure condenses into liquid. The higher the dew point the greater the amount of moisture in the air.

Frost is a deposit of small white ice crystals formed on the ground or other surfaces when the temperature falls below freezing point. In temperate climate, it commonly appears as fragile white crystals of frozen dew drops near the ground, but in cold climates it occurs in a wider variety of forms.

Fog and mist are collection of liquid water droplets or ice crystals suspended in the air at or near the earth's surface. They constitute a cloud layer at or very close to the earth's surface. They form when the difference between air temperature and dew point is generally less than 2.5°C. They mostly begin to form when water vapour condenses into tiny liquid water droplet suspended in the air. The term fog is used when visibility is less than 1 kilometre, while mist is used when visibility extends from 1 to 2 kilometres. Fogs are formed under different atmospheric conditions near the ground. Based on the genesis fog can be classified as follows;

Radiation fog also known as *ground fog* formed at night when the temperature of the air layer at the ground level falls below the dew point. It is associated with a low level temperature inversion.

Advection fog occurs when a warm moist air current is cooled as it moves horizontally over a cold land or sea surface. As the warm air layer loses heat to the surface, its temperature drops below the dew point and the condensation sets in. It commonly occurs over oceans where warm and cold currents occur side by side.

Steam fog also known as *sea fog* is generally more localized than the two main types. It usually develops in situations where cold air blows over much warmer waters. Evaporated air from the water body quickly cools and the resulting condensation is seen as a steaming.

Frontal fog also known as *precipitation fog* forms when two air masses of contrasting temperature and humidity converges, leading to cooling of the warm moist air which causes fog formation. It mostly occurs when precipitation falls into drier air below the cloud as the liquid droplets evaporate into water vapour. The water vapour cools, and at the dew point it condenses and frontal fog forms.

Hill fog occurs when the passage of a front cloud extends down to the surface. This is especially the case over higher ground.

Smog fog, also known as *smoke fog* is a yellowish or blackish fog formed mainly by a mixture of pollutants in the atmosphere, consisting of fine particles and gases such as CO_2 and SO_2. Smog fog is commonly found in cities such as Dhaka and Delhi, and in industrial areas, such as the Ruhr industrial region in Germany.

Precipitation

Precipitation is any liquid or solid water falling from the atmosphere to the surface of the Earth. Precipitation forms in the clouds when water vapour condenses, collide, coalesce and grows bigger enough to form water droplets.

When the drops grow in size, they become heavier enough and drop to the ground surface as precipitation. If a cloud is colder, like it would be at higher altitudes, the water droplets may freeze to form ice. However, precipitation are of different forms depending on the temperature within the cloud and at the earth's surface.

Forms of precipitation

Hail is formed when water droplets are carried upwards by the rising air currents to great height where they are super cooled and turned into ice crystals. Hails fall in the form of small spherical pellets of ice with a diameter of about 5 – 50 milimetres. Hails are associated with conditions of extreme atmospheric instability, and very low temperature leading to supper cooling and coalescence of water into ice or hail stones. When these ice crystals or hail stones fall, water vapour around them condenses into ice and becomes bigger. Sometimes these ice crystals are carried upward again by convection currents and the process is repeated to make them acquire more layers of ice.

Snow is formed when water vapour condenses to form minute white ice crystals at a temperature below freezing point. These ice crystals are of hexagonal plates or prism like, and when condensation continues, they can unite to form snowflakes and reach the ground without melting. The formation of snow is similar to that of a hail but they differ in their appearance and occurrence. For snow to fall there must be both plentiful vapour in the atmosphere and low temperature to prevent melting of ice crystals.

Sleet forms in cold weather when rain enters a layer of very cold air close to the ground and then it freezes. They are a mixture of ice and snow formed when the upper air temperature is below freezing point, allowing snowflakes to form. They are formed in cumulonimbus clouds when the lower atmospheric temperature is around 2°C to 4°C. There are slight differences in the conceptualization of sleets between the American and the British. Whereas in Britain sleets are viewed as a mixture of snow and rain, in America they are regarded as the raindrops which have frozen and partially melted again. Generally, sleets are the intermediate forms of precipitation.

Glaze is the reverse of the sleet and it occurs when water droplets form in the upper air but turn into ice on contact with freezing surface. When glazed frost forms on roads, it is called "black ice".

Dew is formed on cold surfaces during early morning hours, from moisture in the air. This is one of the forms of condensation which occurs when water vapour (the invisible form of water) in the atmosphere changes into visible water droplets upon cooling.

Drizzle is a very fine rain with very small droplets. It originates from layers of clouds with very limited vertical development, such as stratus and stratocumulus.

Mist is tiny liquid droplets dropping from low strata, whose intervisibility extends from 1 to 2 kilometres, usually formed when warm humid air cools suddenly forming small water droplets suspended in air. Unlike fogs, mist results in moderate visibility usually occur in the lower atmosphere.

Rain is a liquid in the form of droplets whose size is greater than 0.5 milimetres. It occurs when condensation process takes place at or just above the freezing point.

Rainfall

Rainfall is formed when water droplets condense from water vapour in the atmosphere on a nuclei and then float as clouds. When these droplets coalesce, they normally form larger droplets which later fall as rain after overcoming ascending air by gravity. Most of the air masses in the atmosphere contain minute particles of matter called *nuclei* which are made of salts, dust, ice and soot (carbon derived from burnt vegetable matter). When raindrops continue to grow around these nuclei, they become heavy and fall on the ground surface as rain. Although the temperature at the level of clouds formation in atmosphere is below 0°C, the droplets do not turn into ice crystals.

Types of rainfall

Rainfall is classified into three main types based on the origin. These includes; convectional, orographic and cyclonic rainfall.

Convectional rainfall

This is a type of rainfall which is formed by vertical moving warm air, which has been heated by the ground surface through conduction. As air rises from the heated surface, it expands and cools adiabatically. Thus, forms stratocumulus or cumulonimbus clouds with very powerful turbulent currents (Figure 6.3). This results in a very strong convectional rainfall accompanied by thunder and lightning. Convectional rainfall occurs throughout the year near the Equator, due to constant high temperatures and humidity. It usually occur in the hotter part of the day and is mainly associated with the hail and graupel. The equatorial region and internal part of continents mainly in northern hemisphere receive convectional rainfall.

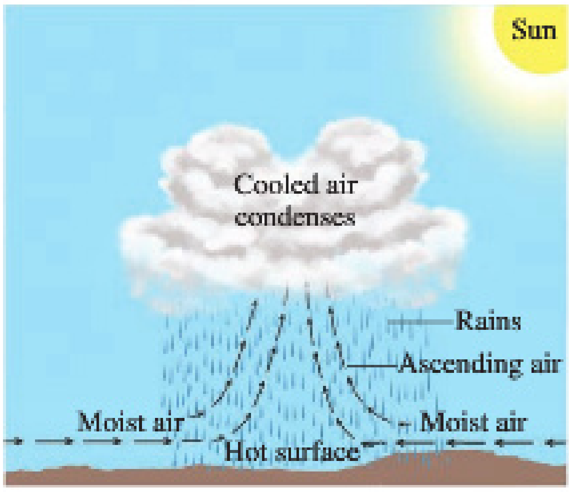


Figure 6.3: *Convectional rainfall*

Orographic rainfall

This type of rainfall is also known as *relief rainfall*. It develops as a result of the influence of topography, specifically a mountain range. It occurs when air mass carrying moisture is forced to rise on the side of the mountain range. Orographic rainfall is common where onshore winds rise-up over hilly or in mountain regions that are at right angles to the direction of the winds.

This kind of rainfall occurs in areas where the surface of the Earth is greatly heated by the solar radiation in all latitudes. Orographic rainfall is common in areas where hills lie parallel to the coast over which moist winds from the sea blow. Because this rainfall is caused by the rising air over one side of the mountain, it makes only one side of the mountain to receive relatively much rainfall. The side receiving orographic rainfall is called the *windward side*, while the side of the mountain that receives relatively little rainfall is called the *leeward side* or rain-shadow.

As the air ascends the mountain ranges, it is cooled down at dry adiabatic rate. This cooling air mass contains moisture from water bodies and evapotranspiration from down mountain vegetation. The air continues to rise at the saturated adiabatic lapse rate until dew point is reached. This cooling releases latent heat which makes the atmosphere more unstable, forcing the air to continue rising until condensation takes place, leading to the formation of stratocumulus and further rising cumulonimbus clouds (Figure 6.4).

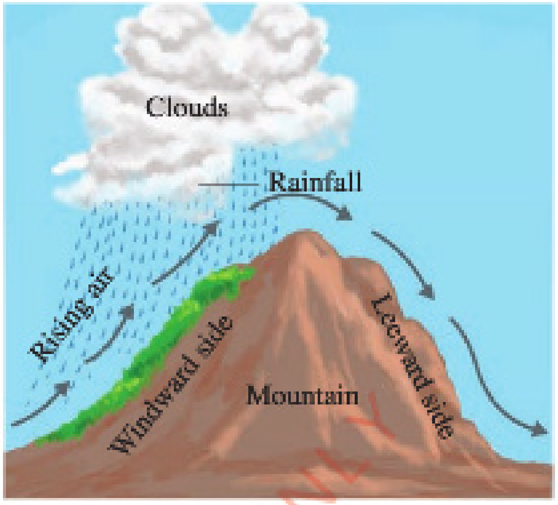


Figure 6.4: *Orographic rainfall*

Cyclonic rainfall

This type of rainfall occurs along the frontal zones of convergence, notably at the Inter-Tropical Convergence Zone (ITCZ) and at the polar front. This type of rainfall develops when patterns of conveying air at ITCZ under prevailing warm and humid conditions cause the formation of massive cumulonimbus clouds with torrential rain and thunderstorms. Normally, cyclonic rainfall occurs when air masses of different characteristics and strength meet and mix-up.It develops when warm moist air of a maritime tropical air mass is forced to rise over the cold air of polar air mass when two air masses meets (Figure 6.5). Cyclonic rainfall is sometimes called *depression rainfall* because it occurs when different air masses of different characteristics meet and form a depression wind (low pressure cell). Depression rainfall in temperate latitudes is usually lighter than convection rain and it takes much longer duration of up to several days. Frontal rainfall occurs in the mid and high latitudes between 40° – 60° North and South of the Equator. These areas are convergence zones of both warm moist and cold dense air.

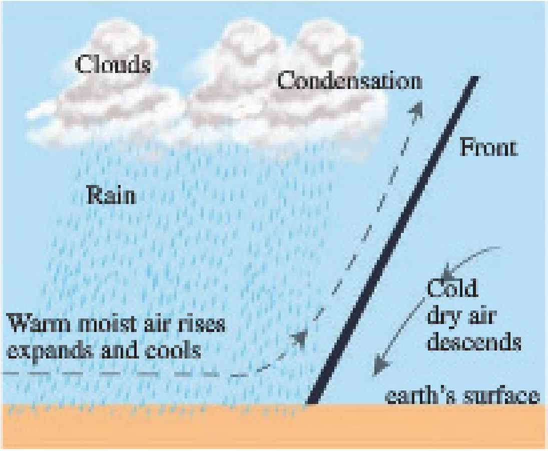


Figure 6.5: *Cyclonic rainfall*

Factors affecting the distribution of rainfall

Rainfall distribution across regions varies considerably due to a number of factors including; the distance from the equator, altitude, ocean currents, the prevailing winds both onshore and offshore winds, the nature and shape of the continent, as well as lack or presence of water bodies which are evaporating surfaces.

Activity 6.2

Visit the school library and other online sources and read about factors affecting rainfall distribution. Then, write a short but detailed summary of what you have read.

Exercise 6.1

1. 'Hydrological cycle influences climate in spatial and temporal dimension'. Discuss.
2. Every day, a tour guide leading groups of tourists from different continents, organizes brief meeting that allow each tourist to share experience on common precipitation occurring in respective areas of their origin. What information on the forms of precipitation do you expect them to provide?
3. Explain the influence of human activities on the local hydrological cycle.
4. Have you ever wondered why certain types of rainfall form in the areas they are formed?
5. What would you advice farmers to do in order to reduce water losses to the atmosphere from their farm plots and irrigation ponds?

Interception

Interception is the process by which water from precipitation is retained or stored in the vegetation. With interception, precipitation does not reach the land surface, instead is captured by the leaves, branches of plants (canopy), stems, and forest floor (litter layers or grasses). Intercepted precipitation is lost or returned in the atmosphere through evaporation. Interception has three main components, which are; interception loss, throughfall and stemflow (Figure 6.6).

Interception loss

This is a precipitation that is retained by plant surfaces and later evaporated back in the atmosphere. Interception loss from the vegetation is usually greatest at the start of a storm, especially when it is preceded by a dry period when plant leaves are not wet.

Throughfall

It is a precipitation that drops from the leaves, twigs, and needles of vegetation. This happens when the storage capacity of leaves and branches is exhausted, and the weight of precipitation overcomes the holding capacity of the plant leaves while precipitation persists or is relatively intense, the fraction of it starts dripping down through the tree canopy.

Stemflow

Stemflow is precipitation which drips along twigs and branches of tree towards down the trunk.

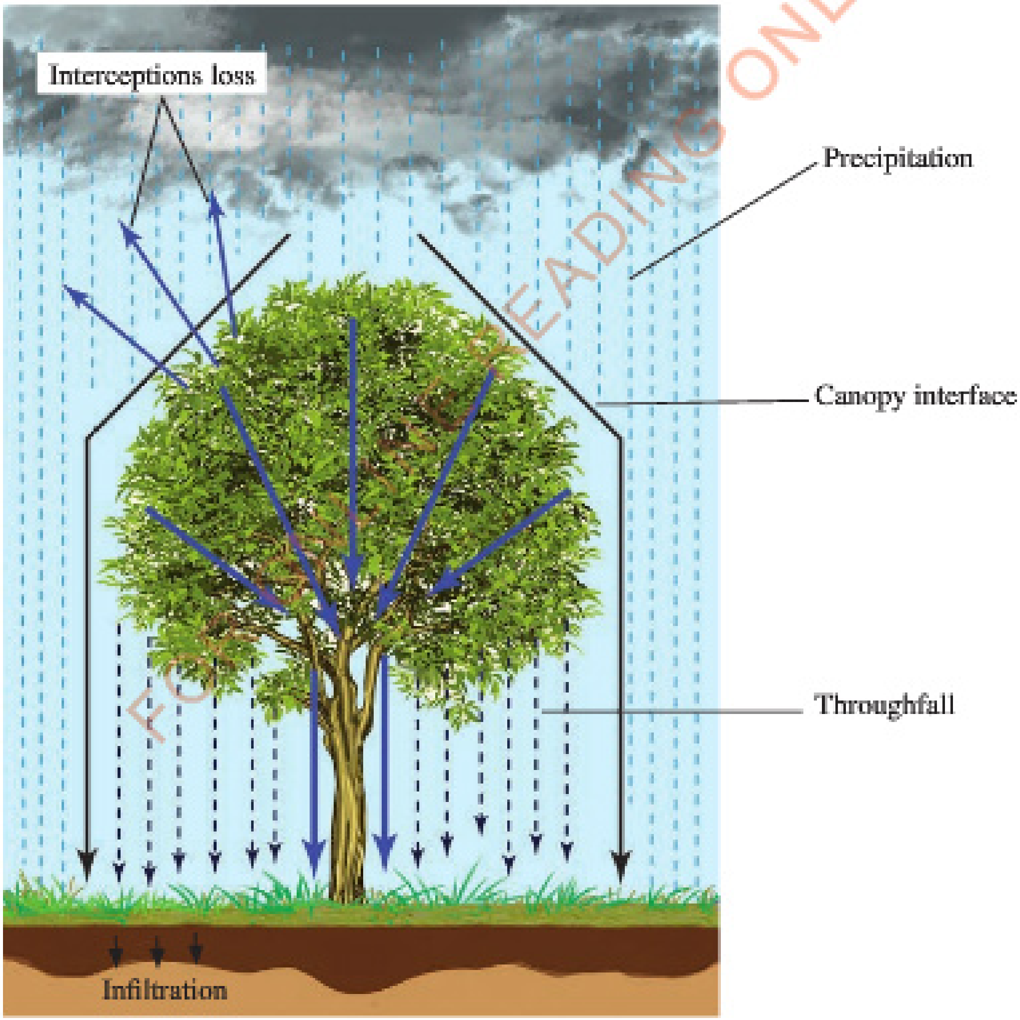


Figure 6.6: *Interception process*

Factors affecting interception

The amount of precipitation intercepted is greatly variable and depends on many factors. Some of the factors include the following:

Type of vegetation

Interception storage capacities of the vegetation vary with the type of plant species, shape, its age and density of stands. In dense, tall, and mature vegetation, interception is quite substantial as opposed to low-lying vegetation in which interception is usually low. Dense grasses and herbs potentially in full growth stage intercept as much precipitation as forest cover. Coniferous vegetation have greater interception capacity than deciduous and hardwoods. Their dense needles give them more surface area for droplets to accumulate, and they have foliage in spring and fall.

Wind velocity

When precipitation is accompanied by high speed turbulent winds, the leaves become incapable of holding much water compared to when the air is still. On the other hand, the blowing of wind shakes plant leaves and speed up the evaporation rate, thereby reducing the amount of precipitation to be intercepted.

Precipitation characteristics

Duration, intensity, frequency, and form of precipitation influence the amount of interception. If precipitation of long duration occurs under cloudy condition, relatively interception loss will be less. If annual precipitation is made up of several small duration of varying time interval separated by dry spells, evaporation will be high and interception will be consequently great. On the contrary, if rain drops of large size come with great speed, their impact removes intercepted drops and leaves cannot hold much water and as a result water will fall on the ground surface. When precipitation occurs in still air conditions with low intensity, interception will be great. When precipitation is light, for example, in snow and drizzle forms, much of the water will never reach the ground surface while liquid precipitation in the form of rainfall has high surface tension and forms an initial layer (sooner than snow) to which subsequent rain coheres and quickly drops down on the ground surface.

Infiltration

Infiltration is the process by which of water on the ground surface resulting from precipitation or irrigation enters the soil. The speed or maximum rate at which water during the course of a storm enters the soil is referred to as *infiltration rate*. *Soil infiltration* refers to the soil ability to allow water movement into and through the soil profile. *Infiltration capacity* is the maximum rate at which a given soil per unit area under given conditions is capable of absorbing water. During infiltration, the infiltrating water has two components, namely; *transmission* and *diffusion*. With transmission, water flows constantly and steadily with unobstructed laminar flow through a continuous network of large pores of the soil. In diffusion, initially water flow rapidly in very small discrete steps from one small pore space to the next, in a random fashion, then increasingly becoming slow, filling-up air-filled pore spaces of the soil from the surface downwards. At the beginning of precipitation, the infiltration capacity is generally superior to the precipitation intensity, therefore, all water from precipitation will be completely infiltrated. Water is retained in the soil until the soil saturation capacity is achieved. Therefore, the process of infiltration continues only if there is room available for additional water on the soil surface. As water continues infiltrating, it is transferred deep into permeable rocks with joints (pervious rocks such as carboniferous limestone) or rocks with pores (porous rocks such as chalk and sandstone) through a process known as *percolation* (Figure 6.7).

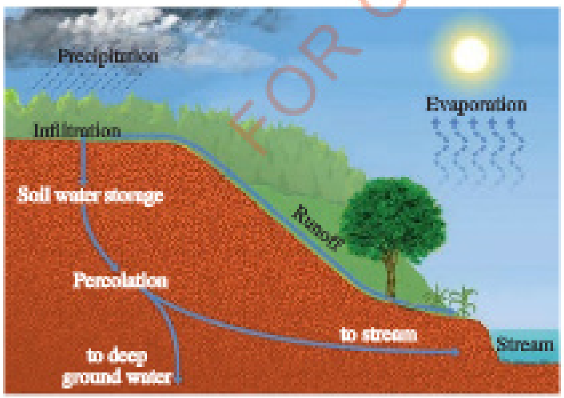


Figure 6.7: *The infiltration process*

Factors affecting infiltration

The rate on infiltration is affected by the following factors;

Precipitation

The form, amount, and duration of precipitation control the rate and amount of infiltration. Precipitation in the form of rainfall speeds up infiltration rates than snow or sleet. In terms of precipitation amount, the more precipitation that reaches on the ground surface, the more infiltration will occur until the soil reaches saturation or infiltration capacity. With duration, initially when the precipitation event starts, the infiltration occurs rapidly as the soil is unsaturated, but as time continues the infiltration rate slows gradually. Precipitation that occurs at fast rate with huge amount and long duration results into high and quick infiltration.

Soil characteristics

Soil porosity, moisture, mineralogy, and texture (percentage of sand, silt, and clay) determine infiltration. The amount and size of pores space between soil particles (porosity) affect infiltration in sense that soils that have smaller pore sizes like clay soils have lower infiltration capacity and thus slower infiltration rate than soils that have large pore sizes like sand soils (Table 6.1). However, clay soils present in dry conditions can develop large cracks creating a direct conduit for water to enter the soil, thus leading to higher infiltration. Again, soil which has high initial moisture content is already saturated, thus it has moderate to low capacity of absorbing or holding more water during precipitation, since the infiltration capacity of the particular soil has already been reached.

Table 6.1: *Infiltration rate of different soil types*

Soil type	Infiltration rate (cm/hr)	Infiltration class
Sand	>3	Very high
Sandy loam	2-3	High
Loam	1-2	Moderate
Clay loam	0.5-1	Low
Clay	0.1-0.5	Very low

Soil compaction

Highly compacted soil caused by rain drops effect, livestock, and equipment traffic, especially on wet soils, dislodge soil particles by filling in and blocking surface pores. This contributes to the development of surface crusts that decrease porosity, thereby restricting water movement within the soils, which ultimately decreases infiltration rate and infiltration capacity of the soil.

Organic materials in soils

Organic materials in the soil (including remains of plants and animals) increase the infiltration capacity of the soil. For example, in savanna and grasslands, the infiltration rate of a soil depends on the percentage of the ground covered by litter, and the basal cover of perennial grass tufts. On sandy loam soils, the infiltration rate under a litter cover can be nine times higher than on bare surfaces as litter increases soil depth. Organic matter from crops promotes a crumbly by structure and improves soil permeability. Moreover, soil which is high in organic matter also provide good habitat for soil biota like insects, earthworms, and reptile that through their burrowing activities, increase pore spaces and create continuous pores linking surface to subsurface soil layers.

Land cover and management

Land cover can be made by impervious or impermeable surfaces such as pavement, tarmac roads, cemented grounds, top roof of buildings, and bare rocks which do not allow water to pass through it. As well, vegetation cover of the land intercepts precipitation and decrease drops intensity reaching the ground surface, thus reducing infiltration. Increased abundance of vegetation cover leads to higher levels of evapotranspiration which in turn decreases the amount of infiltration rate. Again, vegetation contains roots that extend into the soil thereby creating cracks and fissures in the soil and reduce the surface compaction of the soil, allowing high infiltration rate and increased infiltration capacity. Land management like tillage reduces soil cover and soil organic matter, and disrupts continuous pore spaces, thus reducing infiltration.

Activity 6.3

Using the knowledge gained on the infiltration rate, use local materials available in your surroundings to improvise a model of infiltration testing. Conduct experiment using the model to observe the rate of infiltration in different soil types.

Runoff

Runoff is the portion of precipitation which reaches the earth's surface and makes its way towards streams, rivers, lakes and ocean after satisfying all the initial losses like evaporation, infiltration and depletion storage. This portion of precipitation remains unabsorbed by the soil strata. When precipitation falls onto the earth's surface, it does not remain stagnant in one location, instead it starts moving downhill according to the laws of gravity. When precipitation occurs, part of it is intercepted by vegetation, another part is stored in depressions found on the ground surface known as depression storage, later some part of precipitation available on the ground surface evaporates, another part is infiltrated or absorbed by the soil. If the precipitation continues further and reaches the ground surface at a rate that exceeds the infiltration rate, water starts to flow overland and joins the streams, rivers, lakes, or oceans in a form of *runoff*.

Types of Runoff

There are three types of runoff, namely; surface runoff, sub-surface runoff and baseflow.

Surface runoff

Surface runoff is the portion of precipitation which travels over the ground surface all the way towards the streams, rivers, lakes or ocean. Surface runoff is also known as *overland flow* or *quick flow* or *direct flow* or excessive precipitation. Surface runoff occurs when all loses is satisfied and precipitation is still continuing at intensity greater than infiltration rate. At this stage the excess water that remains on the ground surface move from one place to another flooding the surface. Surface runoff occurs soon after precipitation has started and disappears soon after precipitation stop.

Sub-surface runoff

Sub-surface runoff also known as *interflow* or *through flow,* is that part of precipitation which first enters the upper layer of the soil and moves laterally to join the streams, rivers, lakes or ocean under law of gravity without joining the water table.

Baseflow

It is part of precipitation which after falling on the ground surface, infiltrates and percolates into the soil to meet the water table and finally flow towards the streams, rivers, lakes or ocean. Baseflow is also known as *delayed runoff* or *groundwater flow*. The movement of water under this type of runoff is very slow and takes a long time to join the streams, rivers, lakes or oceans, and that is why sometimes it is called a delayed runoff. Therefore, total runoff is the function of surface runoff, sub-surface runoff and baseflow (Figure 6.8).

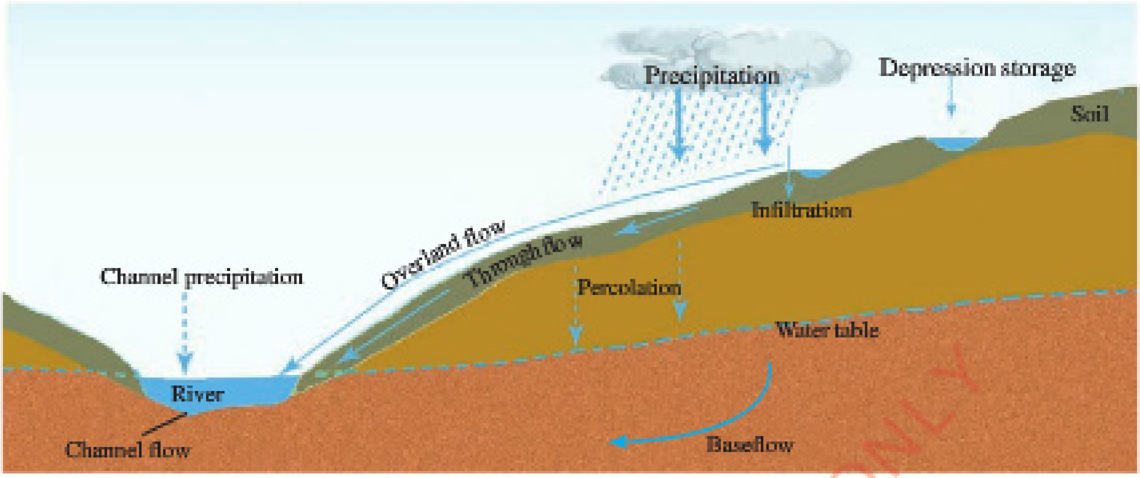


Figure 6.8: *Runoff processes*

Factors affecting runoff

The rate and volume of runoff differs from one catchment to another. Immediately after the beginning of precipitation, some areas generate and receive high runoff than others. The following are factors affecting runoff;

Precipitation characteristics

Precipitation can be characterized by its forms, intensity and duration. Precipitation occurring in the form of rainfall is immediately converted as runoff while precipitation occurring in the form of snow or hail may not result in runoff or takes some time to accumulate and be converted in runoff, thus producing less runoff much later. Again, if precipitation intensity is greater than the infiltration rate of the soil, runoff starts immediately and flow volume increases within short time. Furthermore, duration of precipitation is directly related to the volume of runoff in a sense that infiltration rate of soil decreases with duration of precipitation. That is, soil becomes more saturated with time when precipitation continue reaching the ground surface. Precipitation of longer duration would produce greater runoff due to the decrease of infiltration capacity.

Temperature

High air temperature causes more losses of precipitation through evaporation and transpiration, and hence reduces runoff while low temperature increases runoff. In cold and mountainous areas like the northern part of the continental Europe and America, Himalaya and the Southern part of Africa (South Africa), during winter precipitation may experience snow and water may be temporally stored on the ground surface due to low temperature. Warmer temperature in spring may lead to snowmelt and this can lead to the soil reaching field capacity quickly, thus producing more runoff.

Slope

Slope controls time of concentration of precipitation on ground surface and time of overland flow as there are few or no depression storages. Steep slopes results in greater runoff due to greater velocity of runoff than gentle slopes. If the catchment is mountainous, and is located on the windward side of the mountains, will have greater intensity of precipitation and hence will experience more rapid runoff. On gentle or flatter ground surfaces, runoff is less as water will have more time of concentration to allow more to infiltrate into the soil. Equally, flatter surfaces have many depressions and an undulating relief which allow water to collect and reduce runoff.

Geology

Geology includes the type of surface soil and subsoil, rocks and their permeability. If the surface soil and subsoil are pervious, seepage will be more rapid, which in turn reduces the peak runoff. If the surface is rocky, water absorption will be very small and runoff will be more rapid. However, when the rocks are porous or have many fissures, most of precipitation is lost through seepage, in turn surface runoff become very small as most of the precipitation seeps into the ground.

Soil types and moisture

Light soils like sandy have large pores that allow more water to soak into it in the form of infiltration causing low runoff. Heavy textured soils like clay soil have less infiltration and more rapid runoff. Again, amount and rate of runoff depends upon the initial moisture content present in soil at the time of precipitation. If precipitation occurs after long dry spell, infiltration rate is more, contributing to less runoff.

Land use and land cover

An area with dense forest cover or thick layer of mulch of leaves and grasses has less runoff because precipitation is absorbed more by the thick layer of decayed leaves and grasses. An area under agricultural land use can have the same impact as vegetation cover, because crop leaves intercepts precipitation, and thus, reduce runoff. However, an area under intensive irrigation agriculture causes waterlogged soils and therefore leads to more rapid runoff. Cultivation which uses heavy agricultural machinery to create contour bund and ploughing has direct effect on the runoff. Agricultural machinery can compact the soil and reduce its infiltration capacity, making runoff more likely. Again, urban land use change vegetated surfaces to impermeable concrete and tarmac. As construction takes place can increase the level of runoff in an area since large part of precipitation is unable to infiltrate into the soil.

Exercise 6.2

1. As a hydrologist working in a basin with varying physical and environmental conditions, explain why different locations within the basin respond differently to varying precipitation inputs.
2. Describe how precipitation is transformed into total runoff.
3. An investor wants to buy plots of land to build apartments. From a hydrological point of view, what factors do you think the investor is likely to consider in selecting favourable plots?
4. Hydrological cycle vary with atmospheric variables. Discuss.
5. Discuss the view that vegetation cover is a single most important factor that determine infiltration.
6. Input, process, output and storage components of the hydrological cycle are essential in understanding how water reaches the ground. Elaborate.
7. How do you describe the role of precipitation in determining the quantity of interception in a catchment?

Groundwater

Groundwater also known as phreatic water or subterranean water is the water below the ground surface in the cracks and spaces of the soil and rocks. Also it may also be referred to as the water present beneath earth's surface in rock and soil pore spaces, and in the fractures of rock formations. The main sources of groundwater are rainwater and melt water which infiltrate downward through the pore spaces of surficial materials and collects in large quantity in aquifers of varying sizes and locations. Groundwater is the most vital of all natural resources, which forms the core of the ecological system. It is the major source of water supply for domestic uses such as drinking, cooking, washing and bathing, agricultural, industrial, and recreational purposes. Also, groundwater serves various chemical, physical, and biological water needs in the environment.

The properties of groundwater

Groundwater is the definitive and most fit freshwater resource with trace concentration of salts for human consumption. Groundwater is differentiated from surface water and other forms of water masses through its properties which include;

Composition

The geological nature of the soil determines the chemical composition of groundwater. Water is constantly in contact with the ground in which it stagnates or circulates. Hence, equilibrium develops between the composition of the soil and that of the water in such a way that water circulating in a sandy or granitic substratum is acidic and has few minerals while water that passes in limestone containing bicarbonates during circulation becomes alkaline.

Some of the most typical characteristics of groundwater include weak turbidity, constant temperature, chemical composition, pure microbiological, and almost absence of oxygen. Circulating groundwater can have extreme variations in the composition with the appearance of pollutants and various contaminants.

Movement

Groundwater is in constant motion. However, the rate at which it moves is normally slow compared to its movement in a stream as it must pass through intricate passage between free spaces in the rock. Groundwater moves in two ways which are: vertical (upward and downward) and horizontal (lateral) movement. Groundwater moves downwards due to the pull of gravity while upwards moment of water depends on pressure that is flowing from higher pressure to lower pressure areas. Horizontal movement of groundwater is either due to the influence of gradient or difference in soil moisture between two adjacent soils. Groundwater moves from highly moist soil to dry soil. The rate of groundwater flow is controlled by two properties of rock which are porosity and permeability.

Types of groundwater

Groundwater can be grouped into four types based on its origin. Firstly, *connate water* which is a small amount of subterranean water which may have been retained in sedimentary rocks since the time of its formation. Most of connate water is saline which is normally found in arid and semi-arid areas. Secondly, *juvenile or magnetic water* which is a type of groundwater brought to the surface due to volcanic activities, it usually has high mineral content. Thirdly, *oceanic water* which is the type of groundwater seeped horizontally through rocks from the ocean or sea waters into the ground and it is common in coastal areas. Fourthly, *meteoric water* which is a type of water directly derived from rainfall or snowmelt. Meteoric water accounts for a large percent of groundwater.

Groundwater recharge and discharge

Recharge occurs when surface water, either from direct precipitation or from rivers, lakes and melting snow percolates downwards through the microscopic spaces in the soil and rock profile. Eventually, the infiltrated water may make its way into an underground water-bearing rock formation known as an *aquifer*. *Discharge* is the outflow of groundwater from aquifers. This occurs by diffusion across the landscape such as natural springs, rivers, and lakes. Recharge and discharge rates of groundwater depend on the permeability of the rock and the hydraulic gradient.

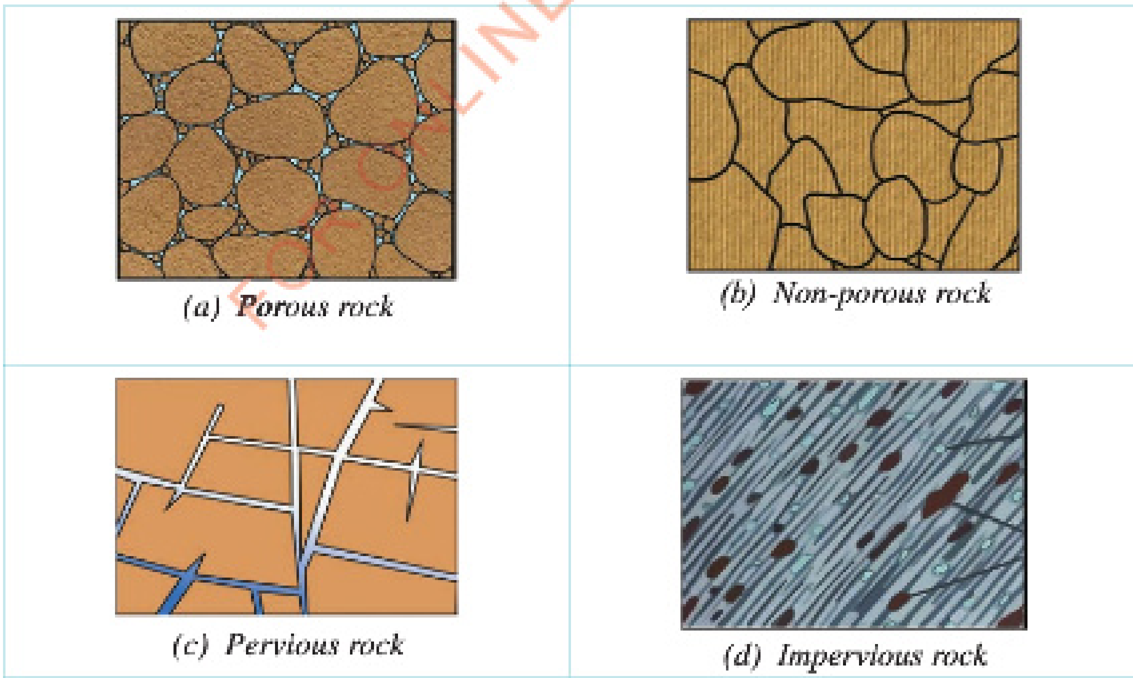
Groundwater recharge and discharge is dependent on other features constituting a water mass, these include, rock porosity, water table, zone of saturation, and non-saturated zone.

Rock permeability

It is the ability of rocks to allow water or other liquid to pass through them. Therefore, a rock can either be permeable or impermeable. *Permeable rocks* are rocks which allow water or other liquid to pass through freely. Permeability is achieved by the rock which is either porous or pervious. *Impermeable rocks* are rocks which do not allow water to pass through due to lack of cracks and on the other hand, they possess too small pores for water or liquid to pass. Examples of impermeable rocks that often lacks cracks or consist of too small pores include shales, unfractured igneous and metamorphic rocks. Moreover, the permeability can be classified as primary and secondary permeability. *Primary permeability* results from the open texture, coarse constituents and loose cementation of the rocks with pores of a certain minimum size, notably sand, sandstone, gravel and limestone. *Secondary permeability* results from the presence of joint cracks and fissures through which water can flow, notably in crystalline limestone, chalk, quartzite and jointed granite.

Rock Porosity

It is a physical state of a rock possessing cavities between the mineral grains making up the rock, which can contain liquid. Therefore, rock porosity can be described into four states (Figure 6.9): *Porous rocks* are rocks with pores or holes (however small), in which water may be held, for example sandstone. *Non-porous rocks* have interlocking grains so that water cannot get into it. Examples of non-porous rocks are granite, slate and marble. It should be noted that igneous and metamorphic rocks are usually non-porous. *Pervious rocks* are rocks through which water may pass because of either cracks or large pores, such as sandstones and granite which are jointed. *Impervious rocks* are rocks through which water cannot pass through because there are no cracks and the pores are too small such as clay rock.



(a) Porous rock

(b) Non-porous rock

(c) Pervious rock

(d) Impervious rock

Figure 6.9: *Rock porosity*

Water table is the upper surface of the zone of saturation. It is the level below which the ground is saturated with water. It occurs when water enters the ground and reaches a point where it cannot go down any further due to presence of impermeable rock. The rise and fall of the water table is determined by the seasonal variation of rainfall per year.

The presence and level of the saturated zone depends upon several factors, including the amount of rainfall, the elevation and shape of the land, nature of the soils and rocks. Hence, there can be a *temporary water table* which refers to the highest level reached by groundwater during the rainy season. It can also be *intermittent water table* which is the zone where spring occurs in wet season only. Again, it can be *permanent water table* showing the level which is reached during the dry season. Therefore, the water table rises after heavy rainfall and melting of snow, and falls during the dry season. Moreover, there is a *perched water table* which occurs above the regional water table. It occurs when there is an impermeable layer of rock or sediment or relatively impermeable layer above the main water table but below the land surface (Figure 6.10).

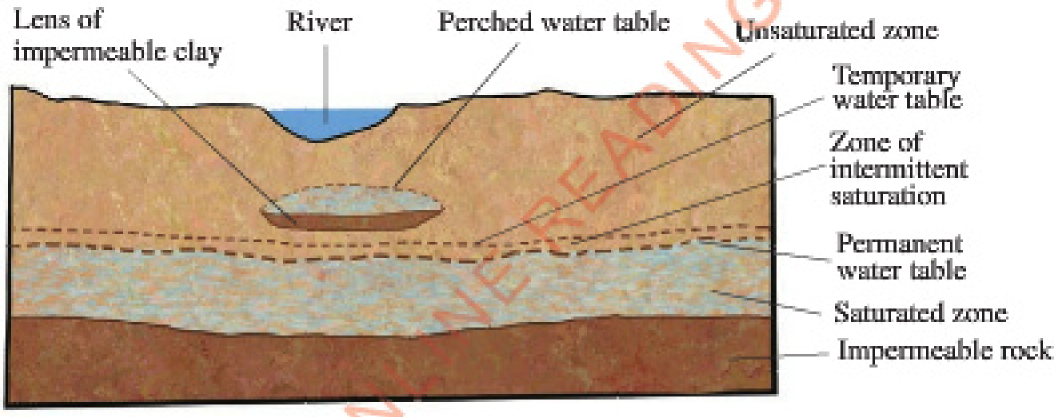


Figure 6.10: *Water table*

Zone of saturation is the area beneath the water table where all pore spaces are completely filled with water. In this zone a solid rock or soil hold a great amount of water in undisturbed zone under specific conditions. This zone is also referred to as *aquifer* or *phreatic zone*. The saturation zone of groundwater is further divided into two namely zone of intermittent saturation and zone of permanent saturation. *Zone of intermittent saturation* is the zone which extends from the highest level reached by groundwater after a period of prolonged wet weather, down to the lowest level to which the water table recedes after drought. *Zone of permanent saturation* is the zone where the pore spaces in a rock are always filled with water. The upper surface on this layer is called the water-table (Figure 6.11). The zone of permanent saturation is also composed of saturated rock called aquifer.

Zone of non-saturation is a zone which is never completely filled with water but acts as an intermediate zone for water to percolate on its way to the underlying zones. During the process of percolation, some amount of water is retained by the soil, and used by plant through plant roots. This zone is also referred to as aeration zone or vadose zone; the term vadose is applied to wandering water found beneath the surface but above the water table.

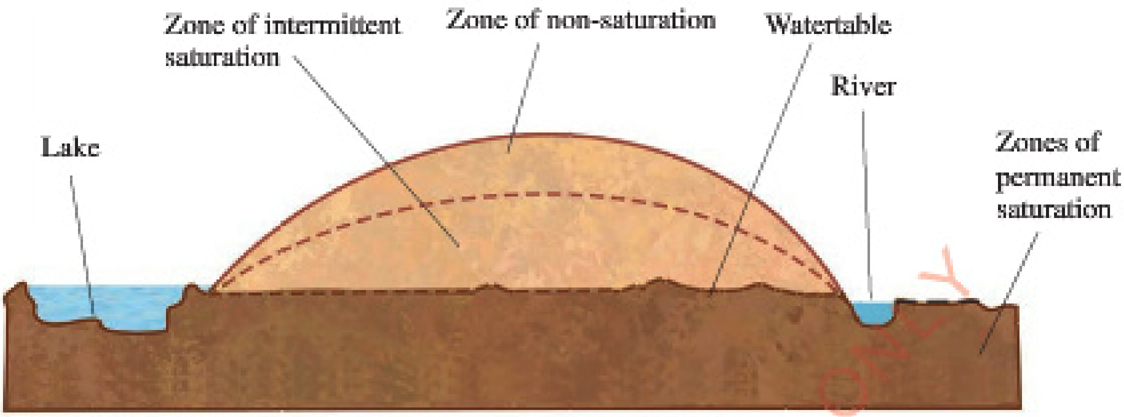


Figure 6.11: *Zones of saturation*

Ground water on geological formation

A geological formation is a layer of rock with consistent set of physical characteristics that differentiate it from other neighbouring rocks. Groundwater can pass through and be stored in the geological formation based on the nature and type of the particular formation. There are four types of geological formation which are *aquifer*, *aquitard*, *aquiclude* and *aquifuge*.

An aquifer: refers to the body of saturated rock through which water can easily move and from which usable volumes of groundwater are stored. Aquifer is both pervious and porous. It is composed of rock types such as sandstone, conglomerate, fractured limestone and consolidated sands and gravels as well as fractured volcanic rocks such as columnar basalts. The rubble zones between volcanic flows are generally porous permeable, and they make excellent aquifers (Figure 6.12). An aquifer can be divided into two types which are *confined aquifer* and *unconfined aquifer*. *Confined aquifer:* Is an aquifer that lies between two layers of impermeable rocks. The recharge of confined aquifer occurs at a place where it exposes to the ground surface. A well that is dug to tap water into a confined aquifer is called *artesian well*. With artesian well, water flow to the land under natural pressure without pumping.

Unconfined aquifer: Is an aquifer that is overlain by a permeable rock. Unconfined aquifers are recharged by the infiltration of precipitation and irrigated water from the ground surface.

An aquitard: Is a zone within the Earth that does not allow transmission of a significant amount of water from one aquifer to another. It transmits water at a slow rate and thus its yield is insufficient. Digging well and pumping water in this zone is not possible.

An aquiclude: This is a layer which is impermeable to the flow of ground water. Aquicludes are made up of very low porous and low permiable rock sedments such as shales or clay. It contains a large amount of water in it but does not permit water through it.

An aquifuge is an impermeable layer which is neither porous nor permeable. It cannot store water in it and at the same time cannot permit water through it. Example of aquifuge are basalt or granite rock without fissures.

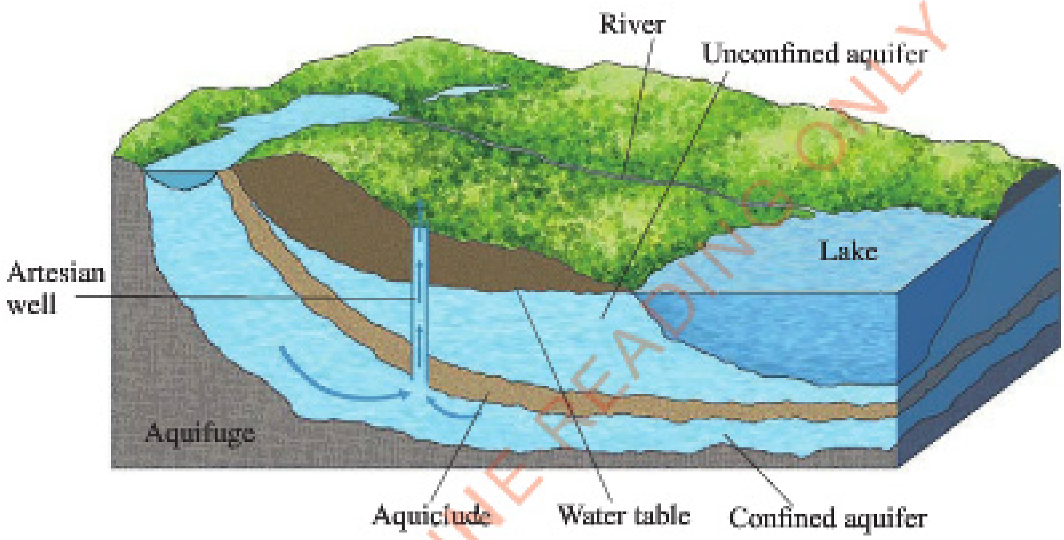


Figure 6.12: *Aquifer*

Activity 6.4

Develop a movable or stationary model of water table and zone of saturation for the groundwater. The model should be designed in such a way that it is mechanical and can be practically operated to visualize three levels of water table and zones of saturation in the ground.

Occurrence groundwater

Groundwater can emerge on the earth's surface as springs, wells, artesian basins, or artesian wells:

Springs

A spring is a natural outflow of water from the ground to the earth's surface. Springs are sometimes referred to as outlets of groundwater. They may flow strongly and ooze or they may seep out. Springs are categorized into two groups namely; *permanent spring* with permanent water table and *temporary spring* with temporary water table. When the level of a water-table rises after heavy rain the spring formed may be permanent, and it falls during periods of dry seasons. When a spring disappears during dry season, it is known as temporary spring. Springs can occur singly or in a series forming a line of springs called spring lines. A spring may develop along the line where the water-table meets the surface and it can develop into a stream, swamp or pond (Figure 6.13).

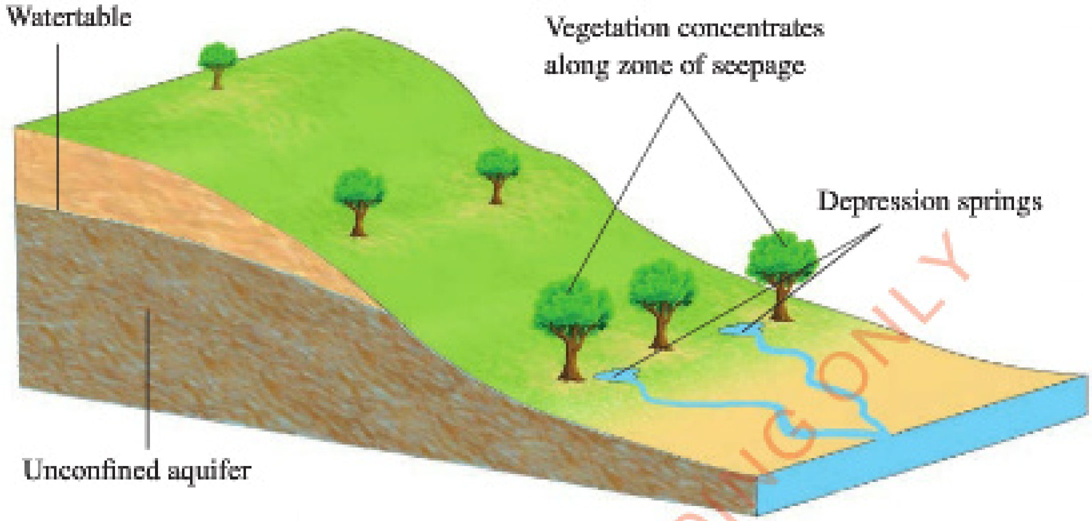


Figure 6.13: *Position of a spring*

Occurrence of spring

The geological structures responsible for the occurrence of springs are extremely varied. Springs may occur in the following ways:

When a permeable rock lies on top of an impermeable rock: A line of spring often develops where an overlying permeable rock meets a layer of impermeable rock beneath it. Figure 6.14 shows two lines of springs where one is permanent and the other is intermittent.

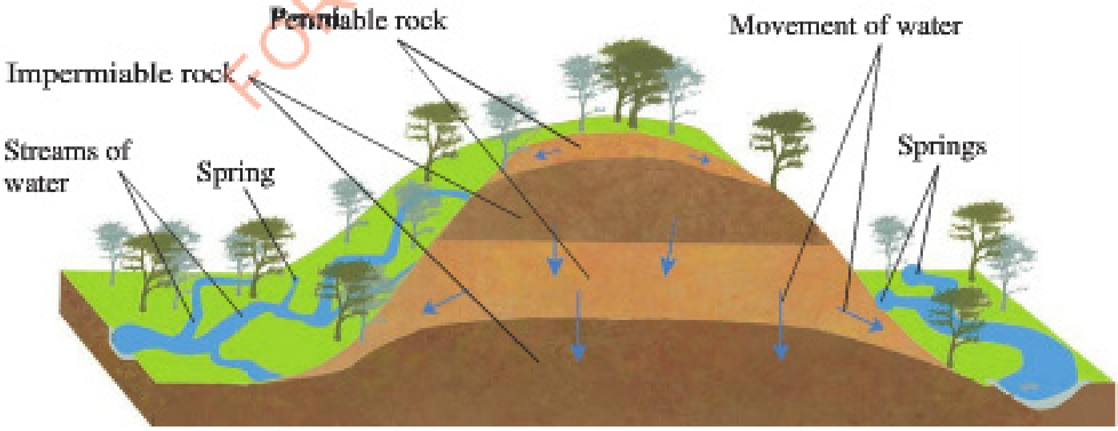


Figure 6.14*: Springs overlying permeable rock*

When well-jointed rocks form hilly landscape: When well-jointed rocks form a hilly landscape, water enters the rocks through the joints, causing springs to occur where the water-table meets the surface (Figure 6.15).

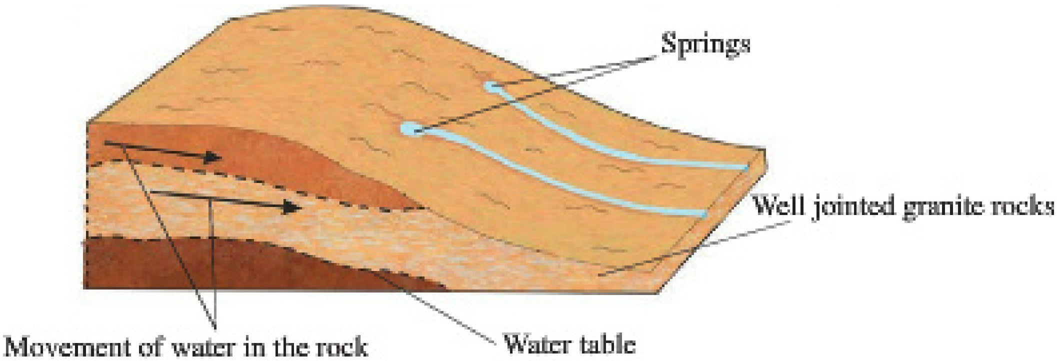


Figure 6.15: *Springs on the slopes of well-jointed hilly regions*

When a dyke acts as a dam: If streams cut across a layer of permeable rock, the water in the upslope side of the dyke is impounded causing the water-table to meet the surface on the gentle slope of a dyke. Some springs are formed due to the damming effect of a dyke, and that is called dyke spring (Figure 6.16).

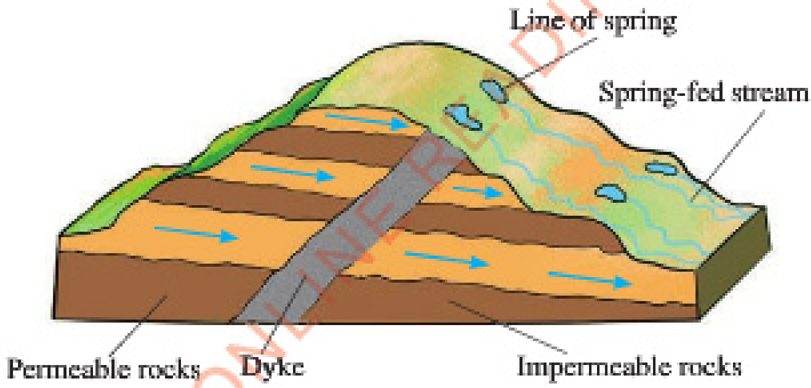


Figure 6.16: *Dyke springs*

When chalk or limestone escarpments overlie impermeable rocks: A spring may occur at the bottom of the steep slope, where the water-table meets the surface (Figure 6.17). Such a spring is known as limestone spring.

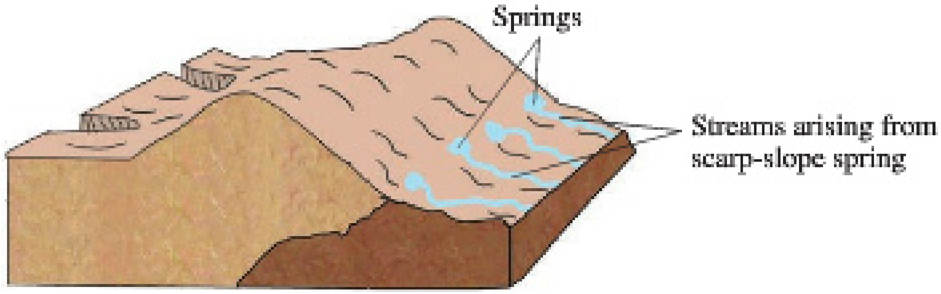


Figure 6.17: *Limestone springs*

When rain falls on the exposed end of gently sloping layers of permeable rocks: This causes the alternation of layers of impermeable rocks, soaking down to the sloping bedding planes and emerges as spring (Figure 6.18). Several lines of springs may develop along the junctions of permeable and impermeable rocks where these form alternate layers in a hilly region.

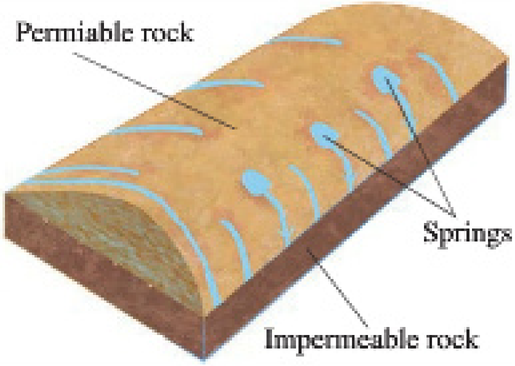


Figure 6.18: *Springs on the slope side of alternate permeable and impermeable rocks*

When a spring develops along a fault: A spring can also occur along a fault where a permeable rock layer has been brought against an impermeable rock layer (Figure 6.19). Such a spring is known as fault spring.

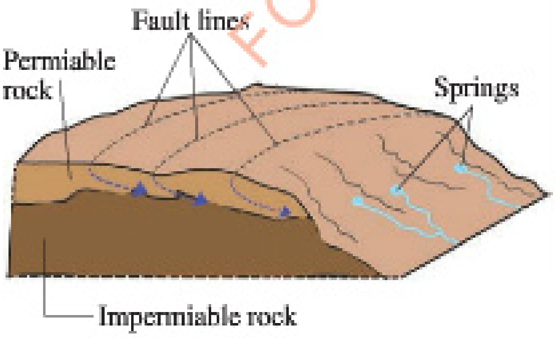


Figure 6.19: *Springs along a fault*

When the water table is cut by the surface profile of the depression: Springs can occur in the depression where the water table is cut by the surface profile of the depression (Figure 6.20). Such spring is known as a depression spring.

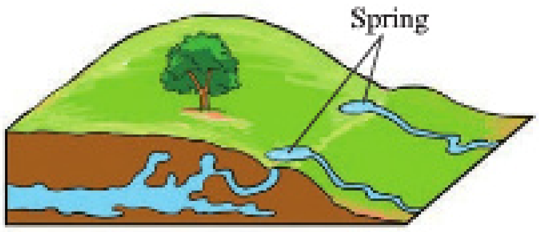


Figure 6.20: *Depression springs*

Wells

A well is a deep hole sunk into the ground to the position of the water table. In most of the wells, the water-level rises and falls in the same way that springs flow strongly or weakly or even cease altogether. Wells are categorized into deep (permanent) or shallow wells. *A permanent well* is the one that sinks to the zone of a permanent water table, while *a shallow well* sinks to the zone of intermittent water table. Some wells are sunk into non-saturation zone, thus are referred to as dry wells (Figure 6.21).

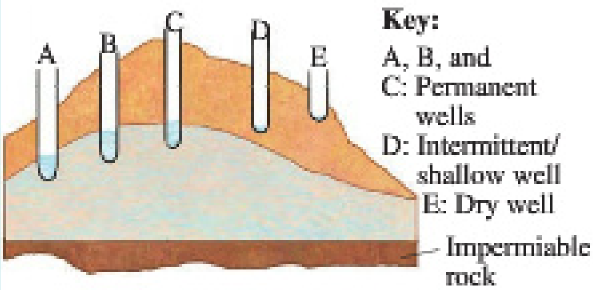


Figure 6.21: *Wells*

Artesian basins

An artesian basin is formed when a layer of permeable rocks lies between two layers of impermeable rocks such that they form a shallow syncline with one or both ends of the permeable rock layer which become exposed on the surface (Figure 6.22). In the artesian basin, groundwater is confined under pressure from surrounding layers of rocks.

Artesian wells

An artesian well is a hole dug to tap water from an artesian basin. When a well is sunk into the artesian basin, the hydrostatic pressure in the ground forces water to come out like a fountain (Figure 6.22). Moreover, when pressure surface lies above the ground surface, groundwater will be under pressure hence water tapped by a well rises above the level at which it may flow out at ground level. On the contrary, if the pressure surface is below the ground, the well will be artesian but water may not flow anymore and therefore it will require a pump to bring water to the surface. Such a well is known as semi-artesian well if hydrostatic pressure cannot force water to reach the surface of the Earth.

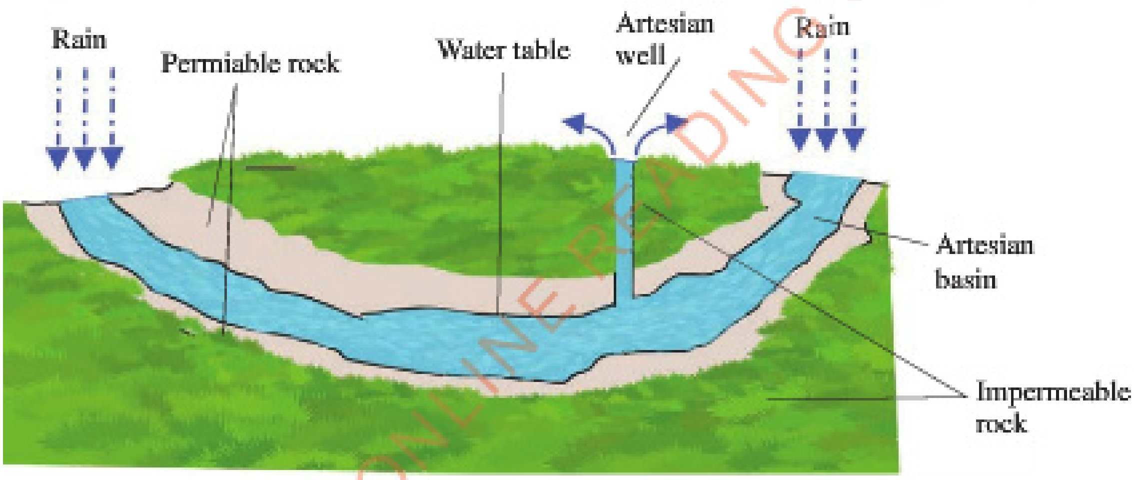


Figure 6.22: Artesian basin and artesian well

Conditions for the location of artesian well and artesian basin

The location of the artesian well demand three main conditions; firstly, presence of a permeable rock layer lying between two impermeable rock layers. Secondly, the permeable rock layer must be exposed in an area of sufficient precipitation; and thirdly, the basin must be dip towards a region where the land surface is lower than it is at the exposed end of the previous formation and there must be partial or total blockage of exposed ends of the permeable rock that allows water to sink and saturate the layer (Figure 6.23).

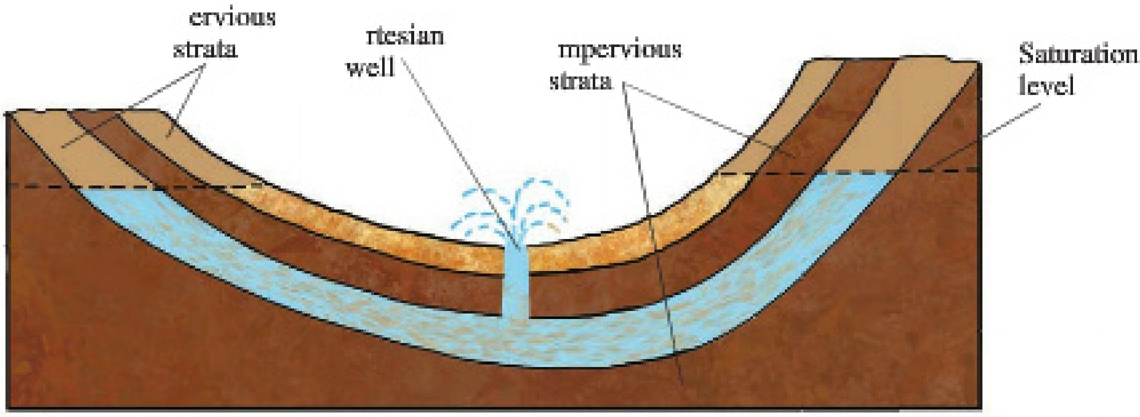


Figure 6.23: *Formation of an artesian well*

Factors affecting the occurrence of groundwater

The occurrence of groundwater is affected by many factors. The most important factors are precipitation and evaporation, rock permeability, gradient and vegetation cover.

Precipitation and evaporation

Low precipitation and high evaporation rate reduce the amount of groundwater which in turn lowers the water table. On the other hand, when the amount of precipitation is high with low evaporation, the water table becomes saturated.

Rock permeability

Groundwater recharge depends on the permeability of rocks. Where there are permeable rocks characterized by open texture, course-grained constituents and rocks with pores of a certain minimum size notably sandstones, gravel and limestone, it constantly allows water to pass through until it becomes saturated, forming a zone of aquifer. However, impermeable rocks, mostly igneous and metamorphic rocks, such as granite, basalt, and schist may result into dry water table since they do not allow water to pass through.

Gradient

The gradient also known as slope can affect water percolation. The nature of gradient greatly influences the rate of water percolation into the ground. On steep slope infiltration is low because water runs fast, but on a gentle slope surface water infiltrates at high rate since water runs slowly or is stationary. Therefore, groundwater can be recharged easily in a gentle slope than in a steep slope.

Vegetation cover

Usually water tends to sink down in areas of dense vegetation cover, but on bare rocks (surface) water runs freely down the slope such that little amount infiltrates into the ground to form groundwater.

Human activities

Several activities undertaken by man, like irrigation, contribute to the amount of water that percolates into the ground and forms groundwater. Therefore, the more the activities of this nature, the larger the amount of groundwater collected underground.

Activity 6.5

Using the knowledge gained on the emergence of groundwater, improvise a model of artesian basin representing an artesian well.

Groundwater Pollution

Pollutants found in groundwater can be classified into two broad groups: biological and chemical pollutants. Chemical pollutants can be further sub divided into two groups, namely; inorganic and organic pollutants. Inorganic pollutants include heavy metals (cations) such as cadmium (Cd), chromium (Cr), lead (Pb), manganese (Mn), mercury (Hg), and nickel (Ni) naturally occurring in the soil.

These highly toxic chemicals may reach groundwater after mineral dissolution with acidic waters (from mining or industrial activities) or after industrial emissions. Organic pollutants are those chemicals that contain carbon as a molecular backbone. Chemicals that most frequently leach into groundwater include trihalomethanes (chloroform and bromodi-chloromethane), solvents (tetrachloroethylene), gasoline components (benzene, toluene, ethylbenzene, and xylene), and pharmaceuticals and personal care products such as caffeine, carbamazepine and sulfamethoxazole.

Biological pollutants include bacteria, viruses, and parasites that are responsible for waterborne diseases, such as typhoid fever, cholera, dysentery, polio, hepatitis, and schistosomiasis. The presence of Coliform bacteria is indicator of recent fecal pollution. This type of contamination is exclusively attributed to human and animal waste.

Sources of groundwater pollution

Groundwater pollution may originate from point sources and nonpoint sources. Point sources can be well identified in space, for example, landfills, underground storage tanks, or septic systems. Nonpoint sources are dispersed over large areas, for example, pesticide application in agriculture. The later is more difficult to identify, measure, and control than the former. Generally, the following are the main sources of groundwater pollution.

Onsite sewage facilities like septic tanks systems. A septic system failure causes untreated wastewater to leak to the surface or to seep into the soils. These systems are known to be ineffective in nutrient (nitrates and phosphates) removal, and therefore, nutrient migration into source of water is directly related to the retention capacity of the soil surrounding the leaching field of the septic system. The chemicals used to clean these systems can create additional pollutants that may eventually end up in the groundwater.

Landfills generate leachates that represent a major threat to groundwater quality. The leachates result from the liquid waste dumped in the landfill and the decomposition of solid waste aided by precipitation and surface runoff events. Improper disposal of untreated industrial and hazardous chemicals into municipal waste landfills increases the presence of toxic and hazardous chemicals in the leachates which contaminate groundwater.

Surface impoundments are shallow lagoons or reservoirs commonly used to temporarily store or treat hazardous liquid waste. These sites are protected by several liners (plastic/clay) at the bottom in order to prevent leaks. However, the liquid waste confined in them may potentially enter the subsoil because these liners are not leak-free.

Application of pesticides and fertilizers especially, once released into the environment, may have different behaviors and fates. Some of them may break down or degrade by biotic and abiotic processes while others remain unchanged for a long period of time, and are called persistent environmental pollutants. As a consequence, they freely move with water and become part of groundwater pollutants.

The use of underground and above ground storage tanks to store chemicals (for industrial processes), fuels (petroleum solvents, motor fuels, heating oil), and wastes (used oil and industrial hazardous wastes) when handled inappropriately, may cause groundwater pollution. Spills out of these chemicals may occur if the tanks are overfilled. Therefore, the chemicals can seep out, move within the subsoil, and eventually contaminate groundwater. Storage tanks are also used for the transportation of chemicals by trucks and trains. Accidental spills over occurring during transportation and transfer operations constitute a relevant source of hazardous chemicals into groundwater.

Pipelines are used to transport any chemical stable substance (liquid or gas) such as industrial chemicals and oil brines. They have been also set for the transport of wastes, for example, sewer pipelines. Regardless of pipe materials, when leaks eventually appear in pipeline systems, groundwater contamination risk is possible. In this regard, a high risk of biological and chemical pollution is associated with sewer pipelines.

Mining activities significantly impact the quality of water resources, thus pose a threat to groundwater. After precipitation events, the acid mine drainages, which consist of leachates containing metals and minerals generated from mine wastes for hundreds of years, can move through fractures and pores of the unsaturated zone down to the saturated zone. Moreover, groundwater can also be contaminated after a spill or leak of the chemicals used to separate a target mineral substance from the ore, for example, cyanide or sulfuric acid.

Exercise 6.3

1. Village A and B located in contrasting environments, constructed two wells to supply water to the communities. A well in village A could yield large amount of water to supply the entire village throughout the year while a well in village B dried

for some months. What were the possible reasons for such variations?

2. As an environmental officer planning for a densely populated city that depend on groundwater supply for domestic uses, explain planning strategies that you will consider to avoid deterioration of groundwater quality in the city.
3. Hydrological cycle reflects the occurrence of groundwater in our environment. How does the two relate?
4. To what extent is the groundwater valuable to the community?
5. Unmonitored groundwater is likely to cause health risks to users. Justify this statement.
6. Subsurface and ground water can easily be studied through their vertical distribution. Justify.

Surface water

Surface water refers to all bodies of water present on the earth's surface. This includes both freshwater bodies such as creeks, ponds, wetlands, streams, rivers, and lakes, as well as the saline water bodies which are mainly seas and oceans. Surface water mainly originates from precipitation and feed by combination of surface runoff and groundwater. However, surface water and groundwater are reservoirs that feed into each other. Surface water flow through a well-defined channel known as drainage. The flow is formed by complex interactions and patterns of wetlands, streams, rivers, lakes and oceans making drainage systems.

Drainage system

Drainage system refers to the origin and development of streams through time. The origin and subsequent evolution of any drainage system in a region are determined and controlled by two factors namely; nature of initial surface and slope and geological structure such as folds, faults, fractures, joint, dips and strikes of rock beds and types of rocks. Drainage systems are divided into two broad categories on the basis of the adjustment of the stream to the initial surface and geological structure. The two categories are sequent streams or accordant or concordant drainage system and insequent streams or discordant drainage system.

Sequent drainage system

This is also known as accordant or concordant drainage system which follows the regional slope and is well adjusted to the geological structure. Sequent streams are further divided into consequent, subsequent, obsequent, and resequent streams.

Consequent streams: Consequent streams which are also called *dip streams* are the first streams to originate in a particular region. These streams have their courses in accordance to the initial slope of land surface (Figure 6.24). In other words, consequent streams follow regional slope. In a region of folded structure in which the crustal rocks are fold due to lateral compressive forces into parallel anticlines and synclines the consequent streams are formed in the synclinal troughs. Such consequent streams are called synclinal consequent streams, which become the master consequent streams of trellis drainage pattern at much later date. The first streams to be initiated on a newly emerged coastal plain are consequent streams which are parallel to each other and thus form parallel drainage pattern. The longest stream of the whole system of consequent streams is called master consequent. River Pangani that flows from Mt Kilimanjaro and Meru is an example of a consequent river (stream). Most of the streams draining the coastal plains of India are examples of consequent streams. The most ideal landscapes for the origin and development of consequent drainage system are domes and volcanic cones. Consequent streams are divided in two types which are longitudinal consequent streams which follow the axis of the depression or syncline in a folded structure and lateral consequent streams which follow the sides of the depressions or the sides of the anticlines.

Subsequent streams: These streams originate after the master consequent stream following the axis of the anticlines or ridges and the strikes of beds (Figure 6.24). The subsequent streams originate on the flanks of the anticlines and join the master consequent at almost the right angle while others maintain their flow parallel to the master consequent. Subsequent streams start as gullies on the sides of the primary consequent valleys, discover and explore belts of structural weakness, due to softer strata, fault, or joint-planes, and shatter zones. The Asan river, a tributary of the Yamuna river and the Song river, a tributary of the Ganga river in the Dehra Dun valley in India are good examples of subsequent streams.

Obsequent streams: These streams flow in opposite direction to the master consequent (Figure 6.24). In fact, obsequent streams are also consequents because they also follow the slopes of the ranges. The streams originating from the northern slopes of the West-east stretching ranges of the Himalayas flow northward to meet the East-west flowing tributaries (subsequent streams) of the southward draining master consequent streams. For example, the Mahabharat Range of the Lesser Himalaya has issued several streams from its northern slopes. These northward flowing streams join the subsequent stream. Similarly, several streams originating from the northern slopes of the Siwalik Range drain northward to join East-west subsequent streams of the southward flowing master consequents of the Ganga and the Yamuna, north of the Someshwar Range in India.

Resequent streams: The tributary streams flowing in the direction of the master consequents are called resequents. These originate much later in comparison to the master consequents. Since they are of recent origin, they are called resequent. The resequent streams originate during the initiation of the second cycle of erosion in a folded structure. The gradual erosion of folded structures as the invention of rolling in the anticlinal ridges and synclinal valley are converted into anticlinal valleys and synclinal ridges, respectively. Therefore, longitudinal streams are developed by the end of the first cycle of erosion begin with the exactions of new valleys in the synclines. Thus, the streams developed in the synclinal protons are formed (Figure 6.24).

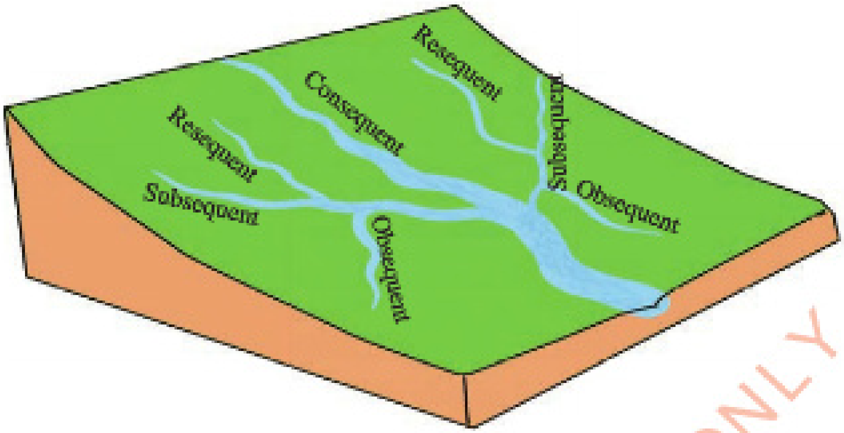


Figure 6.24: *Types of sequent drainage systems*

Insequent drainage system

Insequent streams also known as discordant drainage system do not follow the regional slope and are not adjusted to geological structures as they drain across these structures. Insequent streams are further divided into antecedent streams and superimposed streams.

Antecedent drainage system: This is a type of drainage system in which a river maintains its course by vertically eroding the rising land at the rate which is fast enough to keep pace with the land uplift. Some examples of this system are River Ruaha in Tanzania, Niger river, Indus and Ganges rivers and other Himalayan rivers that are older than Himalayas themselves. The antecedent rivers are older than the existing landform (Figure 6.25).

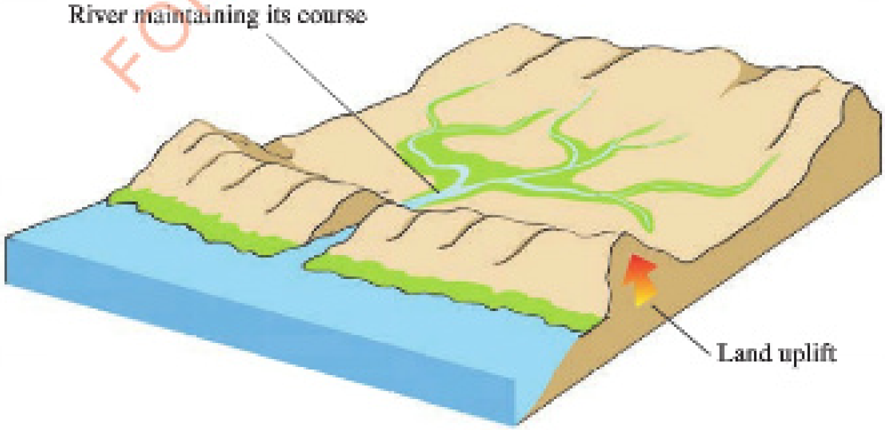


Figure 6.25: *Antecedent drainage system*

Superimposed drainage system: It is the opposite of an antecedent drainage. In this system, a river maintains its course as it flows into a newly exposed rock layer without following the structure of the new rock. The superimposed stream cut through older rocks regardless of the topography (Figure 6.26). Such rivers are younger than the rocks they cut across, for example Zambezi River.

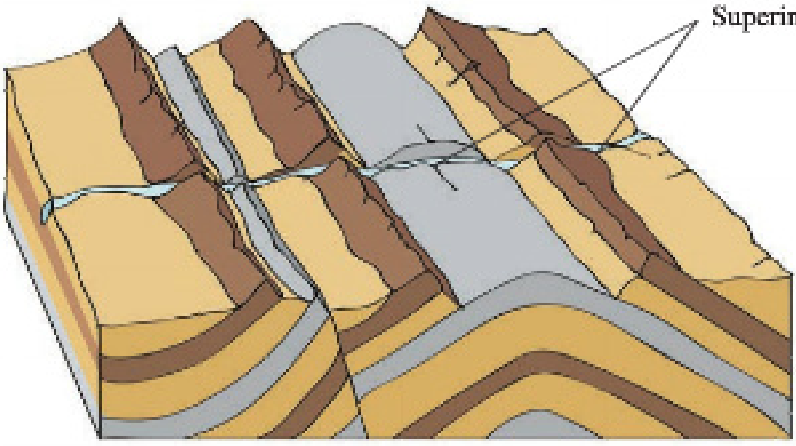


Figure 6.26: *Superimposed drainage system*

Furthermore, insequent drainage system can be an *Ante-position drainage system*: This is the system which has developed as a result of a combination of both antecedence and superimposition. This indicates that the river course is superimposed into the new rock layer with a different structure when the land is being uplifted. An example of this is the Colorado River in USA.

Inland drainage

Inland drainage refers to a drainage system in which rivers do not reach an ocean or sea, instead, it empties their water in lakes or in an inland sea. It is a drainage system that is fed by rainwater and sometimes by melting ice and snow. The volume of water in the streams and rivers varies considerably because of variation in the amount of rainfall and melting of ice or snow. Inland drainage is characterized by different types of drainages systems which are accordant and discordant drainage systems.

The main characteristics of inland drainage are: drainage streams join lakes or inland seas; they are fed by rainwater; during rains, they experience flash floods; they dry up during the dry season; and also, they are less than ten percent of the internal drainage formed by the inland drainage along arid and semi-arid areas. On the whole, an inland drainage should not be confused with inland water. Inland waters are water bodies located within land boundaries such as ponds, lakes, streams, and flood plains. Inland water can be found along coastal areas as well.

Drainage patterns

A drainage pattern is the layout or plan made by rivers and their tributaries on the landscape. The main drainage patterns are differentiated according to their geological structure. It considers relationship with the slope of the land, differences in rock hardness, and the rock structure. This is a spatial arrangement and form of drainage system in terms of geometrical shapes, geological structure, climatic conditions and denudation history. In many areas drainage patterns and individual streams often show a strong relationship with the geological structure. Therefore, drainage patterns can be classified whether as related or not related to rock structure. Streams naturally flow along those lines where erosion is possible, and for this reason they follow areas of weak rock to avoid resistant outcrops. Fault- guided valleys are common in several regions while fault lines and joints may be reflected in drainage patterns. In zones of folded rock, the initial valleys will be determined by slope and will tend to follow the synclines. Later, due to variations in the hardness of rocks erosion may carve valleys along the anticlines, leaving the syncline and anticline valleys to form various patterns. The following are some of the common types of drainage patterns.

Dendritic pattern

This type of pattern possesses a shape like the truck and branches of a tree. Usually the tributaries converging on the main stream from many directions joining at acute angles. It occurs in regions underlain by homogeneous rocks. It is the most common type and is related to rock structure or differences in rock hardness (Figure 6.27). The dendritic pattern is associated with the areas of homogeneous lithologies, horizontal or valley greatly dropping strata, flat and rolling extensive topographic surface having extremely relief.

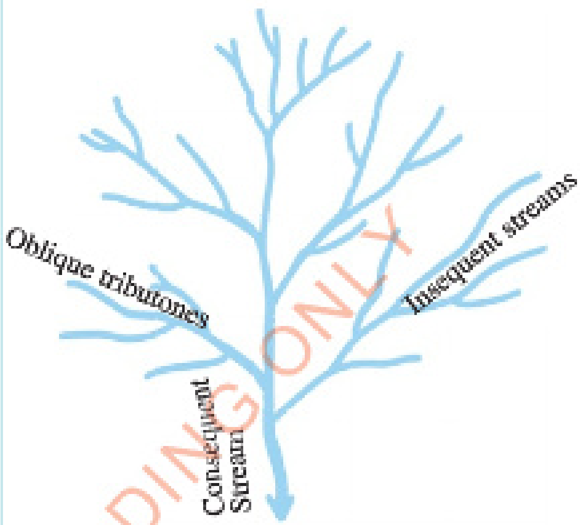


Figure 6.27: *Dendritic Pattern*

Trellis pattern

It is a drainage pattern that is formed between ridge lines in a deformed (typically sedimentary) rock with the chief tributaries joining the main stream approximately at right angles. Usually minor tributaries join the chief tributaries at right angles and flow more or less parallel to the main stream. The pattern is strongly related to structure or differences in the hardness of rocks and it is commonly found in folded sedimentary rocks, and metamorphic rocks. The chief tributaries are usually aligned along down folds or parallel zones of weak rock separated by resistant uplands (Figure 6.28).

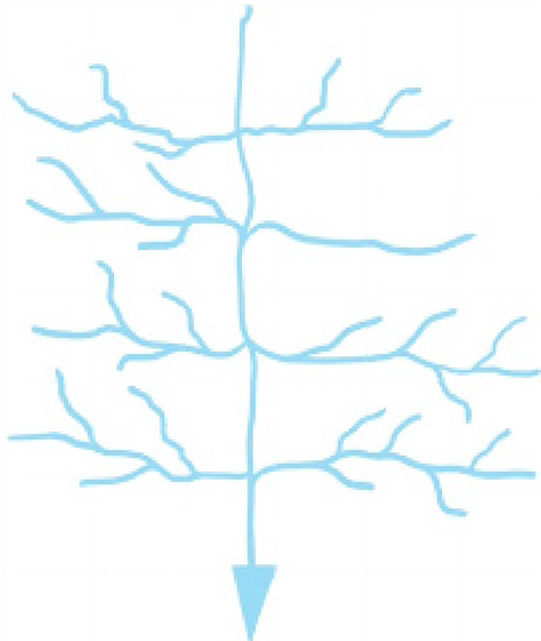


Figure 6.28: *Trellis pattern*

Radial pattern

This is an arrangement of streams flowing outwards down the flanks of a dome or cone shaped upland such as a large volcano. It is common in volcanic regime and the summit of a mountain peak and it is controlled by the slope of the land (Figure 6.29).

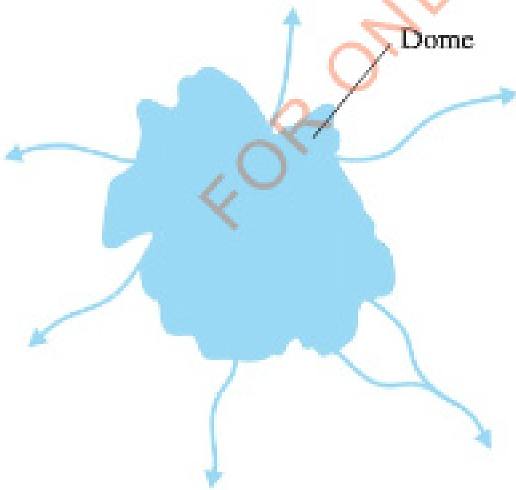


Figure 6.29: *Radial pattern*

Annular pattern

This is also known as circular pattern. In the annular pattern streams often joining the main stream at sharp angles but arranged in a series of curves which dissected a dome basin or crater area (Figure 6.30). It is formed when the tributaries of master consequent streams are developed in the form a circle. In a dissected dome with alternating bands of hard and soft rocks, the pattern may appear as having several concentric curves. It is common in volcanic region.

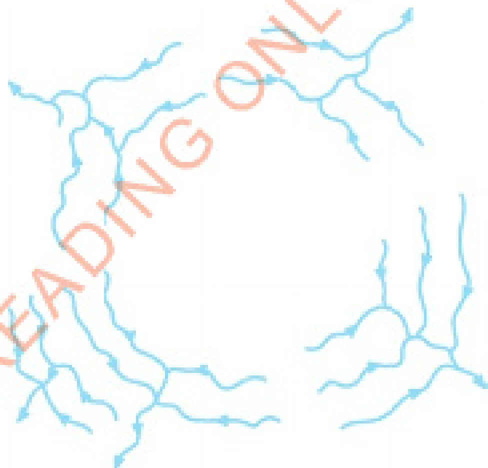


Figure 6.30: *Annular pattern*

Rectangular pattern

This pattern is similar in plan to the trellis, with tributaries joining each other at right angles. It also tends to have individual streams taking sharp angular bends along their course. It is a result of structural control, with streams following joints or fault lines in the rock. It is common in volcanic regions and granitic rocks (Figure 6.31). Generally, a rectangular pattern is developed in the regions where the rock joints form a rectangular pattern.

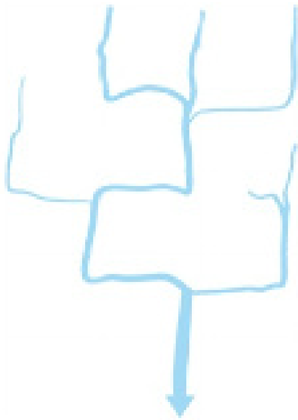


Figure 6.31: *Rectangular pattern*

Centripetal pattern

This pattern is formed by a series of streams which after emerging from surrounding uplands converge in a central low land which may be a depression, or a basin or a crater lake. This is the opposite of the radial pattern as in this case streams flow toward central depression such as craters, eroded structural domes with weak cores, and enclosed desert depression (Figure 6.32). Good examples are the Kathmandu valley of Nepal where the tributary streams of the Baghmati converge in the tectonically formed circular basin, the depression formed at the top of Raigarh Dome in the Lower Chambal Basin and streams of Tibet distributaries in Nepal.

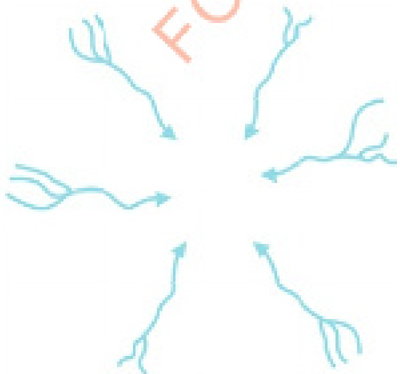


Figure 6.32: *Centripetal pattern*

Braided pattern

It is common on broad flood plains with low gradients often due to back tilting. The pattern formed by the rivers which split into several channels re-joins and split again (Figure 6.33). Braided channels are separated by sand bars or island of alluvium.

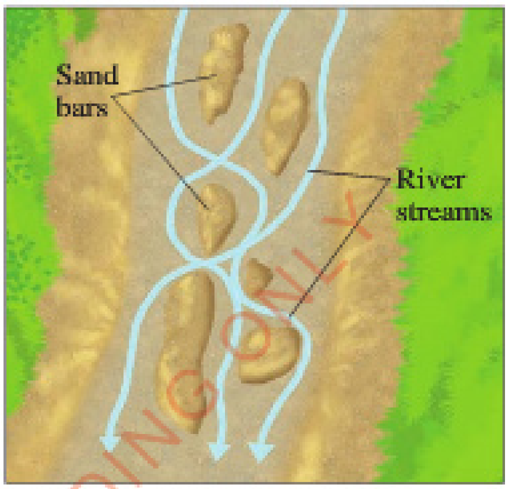


Figure 6.33: *Braided pattern*

Anastomotic pattern

It is mostly found along the flood plains of rivers in coastal line or on reduced gradients inland due to back tilting as shown in figure 6.34. Therefore, it is the reconnection of two streams that previously branched out.

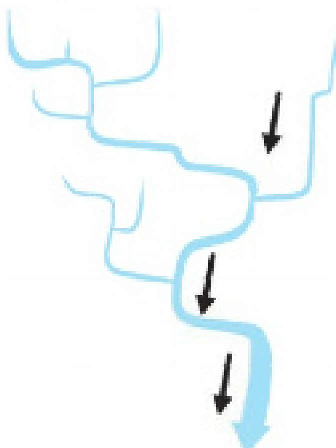


Figure 6.34: *An anastomotic pattern*

Exercise 6.4

1. A cartographer mapped the spatial distribution of drainage patterns in a hilly watershed dominated by igneous rocks. Explain the types of drainage patterns generated in the output map.
2. Nature of the surface and geological structure are the main factors that control the drainage systems of an area. Discuss.
3. How can drainage systems be distinguished from drainage patterns?

River

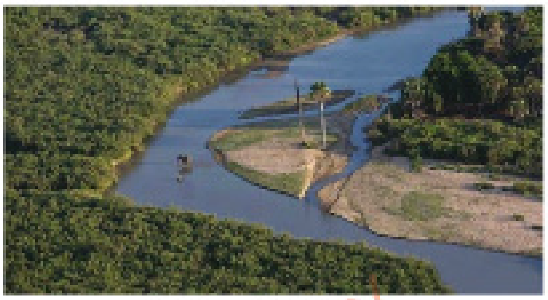
It is a natural flow of water in a valley from the source to the mouth. It is a mass flow of water over the surface in a particular channel from its source mostly in the highland areas, to its mouth, such as lake, sea or ocean. A river branches off into small streams when it is about to enter into the sea or ocean. These small streams at the mouth are called distributaries. The area drained by a river and its tributaries is called a river basin and the boundary which separates river basins is known as a watershed or divide.

Types of rivers

Rivers can be categorised into three main types which are *perennial*, *intermittent* and *ephemeral* rivers.

Perennial Rivers

These are permanent rivers which flow throughout the year. Most of these rivers are situated in the equatorial regions, good examples are Rufiji river in Tanzania, Amazon and Congo rivers (Figure 6.35). Other rivers originate in areas with either permanent ice melting or lakes. Good examples are Rhine river in Western Europe and Nile river in Africa.



(a) Part of Rufiji river

(b) Part of Congo river

Figure 6.35: *Perennial rivers*

Intermittent rivers

These are types of rivers that flow in rain season when the rain is abundant. Most of the tropical rivers belong to this type. They are also known as seasonal rivers. Rivers like Yellow river in China and Colorado (Figure 6.36) are examples of intermittent rivers.

Figure 6.36: *Part of Yellow river in China*

p emer l rivers

Most of these rivers are found in desert. Usually they emerge when torrential rainfall occurs and tends to disappear in a short period of time and sometimes after the rain has stopped. These rivers include Kuiseb river in central Namibia (Figure 6.37), Luni and Son in India.

Figure 6.37: *Part of Kuiseb River in central Namibia*

River Regime

River regime is a seasonal variation or fluctuation in the volume of water in the river. The change of the volume of water is a result of interplay of factors which include climate, gradient, vegetation, nature of underlying rock and human activities.

Types of river regimes

Simple river regime: It is common in areas marked by two seasons in the year, dry and wet seasons especially in the tropics. During rainy season the volume of water increases and decreases during dry seasons. Most of the rivers found in Africa experience simple regime. Example of rivers under simple regime include; River Ruvuma, Malagarasi and Ruvu in Tanzania, Tana and Galana in Kenya.

Double river regime: This occurs when a river experiences two maximum water levels and two minimum water levels. Double river regime is also known as mixed river regime. They are common in the equatorial regions where there are double maximum rainy seasons which experience two major seasons of high rainfall in a year. A good example is the Congo river.

Complex river regime: Complex or composite river regime is a type of river regime characterized by constant high volume of water in the river throughout the year. This type of regime belongs to big and longest rivers whose length cut across several climatic regions. Examples of these rivers are river Nile, Amazon and Mississippi.

Exercise 6.5

1. What would happen if ocean water did not move?
2. Water samples were taken from the Arctic Ocean, Mediterranean Sea, and Baltic Sea. After laboratory test, results showed variation in their salinity concentration. What were the causes for such variation?
3. With examples, describe the categories of river regimes.
4. Explain the factors influencing river regime.
5. Differentiate between cold ocean currents and warm ocean currents.
6. Ocean movements are of great importance to life in the ocean. Justify.
7. Chemical composition of the ocean and sea water affects the movement of water in the ocean and sea. Justify.
8. Describe various features of the ocean floor.

Lakes

Lakes are bodies of either fresh or saline water in natural depressions on the surface of the Earth. The term lake includes a wide range of water bodies such as ponds, marshes and swamps with standing water. The sizes of lakes range from ponds to larger ones. Some larger lakes are called seas, such as the Caspian Sea, the Dead Sea and the Aral Sea. Although most of the lakes are permanent yet some contain water in the wet season only while lakes in basins of inland drainage (which are usually semi-arid) may contain water for a few months in several years. Lakes receive water from streams, overland flow, and groundwater, hence form part of drainage systems. Many lakes lose water at an outlet through outflowing streams, where water drains over a dam. For example, Lake Victoria loses water through River Nile, while Lake Nyasa loses water to the Zambezi Basin through Shire River, lakes Albert and Kyoga loses water to the White Nile, meanwhile Lake Tana loses water to the Blue Nile. Lakes contain four times more fresh water compared to rivers. Without continuous replacement, they can disappear due to desiccation or sediments accumulation. Basically, there are ten largest lakes in the word as shown in Table 6.2.

Table 6.2: *The World's ten largest lakes*

No.	Name	Location	Area in km²
1	Caspian Sea	Russia	371,000
2	Lake Superior	Canada	82,414
3	Lake Victoria	Tanzania, Uganda and Kenya	69,485
4	Lake Huron	Canada	59,600
5	Lake Michigan	USA	58,000
6	Lake Tanganyika	Tanzania, Burundi, Zambia, and DRC	32,893
7	Lake Baikal	Russia	31,500
8	Great Bear Lake	Canada	31,080
9	Lake Nyasa	Tanzania, Malawi and Mozambique	30,044
10	Great Slave Lake	Canada	28,930

Classification of lakes

Lakes are classified according to their modes of formation and the quality of the water they contain, that is, they can either be freshwater or salt water lakes. Lakes are divided into two major types: those occupying basins formed by the earth's movements, volcanic processes and erosion; and those formed by the damming effect of materials deposited by ice, water or lava. Other lakes are formed directly from solution, barrier and human influence.

Lakes formed due to earth's movements

These are also called tectonic lakes. They are formed due to movements of the earth's crust which cause crustal warping leading to the formation of the largest lake. They include *crustal warping* and *rift valley lakes*.

Crustal warping: These lakes are formed when water occupies basins formed due subsidence of the earth's crust as a result of tectonic movements (Figure 6.38). Examples of lakes formed in this way are Lake Victoria in East Africa and Lake Chad in Chad. Other examples of lake caused by crustal warping are the Caspian Sea in Russia, Lake Eyre in Australia and Lake Titicaca in Peru. The Caspian Sea is located in a depression between the Caucasus Mountain and Central Asia and its surface is still varying, millions of years after its emergence. This is an indication of persistent earth's movement.

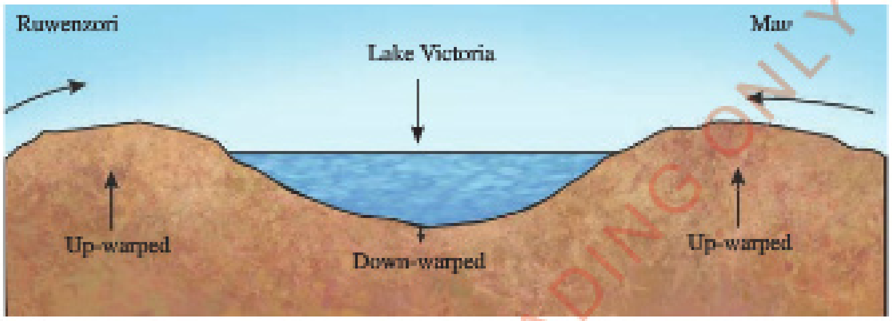


Figure 6.38: *Lakes formed through subsidence of the earth's crust*

Rift valley lakes: A rift valley lake is formed when water occupies a deep steep sided and elongated depression formed due to the divergence of crusted blocks which cause the central part to down-warp (Figure 6.39). The lake occupies a basin on the floor of a rift valley. Rift valley lakes are characteristically long and rectangular in shape, with a fairly uniform width of about 30 to 50 kilometres. They are usually bordered on both sides but sometimes just on one side by fault escarpments and highlands. Some of the examples of rift valley lakes are Albert, Edward, Tanganyika, Nyasa, Turkana, and Rukwa which are found in the Great East Africa Rift Valley (in Africa from north to south).

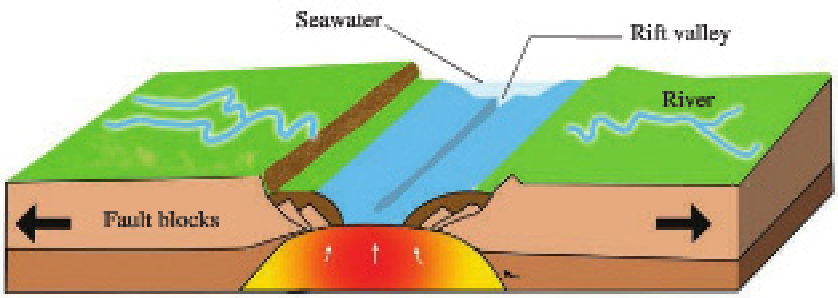


Figure 6.39: *Lakes formed through the divergence of the crusted blocks*

Lakes formed due to volcanicity

These are lakes formed due to volcanic activity. They include crater, caldera, and lava-dammed lakes. They are volcanic lakes; the most common form being those filling the caldera of a shut-off volcano. These include *crater, caldera* and *Lava-dammed lakes.*

Crater and Caldera lakes: These lakes form as a result of violent volcanic eruptions whereby, the top of a volcano is blown-off, leaving a large crater which may be filled with water later on to form a crater lake. Also a crater may be enlarged by subsidence to form a caldera which may be later on filled with water to form a caldera lake (Figure 6.40). Examples of crater lakes are Lake Oregon in USA, Lake Toba in northern Sumatra (Indonesia), Lake Magadi and Empakaai (Ngorongoro Conservation Area, Tanzania), Lake Chala (Tanzania/Kenya), and Lake Ngozi (Mbeya, Tanzania). Examples of caldera lakes are Lake Shela in Ethiopia and Lake Bosumtwi in Ghana. Crater lakes are usually not very large, being confined to the crater of the volcano. They are circular in shape and up to about 500 metres across. Although crater lakes may be formed during volcanic eruptions, most of them do not last long because of erosion on the steep shapes of the mountain cuts through the crater and drains the lake. Caldera lakes are usually much larger because they fill the depression originally occupied by the mass of volcano.

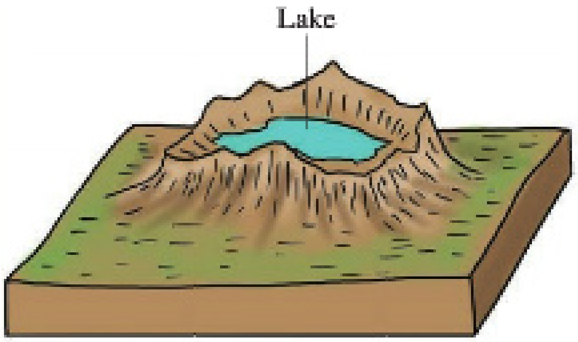


Figure 6.40: *Caldera lake*

Lava-dammed lakes: These are lakes that form when lava flows from volcano towards a river or a stream valley. After the cooling and solidification, the lava blocks the river from flowing longitudinally, and water collects in the upper stream to form a dam called lava-dammed lake (Figure 6.41). Examples of lava dammed lakes are Lake Belera in Rwanda, Lake Tana in Ethiopia, Lake Kivu and Lake Edward in Uganda, and the Sea of Galilee.

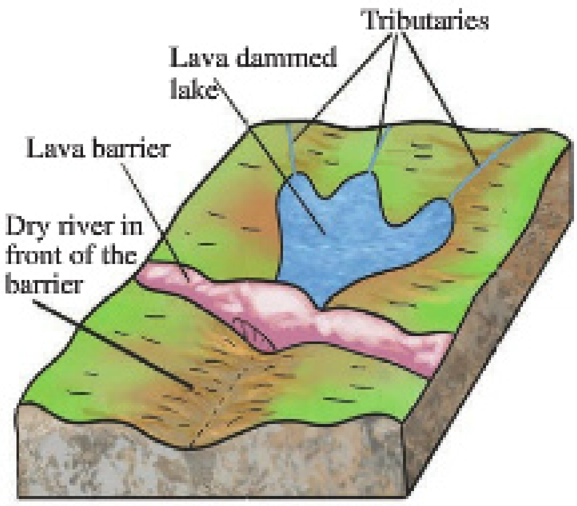


Figure 6.41: *Lava-dammed lake*

Lakes formed due to wind erosion

These lakes are common in desert areas. When dry desert wind blows across the surface, it easily picks up loose particles of dust and sand. Gradually, the surface is deflated (blown away) until the water table is reached in some places. Wind deflation produces depressions which are formed by the action of eddy currents. The lakes formed in these depressions are not always true lakes; they may be nothing more than muddy swamps. Good examples of these lakes are Qattara and Siwa depressions in Egypt. More permanent desert lakes develop when an aquifer is exposed. These lakes are called *oases*. Some desert lakes dry up due to excessive evaporation and what remains is a lake bed of salt. This is called playa or Salt Lake.

Lakes formed due to deposition

These lakes are formed due to deposition by rivers, and sea or oceans and are known as barrier lakes.

Lakes formed due to river deposition

Ox-bow lakes: An ox-bow lake is formed in a flood plain when a meander of a river is so acute that only a narrow neck of land separates the two ends of the meander. The narrow neck is cut-off when the river floods. The cut ends of the meander are sealed by deposition and the meander becomes an ox-bow. Several ox-bow lakes are found along the River Galma in Nigeria. Ox-bow lakes may disappear when vegetation and sediments fill them.

Delta lakes: These lakes are formed at a delta by the movement of silt and sand, building up barriers behind from which water is trapped (Figure 6.42). Delta lakes are found in the Nile Delta in Egypt and Rhône Delta, where Etang de Vaccares Delta lake is found.

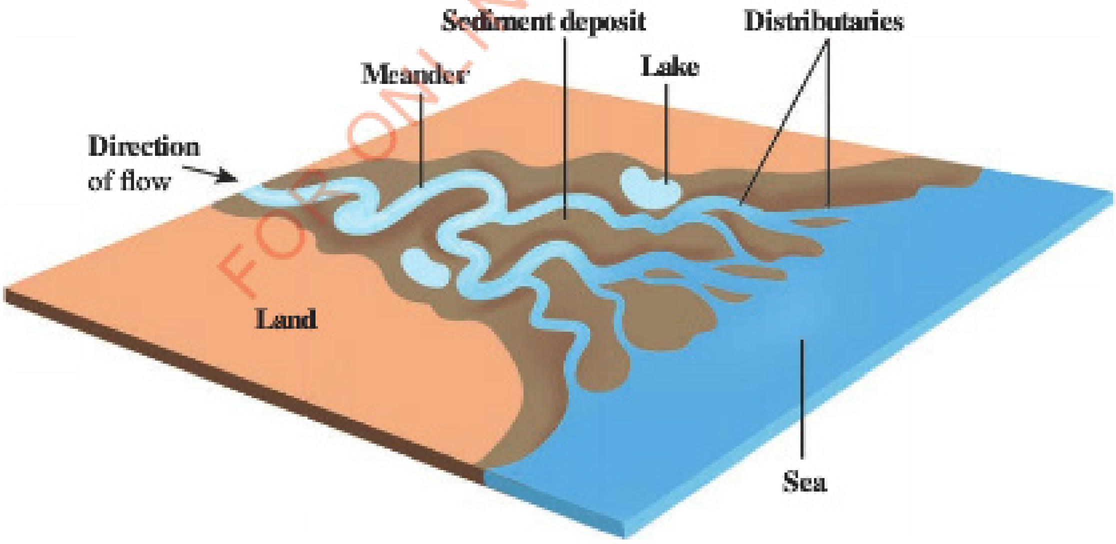


Figure 6.42: *A delta lake*

Flood plain lakes: These lakes are formed in the flood plains when natural levée formed off the river banks prevent water from returning to the river during flood. A good example is Lake Matohi on the Congo basin.

Lakes dammed by landslides and other waste debris

These are small lakes formed when mass movement materials block a river valley. These lakes, however, are only temporary. A good example is Lake Agulu in Nigeria, which was formed by the deposition of materials brought down from the gullies of the Awka Highlands.

Man-made Lakes: These are artificial lakes which are often called reservoirs. They are deliberately formed through construction of dams across a narrow, steep-sided section of a river valley. These lakes are made for the purpose of storing water for irrigation or for production of hydroelectric power or both. Some man-made lakes are formed due to excavation of a piece of land for the purpose of trapping water for local inhabitants' usage. Examples of man-made lakes are; Akosombo Dam on the Volta River in Ghana, Lake Nasser on the River Nile, Lake Kariba on the River Zambezi, and the Mtera and Nyumba ya Mungu dams in Tanzania.

Wetlands

Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, blackish or salt including areas of marine water with the depth of not more than six metres when at low tides. Wetlands are land areas that are completely, partly or temporary inundated. These include flood plains, swamps and marshes, peatlands, lakes, mangrove forests, and river deltas. Wetlands exist in every country and in every climatic zone, from the Polar regions to the tropics. Wetlands are distributed around the world and cover an area of about 13.079 million km^2. Africa has about 131 million hectares (equivalent to 1.31 million km^2) of wetlands varying in types, from saline coastal lagoon in West Africa to fresh and brackish water in East Africa (Figure 6.43). Examples of wetlands include the Okavango Delta in Upper Nile, Lake Victoria basin, Chad basin, Niger and Zambezi, and the mangrove forests of East Africa stretching from Kisimayu in Somalia to Maputo in Mozambique. In Tanzania, wetlands include the Rufiji Delta, the Kilombero Valley, Lake Natron, and Malagarasi- Moyowosi.

Figure 6.43: *Wetland*

Characteristics of wetlands

Wetlands are distinguished from landforms or water bodies due to their unique characteristics. A wetland is a land area that is saturated with water either permanently or seasonally such that it takes on the characteristics of a distinct ecosystem. Wetlands contain vegetation of aquatic plants adapted to a unique hydric-soil (water – soil with specific features). Unlike other water bodies or landforms, wetlands play a number of roles in the environment, through water purification, flood control, carbon sinking, and shoreline stability. Wetlands are considered as the most biologically diverse of all ecosystems, serving as home to a wide range of plants and animals. Water found in wetlands can be fresh water, brackish water or salt water. Thus, wetlands have unique water levels and types of plants that live within them. Wetlands have a water table that stands at or near the land surface for a long period each year to support aquatic plants; and also, wetlands provide a transition between dry land and water bodies. This transition is referred to as an *ecotone*.

Classification of wetlands

Wetlands are unique ecosystems that arise when inundation by water produces soils dominated by anaerobic processes which in turn force the biota, particularly root plants to adapt to flooding. Due to their complex and unique ecosystem, wetlands can be classified according to their location and soil types as follows:

Classification based on location

Based on location, wetlands are categorized as coastal and inland wetlands.

Coastal wetlands (tidal wetland) are found along the oceans and closely linked to estuaries and oceans where sea water and freshwater mix. They are dominated by grass, bushes and tidal salt marshes. Tidal marshes can be found along protected coastlines in middle and high latitudes worldwide. Some are freshwater marshes, delta, and mangrove swamps while others are salty, but they are all influenced by the motion of ocean tides. Tidal marshes are normally categorized into two distinct zones: the lower or intertidal marsh, and the upper or high marsh. Examples of coastal wetlands are mangrove wetlands along the East African coast stretching from Kisimayu in Somalia to Maputo in Mozambique.

Inland wetlands (non-tidal wetland) are frequently found along streams in poorly drained depressions and in the shallow water along the boundaries of lakes, ponds and rivers. Non-tidal marshes are the most prevalent and widely distributed wetlands. Water levels in these wetlands generally vary from a few inches to two or three feet, and some marshes, like prairie pot holes, may periodically dry out completely. Inland wetlands include marshes and wet meadows dominated by herbaceous plants and swamps dominated by shrubs and trees. Highly organic, mineral rich soils of sand, silt, and clay underlie these wetlands. Reeds and bulrushes provide excellent habitat for water fowls and other small mammals, such as red-winged blackbirds, great blue herons, otters and muskrats. Examples of inland wetlands include the Ihefu plains, the Malagarasi-Moyowosi, Kilombero, and Ruvu wetlands, Liwale swamp, Usangu flats, and Bahi swamp.

Classification according to soil types

In this category wetlands are categorized into marshes, swamps, bogs and fens.

Marshes are areas with shallow fresh water or salt water that are mostly grasslands and characterised by soil with low mineral content. The amount of water in a marsh can change with seasons, and in the case of salt marshes, they can also change with tides. Freshwater marshes have soft stemmed and herbaceous plants like grass, shrubs and wild flowers, and tend to occur at the edge of lakes and rivers (Figure 6.44). Salt water marshes include reeds, grass and different types of shrubs such as rushes, sedges and saltbush. They also tend to occur on coastlines inlets and estuaries where they are affected by tides and fresh water. Marshes are home to a variety of animals, including beavers, alligators, newts, shrimp and turtles.

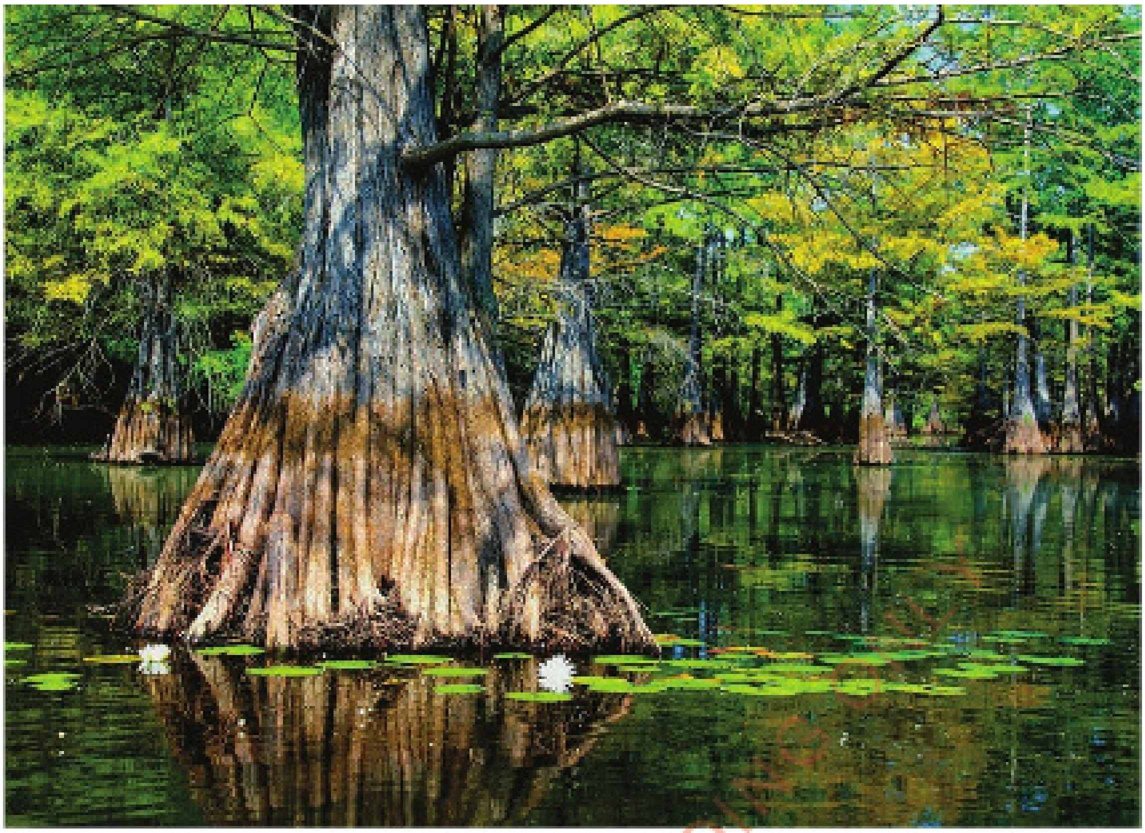


Figure 6.44: *Marshes*

Swamps are wetland ecosystems characterized by mineral soils with poor drainage. Swamps are found throughout the world, most often in low lying regions with poor drainage next to rivers. The nearby rivers supply water to these swamps. Some swamps develop from marshes that slowly fill in, allowing trees and woody shrubs to grow. The major difference between swamps and marshes however, is based on the type of vegetation dominating in each of them. While marshes are dominated by grasses, swamps are dominated by trees. Swamps are characterized by saturated soils during the growing season and standing water during certain times of the year. The highly organic soils of swamps form a thick black, nutrient rich environment for growing of water tolerant trees such as cypress, and shrubs like button bush. Also swamps provide habitat for specific plants, birds, fish and vertebrates such as fresh water shrimps, crayfish and clams. Both marshes and swamps may be fresh water or saltwater. Based on the types of vegetation available, swamps may be divided into two classes which are shrubs swamps and forested (woodland) swamps (Figure 6.45).

Figure 6.45: *Swamps*

Bog is a type of wetland ecosystem characterized by wet, spongy, poorly drained peaty soil, dominated by the growth of bog, mosses, sphagnum and heaths, particularly Chamaedaphne calyculata. Bogs are usually acidic areas, frequently surrounding a body of open water. Bogs receive water exclusively from rainfall. Few animals found in bogs include red deer, dragon-flies and birds such as grouse and plovers. *Fen* is a type of wetland ecosystem characterized by peaty soil, dominated by grass like plants, grass, sedges and reeds. Fens are usually alkaline areas, receiving water mostly from surface and groundwater sources (Figure 6.46).

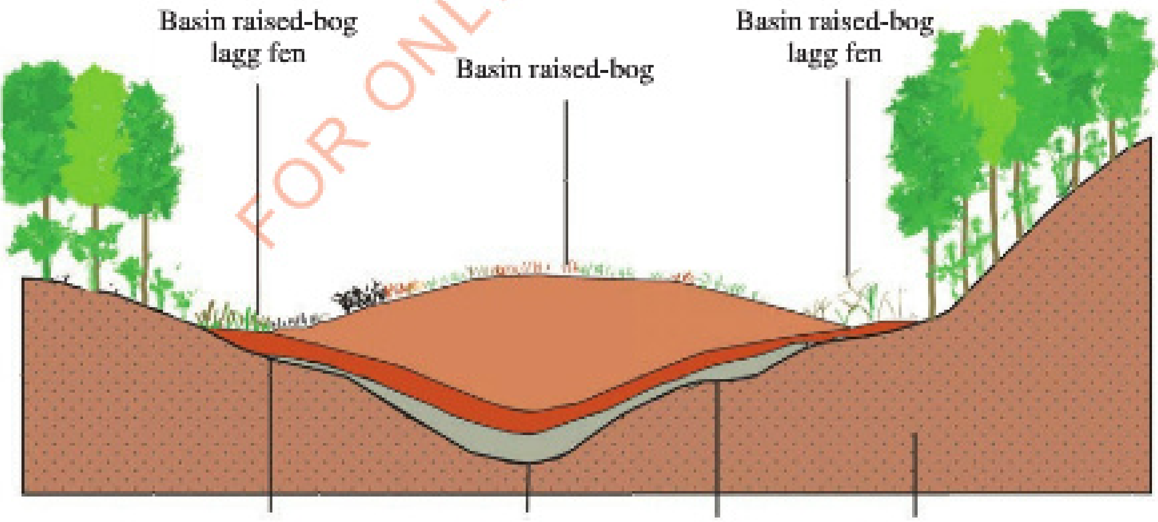


Figure 6.46 *Fens and bogs*

Oceans and seas

An ocean is a large body-mass of saline water that covers the most part of the earth's surface. A sea is also a large body-mass of water which is smaller than an ocean but larger than a lake covering a part of the earth's surface. Seas are partly enclosed by land masses. Oceans and seas together cover almost 97% of the earth's water while fresh water (including lakes, glaciers, ice, groundwater and rivers) covers 3%. The special importance of these large masses of water is that they influence climate, and weather elements such as temperature, rainfall, humidity and wind. Oceans of the world include the Pacific, the Atlantic, the Indian, the Arctic and the Southern oceans as shown in Table 6.3 and Figure 6.57. Seas include the Mediterranean Sea, the Caribbean Sea, the South China Sea, the East China Sea, the Gulf of Mexico, the Baring Sea, the Red Sea and the Baltic Sea.

Table 6.3: *Ocean location, area, volume and average depth*

Ocean Location	Area (Km²)	Volume (km³)	Averages Depth (m)
Pacific	168,723,000	669,880,000	135,663
Atlantic	85,133,000	310,410,900	11,866
Indian	70,560,000	264,000,000	66,526
Southern Ocean	21,960,000	71,800,000	3,270
Arctic Ocean	15,558,000	18,750,000	1,205

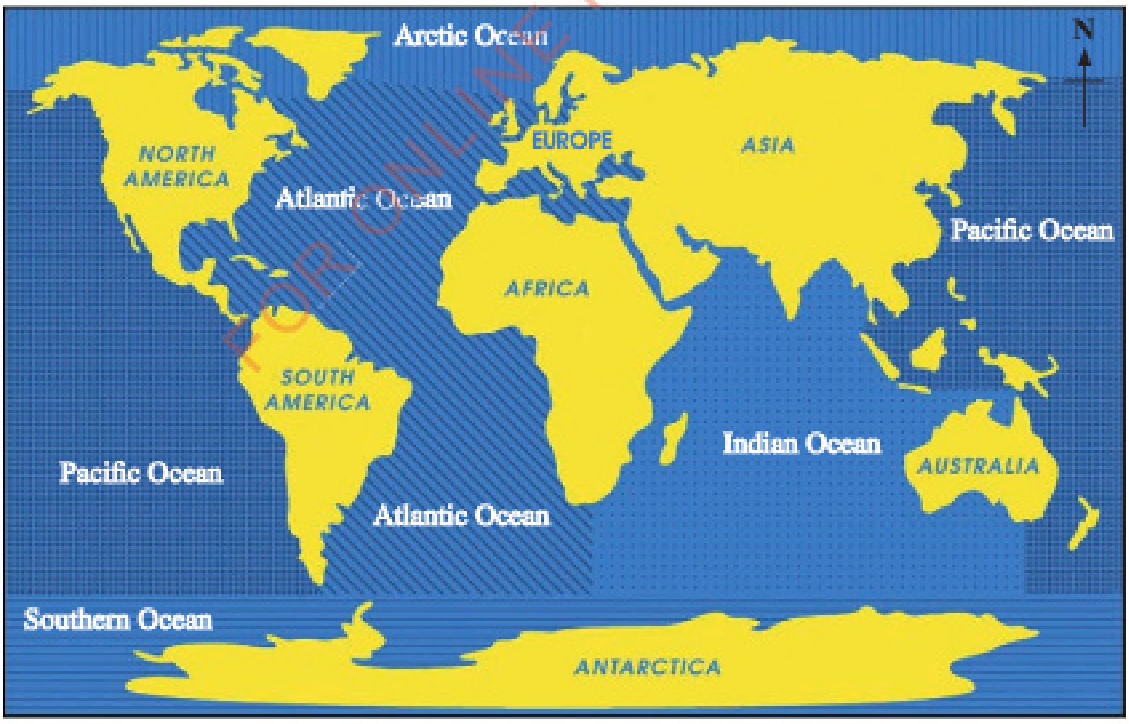
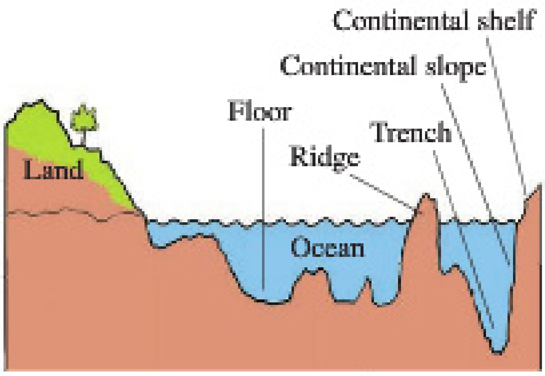


Figure 6.57: *Map of the major world oceans*

Physical features of the ocean floor

The floor of the ocean has complex structures caused by horizontal and vertical tectonic motions, break in the earth's crust, volcanic activities, sedimentation, and other factors. The diversity of underwater relief forms is classified in the following main categories including large areas of the ocean, continental margins, transition zones, ocean floor and mid ocean ridges.

Continental margins are areas where a transition from continent to ocean occurs. They include continental shelf, slope, and foot. The continental shelf originated, when flat coastal areas became inundated due to an increase in sea level over several million years ago. The width of the shelf varies from tens to hundreds kilometers and its depth can vary from 80 to 500 metres. The continental slope adjoins the shelf framing the continental borderland. The slope varies from 1 to more than 30 metres. The bottom of the slope reaches the depth of 3 000 to 3 500 metres where it changes to a very low grade of flatness at the continental foot. The continental foot is characterized by existence of great thickness of sediment accumulations. The transition zone is characterized by a change from continental crust to oceanic crusts. Island arcs, deep water troughs (trenches) and fringing basins are formed in the transition zone. The bottoms of the basins are frequently flat, caused by the expanse of great thickness of the sediments. However, they contain rises, ridges and seamounts. The island arcs separate fringing basins from the ocean, and are formed where oceanic plates collide (Figure 6.58).



i e Common Physical Features of the Ocean Floor

Chemical composition of the ocean an sea ater

Ocean and sea water contains a number of mineral substances (mineral salts) in a solution form. The important minerals are sodium chloride, calcium carbonate, magnesium and potassium. Generally, oceans contain traces of every mineral, whether in solution or held in suspension as solids. Mineral salts are brought into the seas and oceans through rivers and volcanic activities taking place on the seafloor. Although freshwater is continuously supplied in seas and oceans yet its effect is insignificant in diluting the salts concentration due to a simultaneous evaporation process in those large water bodies which make them concentrated ever since they were formed. Moreover, the free movement of water in the oceans result in the proportion of salts remaining in the oceans, but the amount of salts in a given volume of the water varies from one part of the ocean or sea to another. The concentration of mineral salts or salinity is measured or expressed as the number of grains of salts in every 1 000 kilograms of water and its average is 35 kilograms . This means that in every 1 000 kilograms of water there will be 35 kilograms of minerals salts.

Salinity of an ocean and sea

Salinity refers to the concentration of salts in the water or soil. Ocean salinity is the concentration of salts in the ocean or sea water. Salinity is classified as primary salinity, secondary salinity and tertiary salinity. The following are the basic factors affecting salinity of an ocean and sea:

Temperature: High temperature results in high evaporation rate, which in turn increases the concentration of salt. Therefore, seas enclosed in tropical and sub-tropical areas experience higher concentrations of salts. On the other hand, in the oceans and seas located in Polar regions, the concentration of mineral salts is below average because there is low temperature, low evaporation rate, and the snow and ice supply large quantities of fresh water during spring and summer in those regions.

Amount of fresh water from the rivers: High salinity occurs in inland seas such as the Dead Sea in Jordan, the Great Salt Lake in North America and the Aral Sea in the former USSR. This is due to the fact that evaporation is relatively high in these seas and very little fresh water is brought into them by rivers. Likewise, salinity in the Mediterranean and Red seas is high. Contrary to that, the Baltic Sea has relatively low salinity because several large rivers discharge their waters into it. In the equatorial region, ocean and sea water tend to have high salinity because of high evaporation rate.

Ocean current: An ocean current is the movement of ocean water either horizontally or vertically. There is a constant flow of surface water of the ocean due to prevailing winds, rotation of the Earth and differences in temperature intensity. There are two types of ocean currents, namely cold ocean currents, and warm ocean currents. Cold ocean currents are large masses of cold water that move towards the equator. They absorb the near heat they receive in the tropics, thereby cooling the air above them. While, warm ocean currents are large masses of water moving away from the equator with high temperature. They form when salty cold water becomes heavy and sinks in the process forcing warm and lighter water to move in the opposite direction. Ocean currents flow for long distances that create the global conveyor belt which plays a dominant role in determining the climate of many of the earth's regions. More specifically, ocean currents influence the temperature of the regions through which they travel. For example, warm currents traveling along more temperate coasts increase the temperature of the area by warming the sea breezes that blow over them.

Water movements in the oceans

There are two types of water movements in the ocean namely horizontal and vertical movements. Horizontal movement of water gives rise to ocean currents while vertical movement results in the rising of bottom water and sinking of surface water. These movements result from the combined action of water density and winds.

Wind is the principal cause of ocean currents. On the other hand earth s rotation and the shape of land masses influence the *direction of the ocean currents. Examples of horizontal movements include: the* westward flow of the equatorial currents which is influenced by the trade winds *and the slow eastward movement of* ocean current which is influenced by *westerly wind known as the west-wind drift. The west-wind drift covers belts between 35° and 45° in the Northern hemisphere and between 30° and 60° in the Southern hemisphere and approaches the western sides of the continents. It is* deflected towards the Equator along the coast. The ocean current flows towards *the equator are cool currents. They are often accompanied by upwelling along continental margins. In this process, cooler water from greater depths rises to the surface, making vertical movement of ocean current. Examples of cool currents with upwelling are the Humboldt (Peru) current, the Chile current, the Benguela current and the California current. On the Arctic and Antarctic regions in the North-eastern Atlantic Ocean, West- wind drift forms a relatively warm current to the Norwegian coast and British Isles. This makes the Russia port of Murmansk on the Arctic Circle free from ice throughout the year. While in the northern hemisphere, where the polar sea is largely landlocked, cold* currents flow towards the Equator along *the east side of the continents. Examples are the Kamchatka current along the Asian Coast, and the Labrador Current,* which flows between Labrador and the *Greenland Coast.*

The vertical movement is caused by density variations of water in the seas and oceans which is governed by temperature and salinity. When the temperature of water decreases, its density increases. For example, polar surface waters are cold and their density is high, whereas equatorial surface waters are warm and their density is low. If a body of cold water meets a body of warm water, the cold water sinks below the warm water. Therefore, polar waters sink and move towards the equator, while equatorial waters move as surface currents towards the poles.

When the salinity of water rises, the density rises as well. Likewise, if the salinity falls, the density falls. Therefore, when a body of water with high salinity meets another one with low salinity, the more saline water sinks below the less saline water. A good example of this is the Amazon river whose fresh water pushes into the Atlantic as a surface current for about 500 kilometres because its salinity is much lower than that of the Atlantic.

Ocean water circulation

The interaction between the ocean and the atmosphere plays a major role in controlling the climate and weather at the surface. There are four primary factors that control ocean circulation.

Water salinity: Chemical weathering of rocks on land produces dissolved materials that enter the oceans, some of these dissolved chemicals undergo reactions within the ocean. For example, sea creatures extract dissolved calcium from the water to build their shells and when they die this calcium drifts onto the ocean floor.

Water temperature: The surface of the ocean absorbs the solar energy and gains heat. More heat is gained than lost in the low latitude and more is lost than gained in the high latitude. This leads to polar ward movement of warm surface water. This transport of heat from the Equator towards higher latitudes provides good regulation of the earth's climate system, otherwise the poles would be even colder and the tropics would be even hotter than they are at present.

Surface wind: The surface currents of the ocean are driven by the surface winds. For example the trade winds drive the northern and southern equatorial currents moving in westerly direction parallel to the Equator.

Coriolis effect: The surface currents are deflected by the continents and the Coriolis effect to the right in the northern hemisphere and to the left in the southern hemisphere. This creates warm currents along the eastern coasts of Americas, Australia, Asia and Africa. In the north Atlantic this warm current is called the Gulf Stream which brings warm conditions to North - West Europe.

Influence of climate change on the hydrological cycle

The climate change has influenced hydrological cycle in many forms, which include effects in precipitation, evapotranspiration, infiltration, runoff, and surface and groundwater flow.

In terms of precipitation, the effects of climate change are linked to modifications in the quantity and patterns of rainfall mainly due to an increase in temperatures beyond normal among other factors. This has caused variations in the amount of rainfall on the ground, disrupting the process of recharging greatly compromising the distribution, quantity, quality, and functioning of groundwater.

The effect of rising temperatures on evapotranspiration is linked to higher transpiration and evaporation, which results in higher-than-average moisture levels in the atmosphere.

However, because several elements besides moisture availability drive the condensation to precipitation process, the increase in condensation in the atmosphere is not directly correlated with that moisture.

Furthermore, because of an increase in the runoff that is incompatible with the infiltration rate, the effects of climate change have led to an increase in hydrological hazards. These risks primarily consist of flooding and stream flows on one hand, and severe weather, storms, and a protracted drought on the other.

Surface water is suffering greatly from the effects of climate change. The most notable effect of rising temperatures is an increase in evapotranspiration, which causes wetlands to disappear and rivers and ponds to lose a large amount of water converting some of them into seasonal forms. Meanwhile, increased salinity in some of the seas has been a result of increased evapotranspiration brought on by climate change, which has also been connected to increased saline intrusion into the adjacent groundwater. Also, the increased melting of ice in some parts of the world and abnormal heavy rainfall have been connected to the rise of sea levels.

Revision exercise

Answer the following questions;

1. Increasing recognition of the value and importance of wetland has influenced creation of laws, regulations, and plans to restore and protect wetlands around the world. In the context of services they provide, why are wetlands increasingly becoming important conservation target?
2. Tanzania is endowed with many lakes which vary in size and modes of formation. Discuss.
3. Discuss the view that movement and occurrence of groundwater is affected by rock porosity.
4. The hydrological cycle has neither a beginning nor an end. Substantiate.
5. Climate is the single and most important factor affecting the volume of water in the river. Discuss.
6. Drainage systems are a function of geological structure. Justify.
7. Using a long profile of a river, show how the river changes its course.
8. Discus the chemical composition of ten big lakes in the world and suggest dominant economic activities that can take place in each of the lakes.
9. Describe the classification of lakes according to their modes of formation.
10. Describe the classification of wetlands based on their location and soil types.

11. Show how the interaction between the ocean and the atmosphere plays a fundamental role in controlling the ocean water circulation.
12. Surface water and ground water are reservoirs that feed into each other. Discuss.
13. Using examples of socio-economic activities in your area, explain how they contribute to surface water pollution.
14. Suggest possible ways of minimising ground and surface water pollution.
15. Based on your experience in your area, explain how climate change has influenced the hydrological cycle.

Conduct a project in Geography:

Select an issue related to Physical geography, then design and conduct a project.

Glossary

Aquifer	A permeable rock which stores and transfers water
Atoll	A ring-shaped coral reef
Barysphere	The inner most part of the earth
Bedding plane	The boundary between adjacent layers or strata in a sedimentary rock
Biosphere	The whole of the region of the earth's surface, the sea, and the air that is inhabited by living organisms
Cliff	A tall, vertical, or near vertical, rock face
Climate	Aggregate weather conditions of an area over a long period of time which allow for the designation of seasonal patterns and expected future weather
Climate change	Long term variations in climate, particularly related to average annual temperatures and annual rainfall
Clint	Flat-topped block that forms the 'paving stone' in a limestone pavement
Deforestation	Removal of forest covers due to cutting or burning, or a combination of the two
Denudation	Stripping of surface cover. Can apply to both vegetation and soils
Deposition	A process by which sediments, soil and rocks are added to landform or landmass
Escarpment	An elongated, steep slope at the edge of an upland area such as a plateau or cuesta
Geology	The science that deals with the earth's physical structure and substance, its history, and the processes that act on it
Humus	Layer of the soil profile that is composed of decomposed organic matter normally from dead and decaying plants and animals and is usually dark coloured
Lithosphere	A rock layer forming the outermost part of the earth
Loam	A soil having roughly equal proportions of clay, sand and silt

Oasis	A wet-point site in an arid area
Organic matter	Decomposed animal or plant material that is added to the soil and becomes a part of soil profile. After fully decomposition becomes integral part of the soil characterised by dark and moist substance called humus which is rich in nutrients
Pervious rocks	Rocks that allow water to flow along cracks or joints
Ridge	A long, narrow crest of a hill or mountain
Scarp	The steep slope of an escarpment
Scarp slope	A slope in the land that cuts across the underlying strata, especially the steeper slope of a cuesta
Suspension	The transport of load in the body of water in a river i.e., being carried along in the flow
Vent	A pipe-like gap in the ground which allows volcanic material to pass through to the surface
Ventifacts	A stone or pebble which has been shaped by wind-blown sand, usually in the desert, so that its surface consists of flat facets with sharp edges

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