Physical Geography

for Advanced Secondary Schools

Student's Book

Form Five and Six



Tanzania Institute of Education

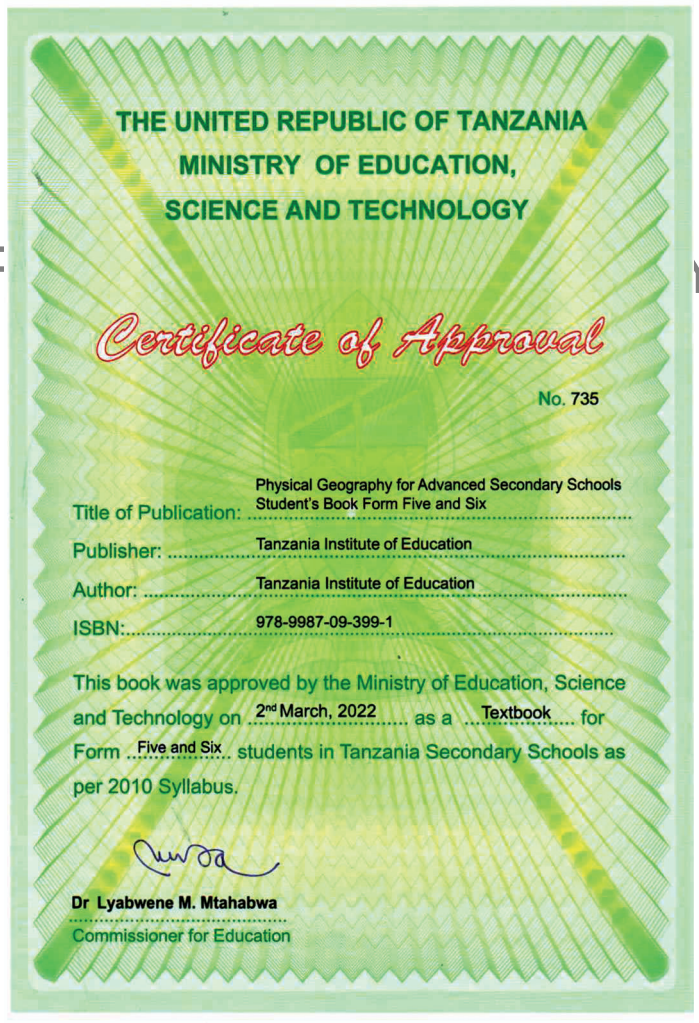
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Physical Geography

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THE UNITED REPUBLIC OF TANZANIA
MINISTRY OF EDUCATION,
SCIENCE AND TECHNOLOGY

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Dr Lyabwene M. Mtahabwa
Commissioner for Education

Tanzania Institute of Education

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Preface

This textbook, *Physical Geography for Secondary Schools* is written specifically for Form Five and Six students in the United Republic of Tanzania. It is prepared in accordance with the 2010 Geography Syllabus for Advanced Level Secondary Education, Form V-VI issued by then the Ministry of Education and Vocational Training.

The textbook consists of six chapters, namely Evolution, composition and structure of the Earth, Endogenic processes of the Earth, Exogenic processes of the Earth, Water masses, Soils, and Atmospheric dynamics. Each chapter contains reading texts, illustrations, activities and exercises. You are encouraged to read all texts, and attempt all the activities and exercises together with other assignments provided by the subject teacher. Doing so, will promote the development of the intended learning competencies.

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Chapter One

Evolution, composition and structure of the Earth

Introduction

The origin and evolution of the Earth along its entire solar system has been researched and debated for hundreds of years. Scientists, astronomers, astronauts, philosophers and religious scholars have propounded different theories and arguments on how galaxies, solar system and the planet Earth evolved and changed overtime. In this chapter, you will learn about the origin of the universe and the position of the Earth in the solar system. Also, you will learn about the Earth as a system, the shape of the Earth as well as layers that form the planet Earth. The competencies developed from this chapter will enable you to critique the assumptions about the origin of the universe, position of the solar system and the planet Earth in particular. Furthermore, you will be able to use the available resources on Earth sustainably.

Origin of the universe

The origin of the universe is largely explained by various theories. These theories have examined processes through which the universe, galaxies, stars and planets were formed and the changes that are still taking place over time. A number of theories have been developed to postulate the origin of the universe from which the planet Earth is believed to be one of its bodies. The theories include the Big Bang theory, Nebula hypothesis, James Jeans' tidal hypothesis, Inter stellar dust hypothesis, and the Creation theory. However, various critiques have been emerged against these theories, though they are still important in understanding the evolution of the universe and the planet Earth in particular.

The Big bang theory

This theory was postulated by Lemaitre Georges and Edwin Hubble in 1920s. The Big bang theory explains that about 15 billion years ago a tremendous explosion occurred which started the expansion of the universe. This explosion is known as the *big bang*. At the point of this event all matter and energy of space were contained at one point. The explosion pushed matter and energy exploding in all directions. As the universe expanded, matter collected

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into clouds that began to condense and rotate, forming the forerunners of galaxies. Within galaxies, including our own *Milky Way galaxy*, changes in pressure caused gas and dust to form distinct clouds. In some of these clouds, where there was sufficient mass and the right forces, gravitational attraction caused the cloud to collapse. Where the mass of material in the cloud was sufficiently compressed, nuclear reactions began and a star was born. Some proportion of stars, including the Sun, formed in the middle of a flattened spinning disk of materials (Figure 1.1). In case of the Sun, gas and dust within this disk collided and aggregated into small grains, eventually formed larger bodies called planetesimals (very small planets). Some of these planetesimals or protoplanets reached diameters of several hundred kilometers. In successive stages these planetesimals coalesced into the current eight planets and their numerous satellites.

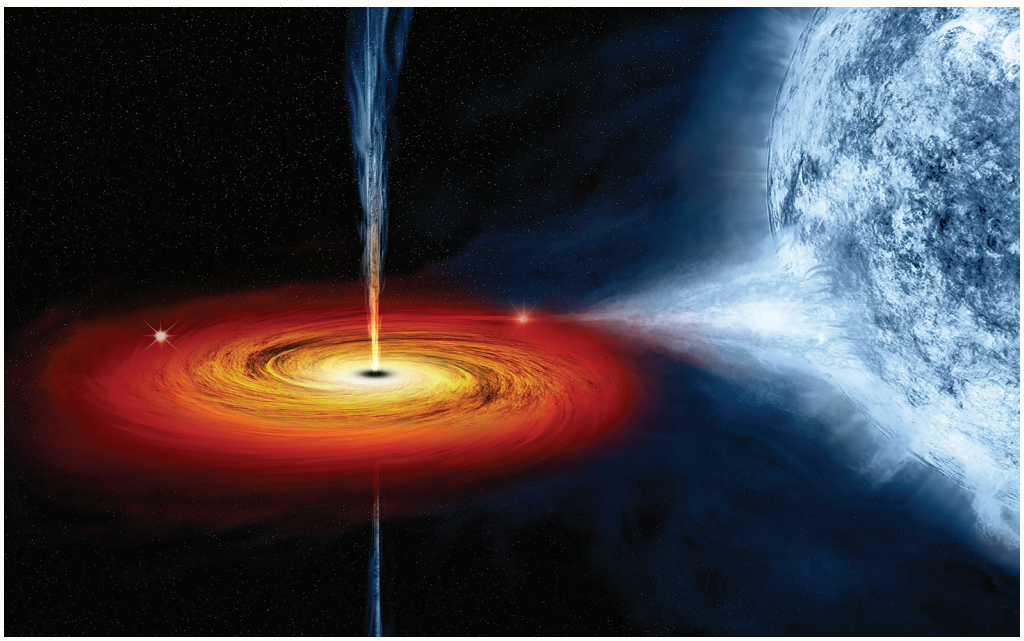


Figure 1.1: *The big bang*

Critiques of the Big bang theory

While the theory provides some insights on how the universe evolved about 13-20 billion years ago, there are arguments put against the theory. Firstly, the theory propounds that the universe emerged from the enormous atomic nuclear, it remained silent on how, and through which mechanisms and processes the atomic nuclear was composed, evolved and developed prior to its accumulation and explosion. Secondly, based on the theory, it appears that all galaxies emerged

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at the same time and therefore could properly have at least the same age, but this has not been the case. In fact, the current astronomic researchers found that while other galaxies are too old, there are many young galaxies around and far from the Earth.

Nebular hypothesis

Nebular hypothesis it is also known as Kant's gaseous hypothesis was proposed by Immanuel Kant and published in his Universal Natural History and Theory of the Heavens in 1755 and modified by Pierre Laplace in 1796. Kant's nebular hypothesis states that the solar system was formed from a cold spinning cloud of gases called the *solar nebular* that resulted from uneven distribution of gases throughout the universe in the Milky Way Galaxy. As the gravitational pull began to condense the gas towards the center, the speed of the rotation increased. This caused the cloud to flatten, and create an accretion disk. Matter continued to collect as the force of gravity toward the center increased. Eventually, the gas warmed from increasing pressure. As the mass further increased, also the gravity increased and the temperature continued to rise. A ball of hot gas formed in the center of accretion disk creating a protostar also known as the Sun.

Finally, when enough gas gathered in the center of the protostar the pressure generated enough heat to fuse the atoms to form a star. Outside the star matter was forming into clumps of gas, dust and rocks which created protoplanets. These protoplanets continued to grow as they trapped materials in their gravitational fields. As the protoplanets were formed from the same cloud of gas and dust, they travelled around the sun in the same direction and the same plane. Also, the Nebular hypothesis explains how the planets are arranged. The heat and wind caused by the Sun swept the lighter gases further out developing the solar system. That is why the rock terrestrial planets such as Mercury, Venus, Earth and Mars are located closer to the sun while the gas giants are formed in the cooler outer region of the solar system.

Critiques on Kant's Nebular hypothesis

Like many other theories, Kant's Nebular hypothesis was challenged by Laplace in 1796 in his book entitled 'Explosion of the World System'. Laplace showed three defects of Kant's nebular hypothesis as follows: (i) large amount of heat cannot be generated due to the collision of cold particles of primordial matter as claimed by Kant, (ii) mutual collision of particles cannot generate motion in the primordial matter and the random motion of the particles cannot generate circular motion in the primordial matter and, (iii) the angular velocity of rotary speed of the nebular cannot increase due to increase in size of the nebular as assumed by Kant.

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Laplace's nebular hypothesis

Pierre Laplace expanded on Kant's hypothesis. In 1796 Laplace hypothesized that there was a huge and hot gaseous nebula in space which was rotating on its axis. Through continuous circular motion of the nebular and the continuous cooling due to loss of heat from its outer surface through the process of radiation, the nebular turn into continuous reduction in its size because of cooling. Thus, reduction in size and volume of the nebula increased its circular velocity (rotary motion). As the size of the nebula continued to decrease, the velocity of rotatory motion continued to increase. Thus, the nebula started spinning at very fast speed and consequently the centrifugal force became so great that it exceeded the centripetal force. When this stage was reached the materials at the equator of the nebula became weightless. Consequently, the outer layer was condensed due to excessive cooling and contracting central nucleus of the nebula, thus the outer ring (layer) was separated from the remaining part of the nebula. This separated ring of material started moving around the nebular. Further, Laplace maintains that the original ring was divided into nine rings and each ring moved away from the other ring. All the materials of each ring condensed at a point or knot in the form of a 'hot mass of gases". Each mass of gases was later on cooled and condensed to form a planet. Thus, nine planets were formed from nine rings and the remaining central nucleus of the nebula became the sun.

Critiques of Laplace's nebular hypothesis

To a large extent Laplace's nebular hypothesis appears to share the common features of those found in Kant's gaseous theory. It is a modified version which tries to correct the weak points raised in Kant's theory. In doing so, the theory attained popularity and respect for decades. However, the Laplace's nebular theory was later challenged by the following arguments. (i) Where did the heat and motion in that nebula come from? (ii) What was the reason behind the formation of certain fixed number of planets from the irregular ring? (iii) Why did only 9 rings come out from the irregular ring detached from the nebula? (iv) Why there were not more or less than 9 rings? (v) The small degree of cohesion between the particles of the nebula would make the formation continuous, not an intermittent process? (vi) If Laplace's hypothesis is accepted that the planets were formed from the nebula, then the planets must have been in liquid state in their initial stage. But the planets in liquid state cannot rotate and revolve around the sun on rings.

James Jeans' tidal hypothesis

Sir James Jeans was a British scientist. He propounded his 'tidal hypothesis' to explain the origin of the earth in the year 1919. Jeans postulated that the solar system was formed from the sun and another intruding star. He furthermore postulated that due to massive

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gravitational force of the intruding star, a huge amount of matter was ejected from the primitive sun, which later on became the building material of future planets. It is argued that, in the beginning the sun was a big incandescent gaseous mass of matter and besides the sun, there was another star termed as 'intruding star' in the universe. This intruding star was much bigger in size than the primitive sun. The primitive sun was stationary and was rotating on its axis while the 'intruding star' was moving along such a path in such a way that it was destined to come nearer to the primitive sun. Jeans claims that there was a great impact of the tidal force of the intruding star on the surface of the primitive sun.

The tidal hypothesis was modified by Harold Jeffreys, a British scientist in 1929, by presenting his concept as *Collision Hypothesis*. According to Jeffreys there were three stars in the universe before the origin of our solar system. One was our primitive sun, the second one was its 'companion star' and the third was 'intruding star' which was moving towards 'companion star. Thus, the intruding star collided against the 'companion star'. Due to the collision, the companion star was completely smashed and shattered. Some shattered portions were scattered in the sky while remaining debris started revolving around the primitive sun. However, the impact of collision and explosion enabled the intruding star to clear itself off from the gravitational attraction of the primitive sun and gradually vanished in the universe. The planets of our solar system were formed from the remaining debris of the companion star.

Critiques of the tidal hypothesis

According to B. Levin the universe is infinite in space and time and the stars are so distant from each other such that a close encounter between them is a remote possibility. James Jeans did not explain the destiny of the intruding star. Also, the tidal hypothesis fails to explain the real distances between the sun and the planets in our present solar system.

Inter-Stellar dust hypothesis

The Inter-Stellar dust hypothesis was proposed by Otto Schmidt, a Russian scientist in 1943 to explain the complex problems of the origin and characteristics of the solar system and the Earth. According to the 'Inter Stellar dust hypothesis' the Sun during its 'galactic revolution' captured the dark matter of the universe. The dark matter of gaseous cloud and dust particles had their own angular momentum. The dark matter after being attracted by the sun during its 'galactic revolution' started revolving around the primitive rotating sun. Schmidt called these dark matters 'Inter-Stellar dusts'. The dust particles after being combined and condensed were changed into a flat disc which started revolving around the sun. It may be pointed out that the flat disc of captured dark matter started revolving around

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the sun under the combined impacts of three types of motions namely; (i) the rotational motion of the sun itself, (ii) gravitational force exerted by the sun on the disc of dark matter, and (iii) the angular momentum of dark matter of the disc.

The particles having larger amount of centrifugal force were thrown out towards the margins of the rotating disc of dark matter around the sun. The particles having small amount of centrifugal force were attracted towards the band of the disc nearer to the sun. The intense heat from the sun dispersed the gaseous particles towards the margins of the disc. Collision among the dust particles started the process of aggregation and accretion around the bigger particles which became the essentials of the future planets. With the passage of time these embryos captured more and more matter and thus grew in size to become asteroids. These asteroids further grew in size due to continuous acceleration of nearby matter around them and thus they became planets.

Critiques of the Inter-stellar dust hypothesis

The hypothesis has been criticized that gravitational force of the primitive sun was incapable of capturing dark matter scattered in the universe. According to some astrophysicists 'meteorites and asteroids were formed as a result of the disintegration of some planets and not the planets were formed out of meteorites and asteroids. Until now no trace of remnants of dark matter could be discovered either in the archaeological drilling on the earth's surface or on any planet.

Creation theory

Creation theory (theological theory) is the religious belief that the universe and life originated from God commands as written in the Holly Bible (Genesis 1:1-31). The scriptures explain that in the beginning, God commanded, 'let be light' and then it appeared. He separated the light and the darkness. The light was named as 'Day' and the darkness as 'Night'. He then commanded dome to divide the water to be in two separate places that is above and under it. The water below the sky were commanded to come together in one place, so that the land will appear and it was done. He named the land "Earth", and the water that comes together as "Sea". God commanded, "Let lights appear in the sky to separate day from night and it will be the signs of days, years and seasons of the year. God made the two larger lights, the sun to rule over the day and the moon to rule over the night; he also made the stars. The two lights were placed on the sky to shine on the Earth. God created the great sea. God created the great whales and all kinds of creatures that live in the water, and all kinds of birds. God commanded the Earth to produce all kinds of animal life that is domestic and

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wild, 'large and small" and it was done. He then created human beings who will have power over the fish, birds, and all animals, domestic and wild, 'large and small'. Also, the Holly Quran (Al-Anbya 21:30) postulates to the theory of creation as it is written, "Do the unbelievers not realize that the heaven and the Earth used to be one solid mass that was exploded into existence? And from water we made all living things. Would they believe?".

Critiques of the creational theory

As in the case of other theories, the creation theory is criticized by atheists and some scientists for being incompatible with scientific principles.

Formation of rocky and gaseous planets in the solar system

According to theories of the origin of the universe, it is believed that rocky planets including Mercury, Venus, Earth and Mars, were formed near the Sun, and the gaseous planets which include Jupiter, Saturn, Uranus and Neptune were formed in more distant orbits. The temperature of the early solar system explains why the inner planets are rocky and the outer ones are gaseous. As the gases coalesced to form a protosun, the temperature in the solar system rised. In the inner solar system temperatures were as high as 2000K, while in the outer solar system it was as cool as 50K. In the inner solar system, only substances with very high melting points would have remained solid. All the rest would have vaporized. So the inner solar system objects are made of iron, silicon, magnesium, sulfur, aluminum, calcium and nickel. Many of these were present in compounds with oxygen. There were relatively few elements of any other kind in a solid state to form the inner planets.

The inner planets are much smaller than the outer planets, and because of this they have relatively low gravity and were not able to attract large amounts of gas to their atmospheres. In the outer regions of the solar system where it was cooler, other elements like water and methane did not vaporize and were able to form the giant planets. These planets were more massive than the inner planets and were able to attract large amounts of hydrogen and helium. This explains why the solar system and the universe are mainly composed of hydrogen and helium.

The four rocky planets namely Mercury, Venus, Earth and Mars are also called terrestrial planets because they are made up of rocks and metals and have solid surfaces, and a core which is mainly made of iron. In many ways, all rocky planets are similar. They all have a solid rocky crust, some form of mantle, and a core. They are the closest four planets to the Sun. They are much smaller than the gas planets and rotate more slowly.

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Gas giants are planets that are made of gases. They include Jupiter, Saturn, Uranus and Neptune. Unlike rocky planets, gas giants do not have a well-defined surface as there is no clear boundary between the atmosphere and the surface. The gas giants have atmospheres that are mostly hydrogen and helium. They rotate relatively rapidly, for instance, while the Earth spins once on its axis every 24 hours, Saturn spins once every 10 hours. Gas giants may have a rocky or metallic core but the majority of their mass is in the form of gas. Jupiter and Saturn probably have liquid metallic hydrogen interiors (liquid hydrogen conducts electricity). Scientists believe Uranus and Neptune have interiors that contain a mixture (or layers) of rock, water, methane, and ammonia. All four gas giants have rings and moons. Figure 1.2 show the formation process of planets from the planetesimals formed in the solar nebular by collisional coagulation.

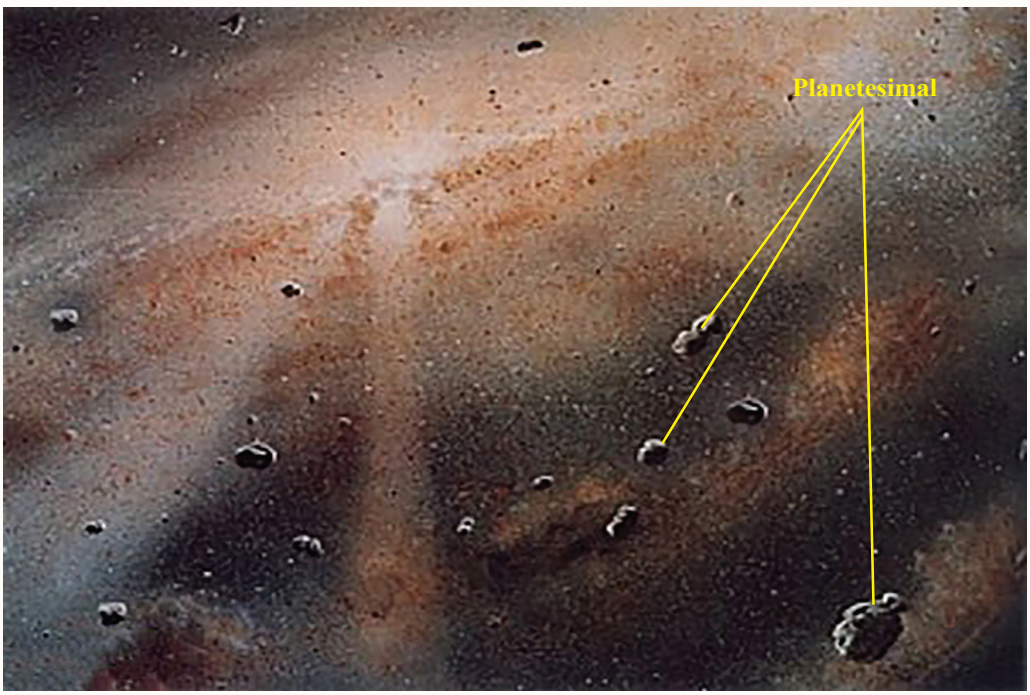


Figure 1.2: *Formation of planets in the solar system*

Position of the Earth in the solar system

The Earth is the third planet from the Sun and the fifth largest planet in the solar system in terms of size and mass. Its single most outstanding feature is that its near-surface environment are the only places in the entire universe known to harbour life. It is about 150 million kilometers from the sun. The earth orbits around the sun taking 365 days and 5 minutes and 46 seconds. Also, it rotates on

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its axis in a counterclockwise motion which takes 24 hours to complete its rotation. This rotation enables the Sun to seem like moving across the sky. The Earth is the only planet which is known so far to support life. The Earth supports life due to presence of water. Water is found in three states; liquid, solid and vapour, which is essential for living things. The Earth has an atmosphere which contains different gasses such as oxygen, essential for life, carbon dioxide which is essential for photosynthesis in plant, hydrogen essential for plants, ozone gas which absorb ultraviolet rays which are the unwanted rays from the sun. Also, the Earth has important nutrients found in the soil, air and water which are essential for living things. Moreover, the Earth has a magnetic field which originates from the core of the Earth which form the magnetic north pole and magnetic south pole. The magnetic field acts as the repellant of harmful radiations from the Sun.

Furthermore, the Earth has suitable climate than other planets, it does not have extreme temperature like that of Mercury where temperature goes to 400^0C and Venus whose temperature is 480^0C or Mars whose temperature goes to -140^0C. In these planets life cannot be possible. According to the origin of the universe, the solar system is found in one arm of the milky way galaxy in the universe. Our solar system is composed of a set of radically different types of planets, moons, asteroids, comets, meteorites, interplanetary dusts and gases. The planets are arranged from the gas giants Jupiter, Saturn, Uranus, and Neptune to the rocky inner planets Mercury, Venus, Earth and Mars. In the solar system, the Earth is an active place. In the planet Earth, earthquakes rip along plate boundaries, volcanoes eject fountains of molten lava, and mountain ranges and seabed are constantly created and destroyed.

Shape of the Earth

The planet Earth is spherical in shape (oblate spheroid). Its diameter from the North pole through the South pole is about 12722 kilometers while from the East to West (equator) the diameter is 12762 kilometers. The circumference of the Earth is approximately 40085 kilometers and the Earth rotates from West to East. The concept of a spherical earth dates back to ancient Greek philosophy from around the 6th Century BC, but remained a matter of philosophical speculation until the 3rd Century BC when Hellenistic astronomy established the spherical shape of the earth. The Hellenistic paradigm was gradually adopted throughout the world during the late Antiquity and in the middle ages. The concept of spherical Earth displaced earlier beliefs in a flat earth. Moreover, recent measurements from satellites suggest that the Earth is, in fact, slightly sphere-shaped. The sphere-like shape of the Earth is called *geoid*, spheroid or oblate sphere. It is not a perfect sphere.

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Theories on the earth's shape

In the early times most of the people believed that the Earth has a flat shape. However, as time went on, new arguiment was put forward by Galileo Galilei and Ferdinand Magellan that the Earth is round in shape. It was around 500 B.C that Pythagoras of Samos first proposed a spherical earth, on aesthetic grounds rather than on physical evidence. Like many Greeks, he believed the sphere was the most perfect shape. There are several theories which elaborate on earth's shape which include;

(i) Plato and Aristotle's theory of natural place: This theory relied on a spherical Earth to explain why heavy things go down (toward what Aristotle believed was the center of the Universe), and things like air and fire go up. In this geocentric model, the structure of the universe was believed to be a series of perfect spheres. Their theory was not easily accepted until they coupled with the evidence of the lunar eclipse and the observations from journeys around the world.

(ii) Heliocentric theory: It was put forward by Nicolaus Copernicus in 16th Century. The theory stated that the Earth was spherical in shape and it is one of the planets revolving the Sun. The theory considered the Sun to be the centre of the solar system and perhaps the universe. Also, he believed that the bodies like planets, comets and asteroids revolved around it.

(iii) Centripetal theory: The theory was put forward by Sir Isaac Newton who used Mathematical evidence to determine shape of the Earth. He believed that the Earth is wider along the equator and flattens along the poles. According to Sir Isaac, bulging along the equator is due to rotation and centrifugal forces which overcome the gravity hence pulling of materials away from the centre. This contribute to the bulging nature of the Earth along the equator.

(iv) Geocentric theory: The theory was propounded by Claudius Ptolemy between 90 -168 AD who argues that the Earth was spherical in shape. He believed that the Earth was the centre of the universe and stationary. However, the theory was partially disproved by modern science as it was realised that the Earth and other bodies like stars, sun, moon and other planets were not stationary.

Evidences that prove the sphericity of the Earth

There are various evidences that prove on the spherical nature of the Earth, including the following;

(a) Aerial photograph

Numerous photographs have been taken by satellites at great distances from the Earth, and all of these show that the Earth is spherical (Figure 1.3).

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Figure 1.3: *The spherical shape of the Earth*

(b) Circumnavigation of the earth

The Earth has been circumnavigated many times by land, sea and air. When navigators sail on the sea or ocean, it has been proven that if they travel from one part following the same latitude they always come back to the same point (initial point). If the Earth were flat, this wouldn't be possible.

(c) Lunar eclipse

Lunar eclipse is the eclipse of the moon which is important evidence on the sphericity of the Earth which was discussed by Aristotle (384-322 BC). He cited two convincing arguments for the earths' sphericity. First is the fact that during a lunar eclipse, as the moon enters or emerges from the earth's shadow, the shape of the shadow seen on the moon is always rounded. Only a sphere can cast a shadow which is always circular (Figure 1.4).

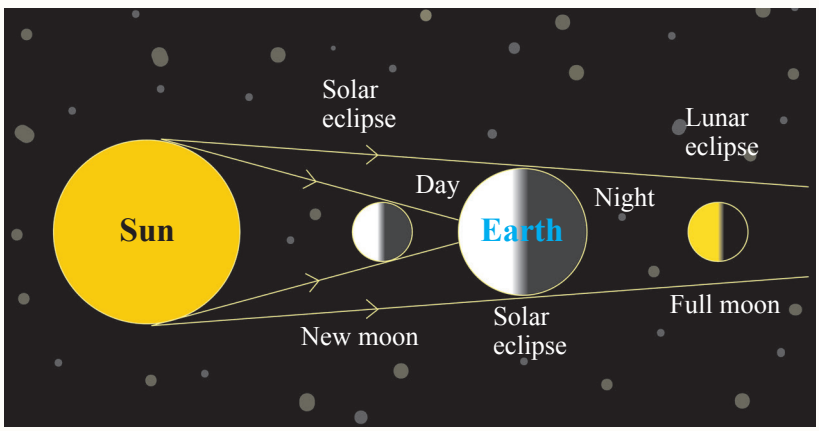


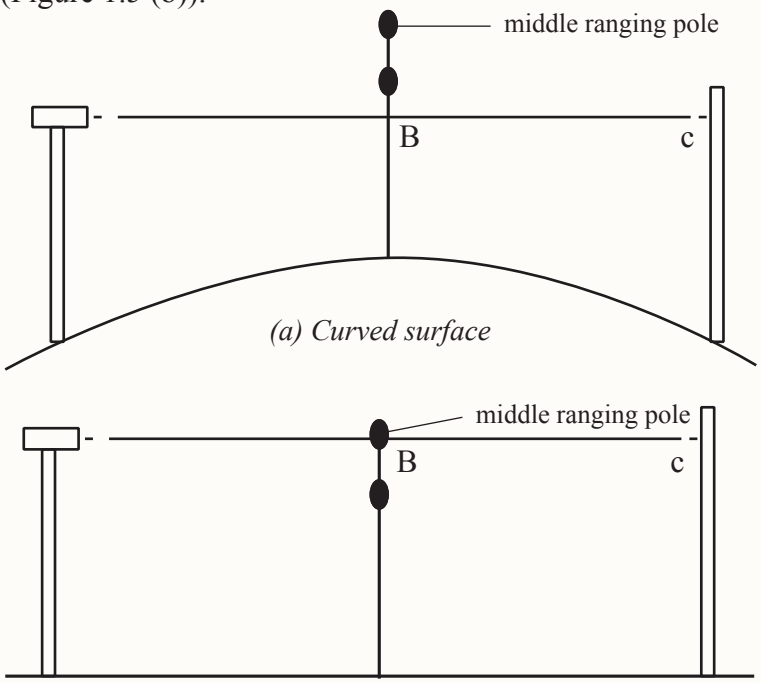
Figure 1.4: *The round shadow of the Earth on the moon*

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(d) Surveying with ranging poles on level ground

It has been observed by surveyors that when they to insert three ranging poles of the same height on the ground at a distance of about one kilometer apart from one another in a straight line they found that, the middle one stands above other two poles (Figure 1.5 (a)). Thus, this proves the sphericity of the Earth. If the Earth were flat, the tops of all poles would lie on the line of sight (Figure 1.5 (b)).



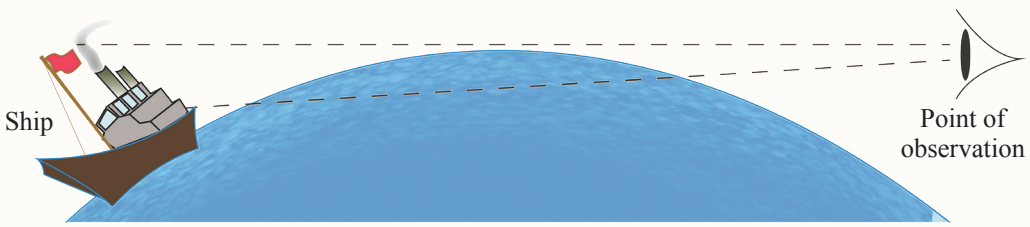
(a) Curved surface

(b) Flat surface

Figure 1.5: *Surveying ground with ranging poles*

(e) Ship's visibility

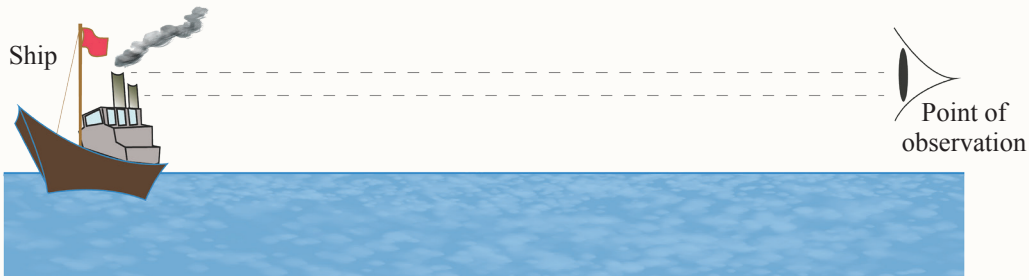
When a ship is approaching the coast, first the smoke will be seen followed by the chimney, and then the whole ship appears at last. Moreover, where two ships are coming along the coast the observer will be able to see the front ship, but if the Earth were flat, the observer would be able to see both ships at once (Figure 1.6 (a) and 1.6 (b)).



(a) Curved earth

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(b) Flat earth

Figure 1.6: *Ship's visibility*

(f) Sun rise and Sun set

The Earth rotates from West to East, which means that places in the East see the sun before places in the West. If the Earth were flat the sun would be seen at the same time in all places all over the earths' surface. Also, sun rise and sun set would be at the same time in all places of the earth's surface (Figure 1.7).

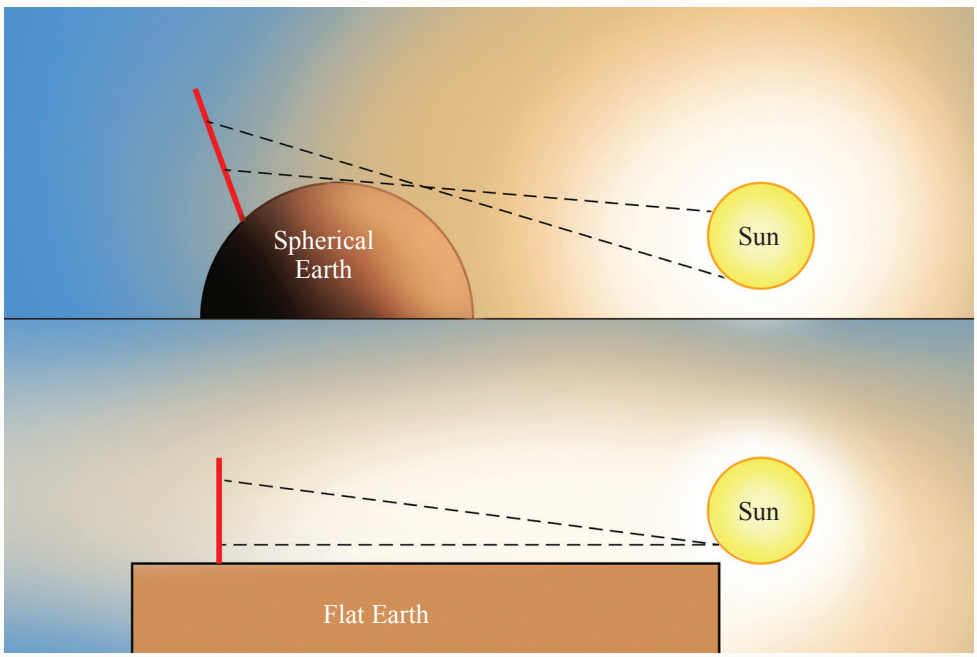


Figure 1.7: *Sunrise and sunset*

(g) Measuring weight using a spring balance

When measuring weight using a spring balance the weight of something at the Equator changes a little bit at the poles since weight depends on gravitational pull. It is as if people are pulling the weight from the centre as the force tries to balance. It can be related as the people of equal weight

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pulling something in a circular motion at the equator (centrifugal force) while at the poles it seems as if they are pulling it towards the centre (gravitational force).

(h) The Earth's curved horizon

The Earth horizon when seen from a ship, a plane or a high altitude appears curved. The curved horizon widens as the observer's altitude increases until it becomes circular. If the earth were not spherical there would be no circular horizon.

Oblateness of the Earth

Despite the above evidences which prove the spherical shape of the Earth, it is argued by Sir Isaac Newton that the Earth is not exactly sphere, it is oblate. It is a bit flat at the poles and bulge at the equator. This is because, near the equator the Earth rotates at very high speed compared to the poles. Due to the high speed the centrifugal force overcomes the gravitational force which leads to pull the matters away from the centre. This causes a bulging of the Earth at the Equator. On the other hand, the force of gravity is so great at the poles due to less speed leading to pulling of matters towards the centre of the earth. This situation causes a bulging at the equator and flattening of the polar region.This shape is caused by the following factors;

High speed of rotation along the Equator: The earth's rotational speed along the Equator is 460m/s roughly equivalent to 1000 miles per hour. This high-speed results into the strong centrifugal force "radially outward force" to overcome the earth's gravitational pull. This results into maximum equatorial departure "bulge" as reflected by larger equatorial diameter 12762 km as opposed by polar diameter 12722 km due to stronger gravitational attraction.

Low speed of rotation at the poles: There is a variation in the gravitational pull at the poles and the equator. Due to high equatorial departure, the gravitation force at the equator is less compared to the same at the poles. This is caused by the fact that points at the equator are far from the center of the gravity, whereas those around the poles are relatively near to the center of gravity and consequently are attracted more. This makes the earth's surface flat because as centrifugal force is less strong due to low speed of rotation, while gravitational force is stronger and overcome the centrifugal force, consequently pulling the materials of the Earth towards the centre of the Earth.

Evidences that prove the oblate spheroid of the Earth

The oblateness of the Earth is justified by five factors namely; inequality of circumference and diameters between equator and poles, measurement of latitude and recent satellite image data. Larger equatorial diameter of

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12762 km results into larger equatorial circumference of 40085 km while smaller polar diameter results into small circumference of 39955 km. This proves that the planet Earth is not a perfect sphere. Variations in the measurements of latitude are caused by the difference in the curvature between the equatorial and polar areas. For example, near the equator 1° measure the length of 110 569 km while near the poles 1° measure the length of 111700 km. Recent satellite data of the Earth suggest that the southern hemisphere is relatively smaller than the northern hemisphere which also proves that the planet earth is not a perfect sphere (Figure 1.8).

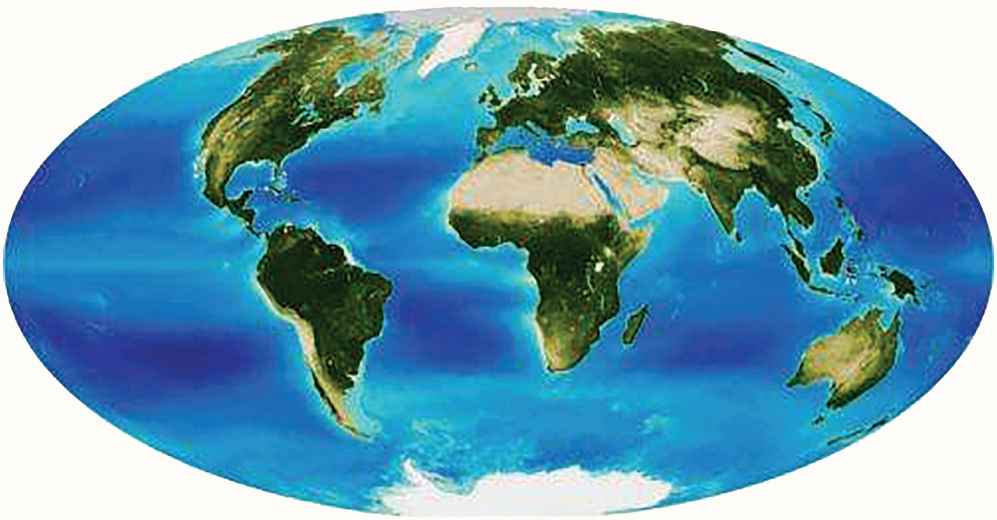


Figure 1.8: *Oblateness of the Earth*

Activity 1.1

(a) Develop a model of ship visibility at different observable intervals, and demonstrate it to the class.

(b) Use three ranging poles on the area with no obstacles, such as along the road with at least 500 metres height. Place ranging poles into three different places but along a straight line then with your fellow student use two ranging poles to view the one erected at the middle. Study if the ranging pole erected at the centre is viewed on the same line with the two. If not, provide concrete reasons.

(c) Explain what you have observed and use the information to prove that the shape of the earth is spherical.

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Exercise 1.1

1. Examine the strengths and weaknesses of Nebular hypothesis in explaining earth's evolution.
2. Appreciate inter-stellar dust hypothesis in explaining the genesis of the planet Earth
3. With vivid evidences justify the sphericity of the planet Earth.
4. Account for the evidence that support the oblateness of earth's shape.

The Earth as a system

The Earth is an integrated system, that can be subdivided into five main interrelated components. Each component has its own collection of materials and processes. These components or parts of the Earth as a system do not operate on their own, they all interact in many ways. They make up the external and internal structures of the Earth. These parts include atmosphere, hydrosphere, biosphere, geosphere, and cryosphere. The *atmosphere,* stands like an envelope of transparent odourless gases held on the Earth by gravitational attraction. It extends up from the earth surface for several hundreds of kilometres. The *biosphere,* a life supporting layer which surrounds the Earth and makes plant and animal life possible without any protective device. The *geosphere,* it includes the rocks and minerals on Earth from the molten rock and heavy metals in the deep interior of the planet to the sand on beaches and peaks of mountain. Thus, it includes all minerals, rocks and soils. The *Hydrosphere,* is the sphere that covers total amount of water on a planet Earth. It includes water available on the surface of the Earth, underground and in the air. The *cryosphere,* is an all-encompassing term for those portions of the earth's surface where water is in solid form, including sea ice, ice sheets, lake ice, river ice, snow cover, glaciers, ice caps, and frozen grounds.

External structure of the Earth

The external structure of the Earth consists of atmosphere, hydrosphere, cryosphere and biosphere.

Atmosphere

The word atmosphere is the combination of two Greek words; *'atmos'* meaning "vapour" and *'sphaira'* meaning "sphere" it is a layer of a gases surrounding a planet Earth or other material body of sufficient mass that is held in place by the gravity of the body. The earth's atmosphere is comprised of mixture of gasses, suspended solids and liquids that surround the Earth. Thus the atmosphere is the blanket of air that envelops the

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Earth. It is the zone of mixed odorless gas or air. The earth's atmosphere is about 600 to 1000 kilometres thick.

Atmospheric composition

The atmosphere is constituted of both living and non-living components. The living organisms include bacteria in which some are harmful to human life. Non-living components include gaseous (Table 1.1), and non-gaseous components such as dusts and particles. The atmosphere is composed of various gasses as follows:

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

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

(c) *Carbon dioxide:* 0.03% plants use it to make oxygen. Acts as a blanket and prevents the escape of heat into outer space.

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

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

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

The usefulness of atmosphere is highly determined by its composition. For instance, water vapour facilitates weather processes, dusts and soot particles act as condensational nuclei or hydroscopic nuclei, while gases support life among others.

Table 1.1: *Atmospheric gaseous composition*

Gas name	Chemical formula	Percent (%)
Nitrogen	N_2	78.085
Oxygen	O_2	20.95
Water vapor	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
Ozone	O_3	0.000004

Layers of the atmosphere

The atmosphere is divided into layers based on its temperature. These layers are the troposphere, the stratosphere, the mesosphere and the thermosphere. The uppermost region, beginning about 500 km above the Earth's surface, is called the exosphere.

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(a) Troposphere

The troposphere is the bottom and, immediate layer from the earth's surface. It starts at the earth's surface and extends to an average of 12 kilometers high being 8 kilometres at the poles and 17 kilometers at the equator. The temperature in the troposphere decreases with increase in altitudes by 0.6° C for every 100 metres or 6.5° C for every 1 kilometer (environmental lapse rate). Pressure falls with altitude due to decrease of gravity. The air pressure at the top of the troposphere is only 10% of that at the sea level (0.1 atmospheres). The troposphere is where clouds, precipitation and violent storm form. Here wind speed increases with height. About 99% of all water vapour is concentrated in this layer. It is by far the wettest layer of the atmosphere. Also, it contains three-quarters of the mass of the entire atmosphere. The troposphere is where all weather takes place; it is the region of rising and falling pockets of air. There is a thin buffer zone between the troposphere and the next layer called the tropopause. The tropopause lies above the troposphere. It extends from 12 km to 20 km. Here temperature is constant. The layer is unstable and contains most of the atmospheres water vapour, gasses, clouds dust and pollutants. Troposphere plays greater role on life including formation of precipitation, providing oxygen and hydrogen and carbon dioxide which is essential for photosynthesis. It provides water vapour which regulates temperature by preventing the outgoing radiation from the sun.

(b) Stratosphere

This is the layer above the tropopause. It extends to about 50 km. It is characterized by steady increase in temperature caused by concentration of ozone (O_3) which absorbs ultraviolet radiation from the Sun. It acts as a protective shield against deteriorates which usually burn out as they enter into gravitational field. Winds are low in the lower troposphere but increase with height. Air is dry, and pressure continues to fall with altitude. There is a recent concern that man-made fluorocarbon is depleting the ozone layer. This has potentially a devastating consequence to life on Earth. The boundary separating stratosphere with the next layer is called the stratopause. It lies above the stratosphere and extends from 49 km to 52 km.

The stratosphere contains 90% of ozone layer primarily between the top of the troposphere and about 50 km (31 miles) altitude. It is approximated that about 16–50

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km (10–31 miles) above earth's surface, ozone forms a thin invisible shield protecting life from the sun's ultraviolet (UV) radiation. Ozone is a molecule that contains three oxygen atoms. At any given time, ozone molecules are constantly formed and destroyed in the stratosphere. The total amount has remained relatively stable during the decades that it has been measured. Ozone layer absorbs the harmful ultraviolet radiation which is emitted from the sun. Without this layer the life wouldn't be possible since it filters harmful radiation from the sun that can destroy animal tissues. The stratosphere is another layer where the temperature increases with the increase in height. The stratosphere is a convenient layer for flying of plane to avoid turbulence which is common in the troposphere.

Activity 1.2

In groups of five students, discuss the causes and effects of ozone layer depletion to the following;

(a) Living organisms

(b) Non-living organisms

Present answers in the classroom for discussion and incorporate their contributions. Write answers in your exercise book.

(c) Mesosphere

The mesosphere is a layer above the stratopause. It extends from 52km to 80 km above the surface. In this layer temperature decreases rapidly with increasing height in the absence of water vapor, dusts and clouds to absorb incoming radiation. This is the region with lowest temperature which drops to -90^{0}C and the strongest wind with the speed of 3000 km/hr. The wind is estimated using temperature dates which is usually collected by satellites. Also, this layer contains fairly high concentrations of ion and metal atoms. The shooting stars you observe in the night sky are meteorites that evaporate as it burns up in the mesosphere. Gases here are mixed, not layered by masses, and air is so thin that you cannot breathe. Mesosphere has various importance to human life.

Mesosphere can be seen as a protective layer of the earth's surface because meteorites of various sizes are burn up in this layer. It is estimated that meteorites with 20 meters in size, are burnt every year. For this case, the mesosphere is important layer in protecting us from the falling meteor shower, with hundreds of rocks with 20 meters in size that would have reached on earth's surface at supersonic speed. Life could not be possible on earth.

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Also, the mesosphere protects us from solar radiation with varying wavelengths. At the end of this layer is the mesopause. Mesopause lies above mesosphere. This layer shows no change of temperature and is characterized by lowest temperature.

(d) Thermosphere

Thermosphere broadly corresponds with the ionosphere. This layer lies above mesopause extending from 80 km into space. In this layer temperature ranges between 1 000^{0}C and 1 500^{0}C. However, it cannot be felt because air molecules are far apart. Also, it is due to presence of atomic ions (oxygen) which absorb a very short wave solar energy by absorption of oxygen and nitrogen. In this zone the air is extremely thin with almost zero amount of air density and almost without existence of gravity. The little air present in the thermosphere mainly consists of helium, atomic nitrogen, and atomic oxygen. For this reason it is not possible to breath in the thermosphere. The thermosphere contributes to the protection of the Earth as it absorbs x-rays and extreme ultraviolet radiation. Also it enables space exploration and easy communication. The charged particles in the thermosphere make it easy for long distance communication through radio, by which radio signs travel in straight line and bounces forth between the earth's surface and the ionosphere. It absorbs the sun's energy and creates moderate temperature.

(e) Exosphere

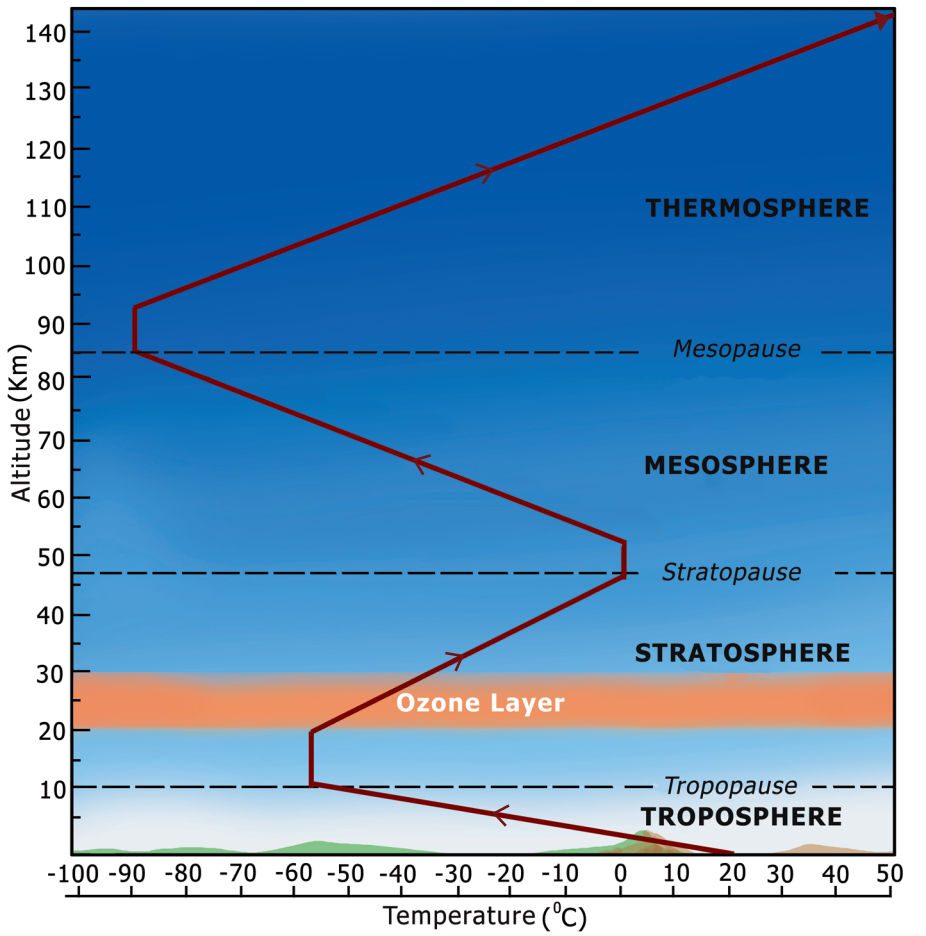
This is the highest and top layer of the earth's atmosphere. It starts at 500 kilometers high and marks the edge of space. There are very few molecules layer mainly composed of extremely low densities of hydrogen, helium and several heavier molecules including nitrogen, oxygen and carbon dioxide. This layer is the earth's first line of defense against the harmful sun rays. Also, it is the first layer to come into contact and protect the Earth from meteors, asteroids and cosmic rays. Figure 1.9 (a) and (b) show layers of the earth's atmosphere and its vertical structure.



(a) *Layers of the earth's atmosphere in relation to height*

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(b) *Vertical structure of the earth's atmosphere and change in temperature*

Figure 1.9: *Layers of the earth's atmosphere and their vertical structure*

The importance of atmosphere in life

The atmosphere is shared by every person living on earth. Without the atmosphere we would find it very hard to survive. Humans can last weeks without food, days without water, but only minutes without air. Our daily lives are influenced by the atmosphere. Also, we are protected by the atmosphere. It acts as a huge blanket, keeping the earth warmer than it would be without the atmosphere. This is known as the greenhouse effect, without the atmosphere, the average temperature on Earth would be below freezing.

The atmosphere protects living things on Earth from the sun's harmful ultraviolet radiation. A thin layer of gas called ozone high up in the atmosphere at stratosphere filters out these dangerous rays. Also, the atmosphere helps to sustain life on Earth. It provides oxygen for humans and animals to breath, and carbon dioxide for

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plants. Through the hydrological cycle, plants and animals receive the water needed to survive. Another importance of the atmosphere is to protect us from objects coming towards the Earth from outer space. Everyday meteoroids enter the earth's atmosphere. These are pieces of rock that are travelling through space. When they reach the atmosphere, most of them burn up due to the friction of the air. The ones that don't completely burn up reach the surface of the earth in a much smaller form. When they reach the Earth we call them meteorites. The atmosphere protects us from space junk that would do damage to us, to our homes, and to the Earth itself. It is because of the heat created by the friction of the atmosphere that the space shuttle had to be equipped with a heat shield to prevent it from burning up as it re-entered the earth's atmosphere. The heat caused by friction is dangerous to the astronauts but it is very important to protect us from things coming in from outer space.

Activity 1.3

Visit the school library, and read from various physical geography books and other online sources about the following concepts as they are used in the atmospheric spectrum

(a) Ozone layer
(b) Magnetosphere
(c) Ionosphere, and homosphere
(d) Auroras and Turbopause

Exercise 1.2

Answer the following questions.

1. Account for the changes of atmospheric layers with temperature and altitude.
2. Why is the atmosphere crucial to life?
3. With concrete reasons and examples argue for or against the statement that, "the atmosphere is never stable".
4. Compare and contrast between troposphere and thermosphere.
5. Explain disadvantages of atmosphere to life.

Hydrosphere

Hydrosphere is the area that includes all earth's water in the state of liquid, frozen or floating ice in the upper part or beneath the soil. Most (97%) of water is found in oceans and seas; freshwater accounts for 3% only of the hydrosphere and most of this is found in glaciers, permanent snow covers at the poles, lakes, rivers, groundwater, and in mountainous regions. The rest is in lakes, rivers, and ground water. 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

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water molecules from the vegetation and oceans to the atmosphere and back around. This movement of water is through the process of evapotranspiration, condensation, precipitation, infiltration, runoff, and subsurface flow of which are the wheels in the hydrologic cycle. When water evaporates, the surroundings are cooled; as it condenses, water releases energy and warms its surroundings. Water is responsible for the formation of landforms through erosion deposition, and the movement of minerals. It further hydrates life on the planet and transfers the energy from terrestrial to aquatic systems. Generally, without these cycles, and water itself, life would cease to exist on the planet Earth.

Biosphere

Biosphere refers to the narrow zone of the Earth in which all life forms exist. Life becomes possible in this zone due to presence of land, air and water which support all forms of life. Biosphere extends vertically into the atmosphere to about 10 kilometers, downward into the ocean to a depth of about 10.4 kilometers. There are three basic components of the biosphere namely; abiotic, biotic and energy. The abiotic component consists of all non-living elements which are essential for survival of all living organisms. These elements are lithosphere, atmosphere and hydrosphere which in turn provide mineral nutrients, water and certain gases.

The biotic component is composed of plants and animals include human beings, plants, micro-organisms and macro-organisms. Also, energy is another component which is essential for generation and reproduction of all biological lives of this planet. The biosphere is characterized by the continuous cycling of matter and an accompanying flow of solar energy through which certain large molecules and cells are self-reproducing.

Cryosphere

In some places on the Earth water exists in a form of solid ice or snow (Figure 1.10). These frozen places of the Earth are called 'cryosphere.' The word 'cryosphere' comes from the Greek word, 'kryos' which means 'cold.' The cold regions of our planet influence our entire world's climate. The cryosphere is central to the daily lives of people, plants, and animals. Also, it has a great impact on the global cooling and distribution of cold winds. According to scientists the cryosphere, are places where water is in solid form, where very low temperature freezes water and turns it into ice. 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. For example, the snow on top of Mount Kilimanjaro found in Tanzania. Frozen soil can be

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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.



(a) Snow



(b) Sea ice

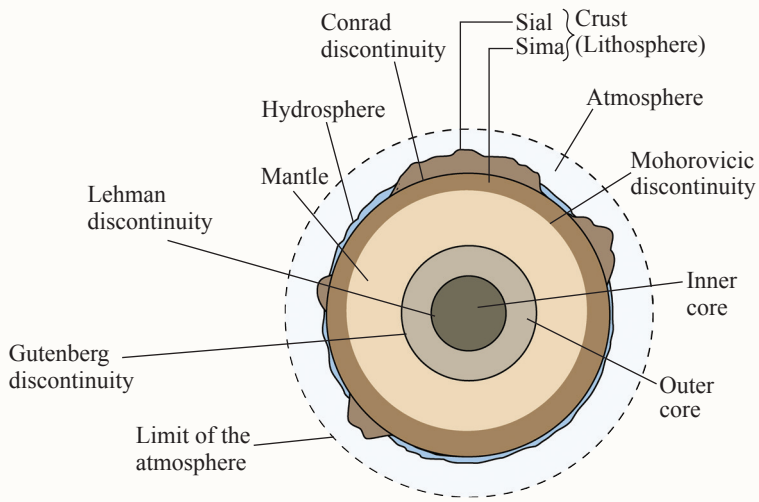
Figure 1.10: *Water in the form of solid ice and snow*

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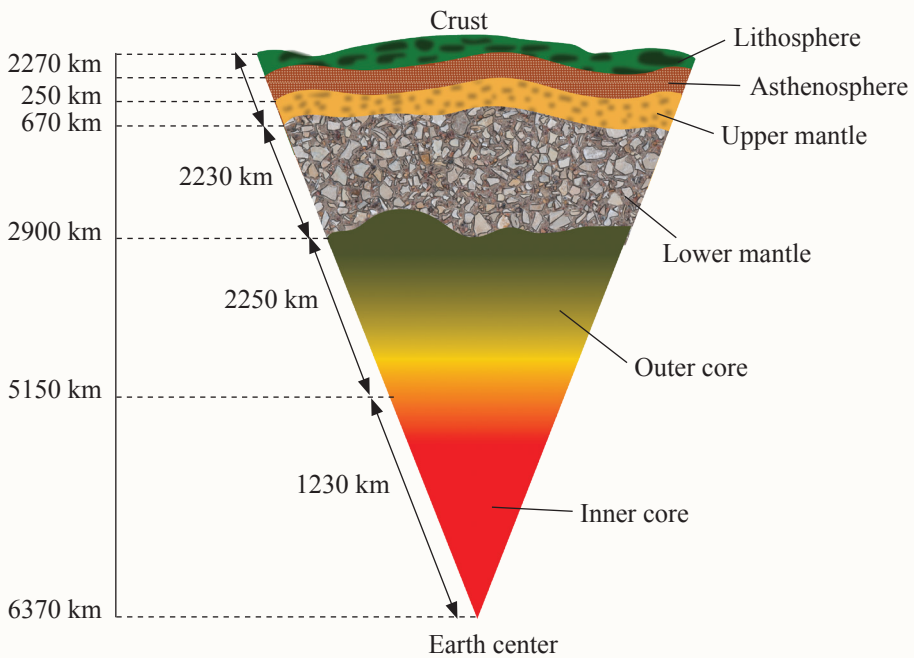
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Internal structure of the Earth

The internal structure of the Earth is layered in spherical shells, like an onion. These layers can be defined by their chemical and geological properties. The Earth has an outer silicate solid crust, a highly viscous mantle, a liquid outer cover that is much less viscous than the mantle and a solid inner core (Figure 1.11).



(a) Internal structure of the Earth



(b) Inner structure of the Earth with its components, depth and temperature

Figure 1.11: *Structure of the Earth*

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Composition of internal layers of the Earth

The Earth's interior layers have different densities. This is the result of heated gas cooled the heavier particles gathered in the centre of the swilling mass forming the great core of heavy liquid metal (Nickel-iron) which is the centre of the Earth (the core). Also, around the core, less heavy particles collected and formed another layer (iron and magnesium) called mantle. Moreover, the layer of iron and magnesium (the mantle) formed the outer layer of silicate and magnesium, (the SIMA) and the lightest layer of silicate and aluminium (the SIAL). Deeper beneath the Earth is hotter. For every 33 metres depth temperature increase by 1^0C. But the greater the pressure on top of something the more difficult it will make it boil. The pressure at the centre of the Earth is high due to many heavy layers on top of it. Pressure in the core is 3.6x106 Atm. Thus, because of very high pressure it is believed that the Earth is solid to the great depth. The structure of Earth can be defined in two ways, these are; mechanical and chemical properties. Mechanical properties can be divided into lithosphere, asthenosphere, mesospheric mantle, outer core, and the inner core. However, chemically the interior of Earth is divided into three important layers; the crust which is divided into two parts namely; SIAL (made up of Silicate and Aluminium) at the upper most crust and the SIMA (made up of Silicate and Magnesia) at the lower most crust. Second part is the mantle which is divided into two parts; the upper mantle and the lower mantle, and below the mantle is the core which is also divided into two; the outer core and the inner core.

The crust

The crust ranges from 5-70 km (3-44 miles) depth and is the outermost thin layer of the earth. Usually there are two kinds of crust: continental crust, and oceanic crust. First, the thicker crust is continental crust (SIAL), which is less dense and is composed of large proportion of silica and alumina (felsic), silicate rocks like granite and quartz. The composition is very important because it makes the continental crust less dense than the ocean crust. The ocean crust (SIMA) is thinner, and predominantly mafic in composition. Mafic rocks contain minerals with less silica, but more of iron and magnesium. Mafic rocks (ocean crust) are denser than the felsic rocks of continental crust. The crust floats on the mantle. Continental crust floats higher in the mantle than ocean crust because of the lower density of continental crust. The rocks of the crust fall into two major categories namely; SIMA and SIAL. It is estimated that SIMA starts about 11 kilometers below. The upper crust

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(SIAL) and the lower crust (SIMA) are separated by the border of discontinuity called Conrad discontinuity. The boundary between the Earth's crust and the mantle is called a Mohorovicic discontinuity or Moho. This is the surface of discontinuity between the mantle and the crust. It was discovered in 1909 by Andrija Mohorovicic. Here the speed of earthquake waves suddenly accelerates from 5.0 to 8.1 km/sec. The cause of the Moho is thought to be a change in rock composition from rocks containing plagioclase feldspar (above) to rocks that contain no feldspars (below). In oceanic crust, there is a chemical discontinuity between ultramafic cumulates which has been observed from deep parts of the oceanic crust that have been sub-ducted onto the continental crust and pressed as ophiolite sequences. Many rocks now making up the earth's crust were formed less than 100 million years ago.

However, the oldest known mineral grains are 4.4 billion years old, indicating that the earth has had a solid crust for at least that long. The thin parts of the crust are the oceanic crust, (SIMA), which underlies the ocean basins and below the continental crust (5-10 km), they are composed of dense (mafic) iron magnesium silicate igneous rocks, like basalt. The thicker crust is continental crust (SIAL), which is less dense and is composed of large proportion of silica and alumina (felsic) silicate rocks, like granite. It is estimated that sima starts about 11 kilometres below the Conrad discontinuity. The upper most mantle together with the crust constitutes the lithosphere. There are two different types of crust, thin oceanic crust that underlies the ocean basins and thicker continental crust that underlies the continents. The thin oceanic crust is composed of primarily of basalt, is heavy in weight and dark in colour, fine grained and the thicker continental crust is composed primarily of granite light in weight, light in colour, courser grain (granite). The lithosphere combines the crust and upper mantle.

Mantle

Earth's mantle is the thickest layer of the Earth. The mantle is also known as *mesosphere*. The mantle extends to about 2890 km where temperature may reach to about 5000^0C, with an average density of about 3.3g/cm3. The most important characteristic of the mantle is the presence of a thin layer between upper mantle and lower mantle. It is a layer of semi-molten materials acting as the center of isostatic adjustment, known as *asthenosphere*. The lowest part of the mantle next to the core that make a mantle boundary is known as the 'D' layer (D double prime). The mantle is ultramafic in composition which means it is made of iron and magnesium. Although the mantle has a similar chemical composition throughout, it has layers

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with different mineral compositions and different physical properties. It can have different mineral compositions and still be the same in chemical composition because the increasing pressure deeper in the mantle causes mineral structures to be reconfigured. This is the surface of discontinuity between the core and the mantle called Gutenberg discontinuity, that was named after a study made by a German seismologist called Beno Gurtenberg in 1914. It is about 2 900 km depth and temperature is estimated to be 3 700^{0}C.

Core

This is the innermost part of the Earth, which is also known as barysphere. It is made up of iron and nickel. Its size is that of Mars which is about 6900 km thick. It is divided into two major parts; outer core which is about 2270 km thick and it is in molten state while the inner core is about 1216 km radius which is in solid state. The earth's core is composed mainly of iron and nickel alloy because the average density of surface material is only around 3000 kg/m^3. The core's temperature is about 6200^{0}C. It is hotter than the surface of the sun (5600^{0}C) due to existence of uranium and nickel elements. The liquid outer core surrounds the inner core and is believed to be composed of iron mixed with nickel and trace amounts of lighter elements. Recent speculation suggests that the innermost part of the core is enriched in gold, platinum and other siderophile elements. There is the boundary which separate the outer core and inner core which is known as Lehman discontinuity which occurs at the depth of roughly 5100 km. The solid inner core is too hot to hold a permanent magnetic field but probably acts to stabilize magnetic field at the surface. Seismic measurements show that the core is divided into two parts, a 'solid' inner core with the densities 16-17 and liquid outer core with the densities ranging between 9 900 and 12 200 kg/m^3. The inner core was discovered in 1936 by Inge Lehmann and is generally believed to be composed primarily of iron and some nickel. It is not necessarily solid, but because it is able to deflect seismic waves and because it is under high pressure, it is believed to be in solid form.

Activity 1.4

In a group of five students, do the following;

(a) Use available local material to prepare a model that shows the layers of the internal structure of the earth.

(b) With the assistance of the subject teacher, use the model prepared in (a) to explain the internal layers of the Earth basing on the characteristics of each layer.

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(c) With the assistance of the teacher, give chance to fellow students to ask questions and make contributions.

(d) Write in your exercise book then submit work to subject teacher for marking.

Earth's gravity

Every planetary body (including the Earth) is surrounded by its own gravitational field, which can be conceptualized with Newton's law of universal gravity as exerting an attractive force on all objects. The rate of acceleration of falling objects near the earth's surface varies very slightly depending on latitude, surface features such as mountains and ridges, and perhaps unusually high or low sub-surface densities. The strength of gravity is not the same at all places on the Earth. Three factors determine the strength of gravity at any given place namely; the distance from the centre of the earth, the spin of the earth on its axis, and the nearby sources of gravity variations, such as mountains or underground caverns. Gravity or gravitation is a natural phenomenon by which all things with energy are brought towards (or gravitate towards) one another, including stars, planets, galaxies and even light and sub-atomic particles. Gravity is responsible for many of the structures in the universe by creating spheres of hydrogen where hydrogen fuses under pressure to form stars and grouping them into galaxies. On the Earth, gravity gives weight to physical objects and causes the tides. Gravity has an infinite range although its effects become increasingly weaker on further objects. Gravity is a very important force. Every object in space exerts a gravitational pull on every other, and so gravity influences the paths taken by everything travelling through space. It is the glue that holds together entire galaxies. It keeps planets in orbit. It makes it possible to use man-made satellites and to go to and return from the moon. It makes planets habitable by trapping gases and liquids in an atmosphere.

Exercise 1.3

1. Explain the structure of atmosphere basing on temperature changes, altitude and chemical composition.
2. Write short notes on the following;
   (a) Earth gravity?
   (b) Why is earth's gravity important?
   (c) What factors determine the force of gravity between two bodies?
3. What are the effects of ozone layer depletion to human beings and environment?
4. With tha aid of a well labelled diagram discribe the internal structure of the Earth.

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Revision exercise 1

Answer all questions.

1. Write short notes on the following;
   (d) Origin of the universe
   (e) Sphericity of the earth
2. Describe the composition of the atmosphere and its functions to the universe.
3. Examine the consequences brought by the depletion of the ozone layer in the atmosphere.
4. With the aid of a well labeled diagram, describe the concentric zones of the Earth.
5. Justify the sphericity of the planet Earth with vivid examples.
6. With examples, account for the usefulness of hydrosphere in the life of living organisms.
7. Differentiate between centrifugal and centripetal theory in explaining the Earth gravitation.
8. 'The materials of the inner zones of the Earth increase with the increase depth in terms of density, temperature and pressure.' Justify.

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Chapter Two

Endogenic processes of the Earth

Introduction

The earth's crust might seem fixed and rigid, but evidences show that it is constantly moving as a result of various forces exerted within it. In this chapter, you will learn about theories of the earth's formation which include Isostasy theory, Continental drift theory, Seafloor spreading theory, and Plate tectonic theory. Also, you will learn about materials of the Earth's crust, and internal geomorphic processes such as earthquakes, vulcanism and diastrophism. The competencies developed from this chapter will enable you to undertake various activities on the physical environment with the knowledge of how the planet Earth is constantly develops and replenishes. Also, the competencies gained from this chapter, will enable you to critique theories, approaches and principles about the internal processes of the Earth.

Concept of endogenic processes

The earth is constantly shaped by various forces that originate beneath the earth's surface. The forces that shape land can result in folding, faulting, volcanic eraption and earthquakes. The driving force for the occurance of these 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, for example, oceanic basins, ridges, and trenches, mountain ranges, rift valleys, folds, faults, and vulcanic features. Endogenic forces largely operate within the earth's crust mainly into two movements which are horizontal and vertical movements. These forces are responsible for the earth's movements. Hence, the study of endogenic processes and their resulting landforms and landscapes remarks important consideration on the internal evolution and the surface history of a geologic body (Figure 2.1).

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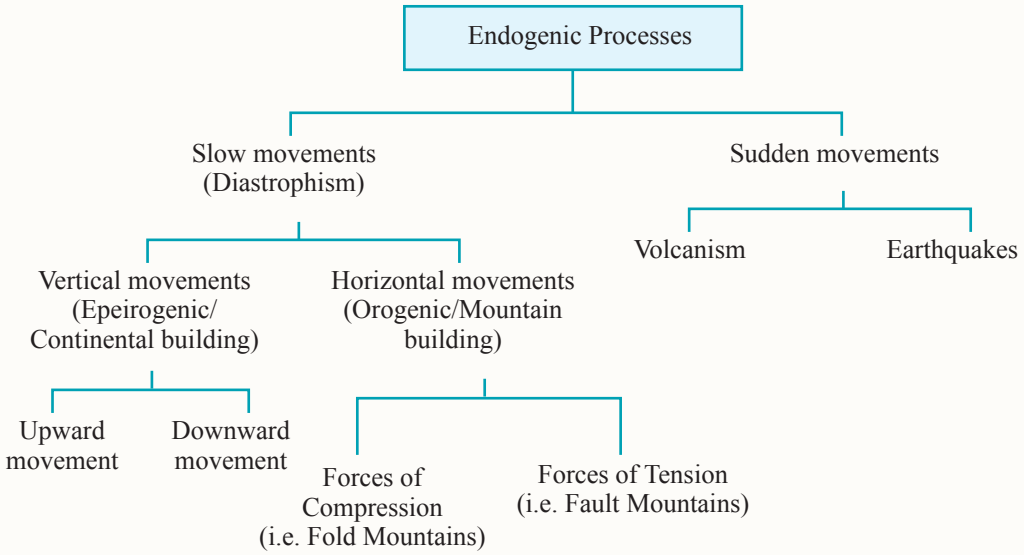


Figure 2.1: *Endogenic processes affecting the Earth*

The endogenic processes of the Earth are explained by several theories, the major ones are described below:

Isostasy theory

This theory was proposed by Clarence Dutton who was an American Seismologist and Geologist in 1841-1912. 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 stand still. 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

It is assumed 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. The theory explains 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 2.2). This means that the weight of continental rock (*sial-silica and aluminium*) underlies oceanic rocks (*sima-silica and magnesium*) of the crust, which results to a state of balance.

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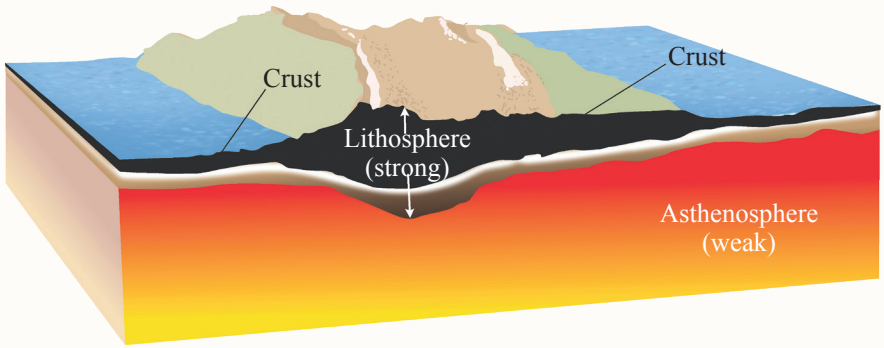


Figure 2.2: *Lithosphere floating on asthenosphere*

The theory further states that where the continental masses (*Sial*) rise to form a mountain then the penetration of *Sial* downward to *Sima* is greater to compensate the excess mass. Moreover, where the continental mass is thin, the Sima layer come near to the surface or reach 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. Thus, the root of the mountains sinks to depth proportional to the height above. This state of balance between different parts of the earth's crust is called Isostasy where equal mass underlying 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 sinking and uplift movement of the earth in order to balance itself. The disturbance can either be erosion or melting of the large accumulated snow while restoration can be deposition or accumulation of large snow or a volcanic hill. The theory therefore, describe the state of balance achieved between erosion and deposition.

Isostatic movements

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

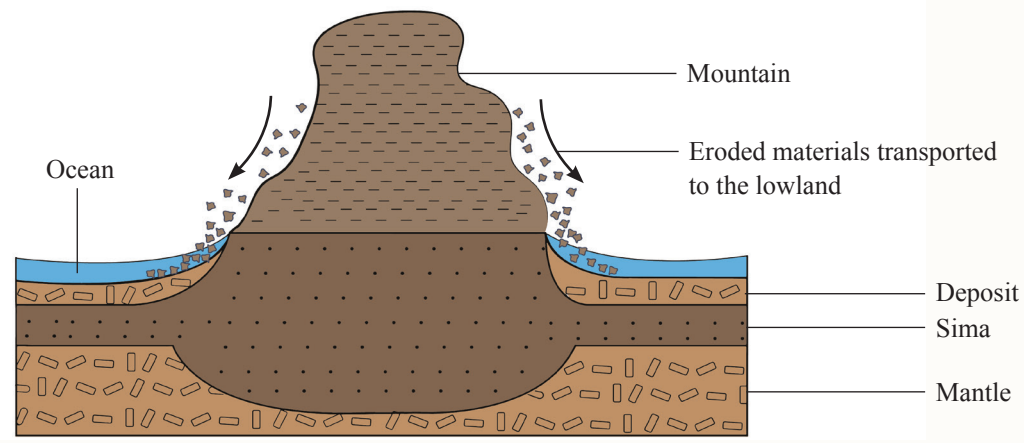
It involves upward and downward movements of materials which enhance isostatic adjustment. The process is slow and thus takes thousands of years in maintaining the balance between oceanic mass and continental rocks. Several evidences to prove the existence of vertical movements can be indicated in various parts of the world especially in the poles in connection to the formation of ice (ice age) and its melting. Therefore, it happened that when the great ice caps was formed, the weight of ice caused sinking or sagging of the crust, and when the ice melted, recovery gradually took place producing considerable changes in the level of the land relative to that of the sea. The best examples of

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vertical movement can be evidenced in different parts of the world including, the continental shelf of Antarctica which is deeper than others, its water depth is about 750 m compared with 180 m around other continents which may be a result of weight of the present ice sheet. Another one is the ice cap of Greenland whose landscape is covered by enormous weight of ice cap unless otherwise, the surface of underlying plateaus would be 1100 m higher. Also, the disappearance of ice sheets in northern Europe due to changes in weather and climate. Moreover, there is beach formation in Scandinavia due to uplift of land such as "raised beach".

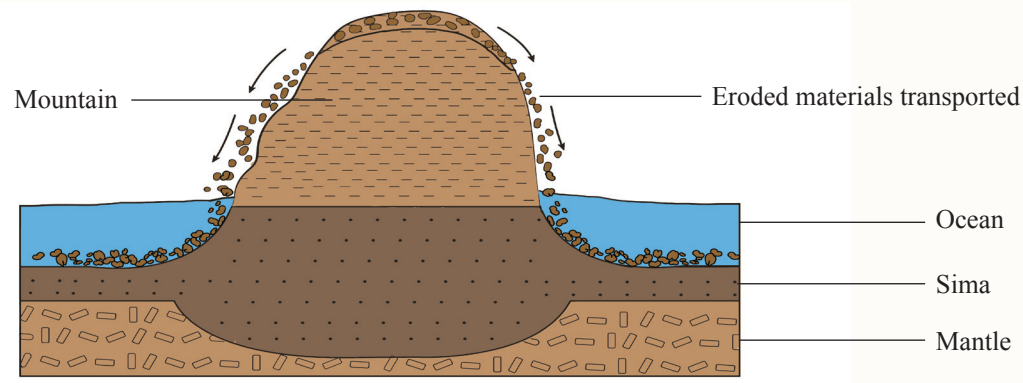
As the weight of continental rocks increased due to restoration it results to extra weight which disrupts the balance in the area which finally causes sinking. The extra weight is caused by several reasons such as volcanic eruption, deposition of sediments, the accumulation of snow and ice, the decrease of weight of continental rock as well as denudation and melting of ice. *Large volcanic eruption:* The outpouring of lava due to huge volcanic eruption that forms volcanic mountain 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, for example submergence of . *Accumulation of snow and ice:* The formation of ice sheets and 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 of weight of continental rock:* If the weight of continental rocks is decreased because of erosion and melting of ice in one area, it results in 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 down, the reduced range rebounds upwards to a certain extent (Figure 2.3 a, b and c).



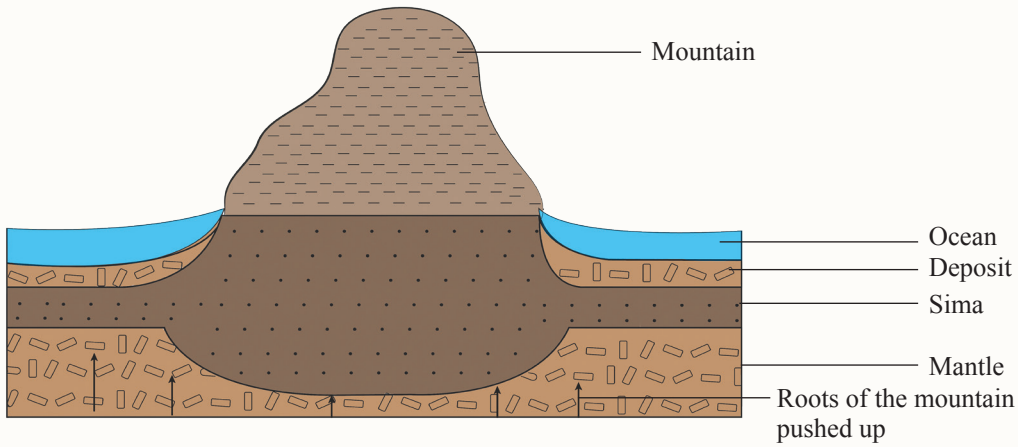
(a) Mountain showing Eroded high elevation

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(b) Eroded mountain materials deposited on the base of sea or on the side of mountain peak



(c) Regained balance

Figure 2.3: *Isostatic movements*

Melting of ice. Isostatic post glacial rebound is observed in areas once covered by ice sheets that have now melted for example, 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 meters above present day sea level. The rebound movements are so slow that the uplift caused by the ending of the last glacial period is still continuing.

Horizontal movement

This occurs when there is a horizontal flow of mantle from the area of depressed to the area of uplift for adjustment. The adjustment involves horizontal flow or convection current. It involves accumulation of heat. It takes place in the simatic layer, especially in the asthenosphere where there is maximum plasticity (Figure

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2.4). There is continuous radioactive disintegration within the simatic layer specifically in the asthenosphere. The disintegration releases heat which may be accumulated and prevented by the overlying more solid layer from escaping at the earth's surface by radiation. The heat therefore makes the sima mobile resulting to the sinking of the *sialic* continents, hence periodic ocean transgression. Contrastingly, if it happens that, the accumulated heat is degenerated due to various processes such as widespread volcanic activities thus the sima become less fluid 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 warping and tilting of the sialic blocks.

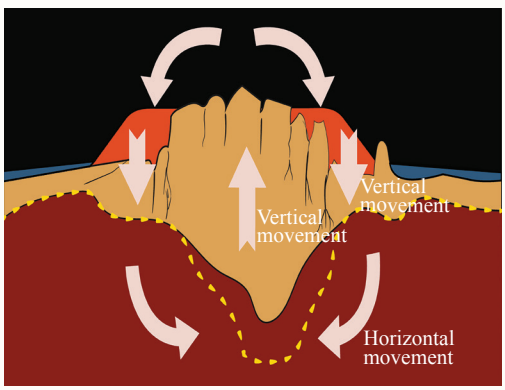


Figure 2.4: *Combined isostatic movements*

Analogy of Isostasy theory

Analogy of Isostasy theory may be made with things like; floated icebergs, floated pieces of wood, and loaded and unloaded ship. *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 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 the surface of the water. The portion below the surface of water is compensation portion (Figure 2.5). 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 as the iceberg floats on water.



Figure 2.5: *Iceberg floating in water*

A floated piece 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 a taller one will remain tall and sink down more than a shorter one (Figure 2.6). The wooden blocks emerge by amounts which are proportional to their respective heights. The submerged pieces of wood are proportional to their respective emerged parts.

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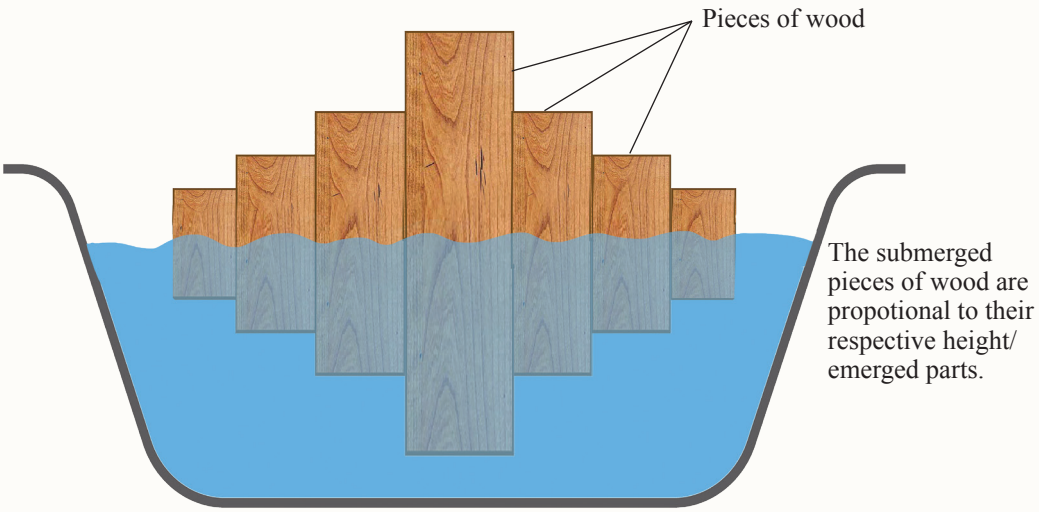


Figure 2.6: *Blocks emerging by amounts proportional to their respective heights*

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' rises in the water and ship 'B' sinks (Figure 2.7). Gradually corresponding to the process of loading and unloading of the cargo.

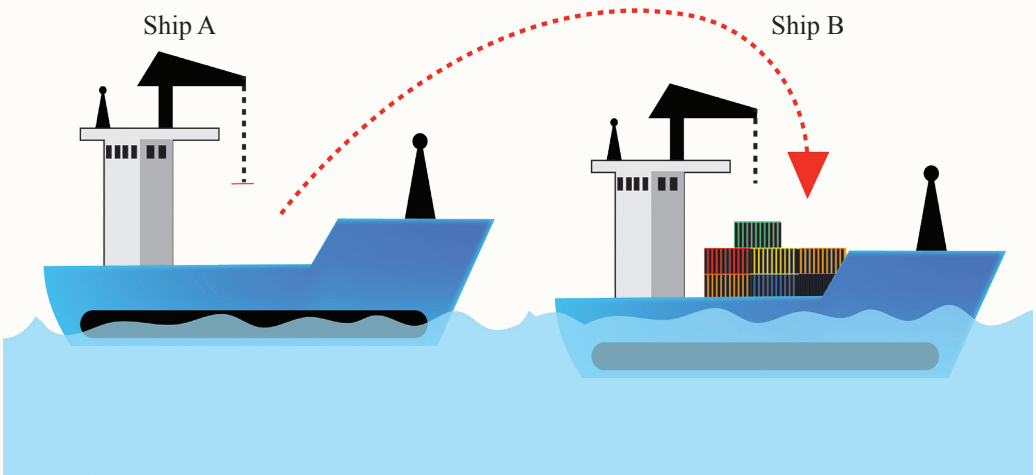


Figure 2.7: *Compensation process*

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 takes over thousands of years.

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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 as follows;

The presence of raised beach in Scandinavia: The raised beach in Scandinavia which was covered by a vast ice sheet about 10 000 years ago, is still rebounding isostically at the rate of up to 1m per country. The result is the formation of raised beaches which lie between 8-30 m above present beaches. Similarly, the Ballyhillin beach in Ireland is rebounding isostatically to form raised beaches (Figure 2.8).



Figure 2.8: *Ballyhillin raised beach in Ireland*

The evidence of old constructed dock that is Coastal cities in Scandinavia have been uplifted rapidly enough and the docks which are 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.

Depression formation: This is another evidence. A depression is a landform sunken below the surface area. Depressions may be formed by various mechanisms for example, erosion-related whereby features like blowouts are created by wind erosion typically in either a partially vegetated sand dune ecosystem or dry soils. Also, 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 glacial ice so as to maintain balance.

Land uplift in Canada: is another evidence in which isostatic rebound has also occurred indifferent areas such as

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Eastern Canada and Southern Ontario where the land has risen as much as 100 m during the last 6 000 years. Across which of Canada, the land is raising. 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.

The depth of continental shelf: This is another evidenced where the continental shelf around Antarctica is covered with water to a depth of about 2 500 feet (750 m) compared with 600 feet (180 m) around other continents. This may be the result of the weight of the present ice. The present Antarctic ice sheet as a surface load makes the Earth deform. This explains why continental shelf of Antarctica is very deep than that of the whole Antarctica continent including the continental shelf that subsided by the existence of Antarctic ice sheet as a huge load on earth's surface compared with other continental shelf of 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 m for thousands of years.

Existence of water bodies and depression areas: 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. Also, the emergence of emerged coast formed as the result of land uplift around the coast of scandinavian countries.

The significance of the Isostasy theory

Several implications of the isostasy theory can be provided. However, the most significant are; the theory signifies the state of equilibrium in the earth's crust with equal mass underline 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 whereby the crust floats on mantle just like the iceberg on the ocean or seawater is important in understanding of plate tectonic and continental drift theories. Precaution can be taken depending on nature of the climatic condition of a given area especially in the occurrence of ice sheet and melting of ice. It provides the basis for predicting the future of the crustal state at any place on the surface of the earth and understanding how different landforms were formed and the mechanism involved in their formation.

The effects of isostatic movements

Several effects on the earth's surface may be caused by isostatic movements. The vertical and horizontal movements of isostasy result into occurrences of faulting and folding of the earth's crust. Faulting and folding have the prolonged impact of causing rift valleys, Mountains

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as well as volcanic eruptions with their associated features. Despite the geomorphological effects of the Isostasy theory, still it is criticized on the failure to explain the formation of inland and undersea mountain or the presence of volcanic Island.

Activity 2.1

In a group, read books and internet sources in attempt to;

(a) Discuss reasons for having mountain ranges around the world despite the active denudation processes.

(b) Present your work to the class for discussion in the presence of a subject teacher.

(c) Write in your exercise book and submit to the subject teacher for marking and feedback.

Exercise 2.1

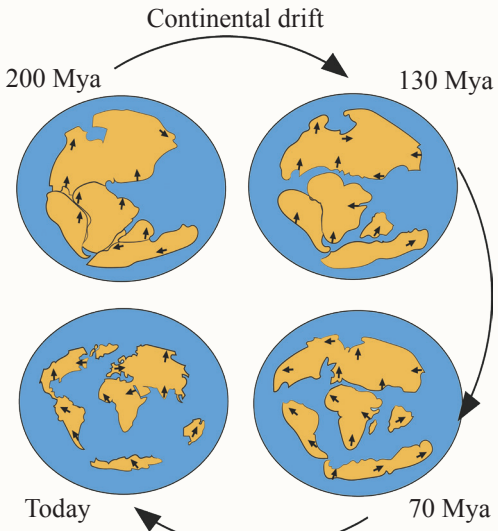
1. Examine the interrelationships between erosion and deposition in the context of isostatic balance
2. Isostasy theory has never been the realistic geographical concept rather a theoretical. Argue for or against.
3. With the aid of diagram, explain various assumptions that govern the theory of isostasy.
4. Examine evidences and significances of isostatic re-adjustment.

Continental drift theory

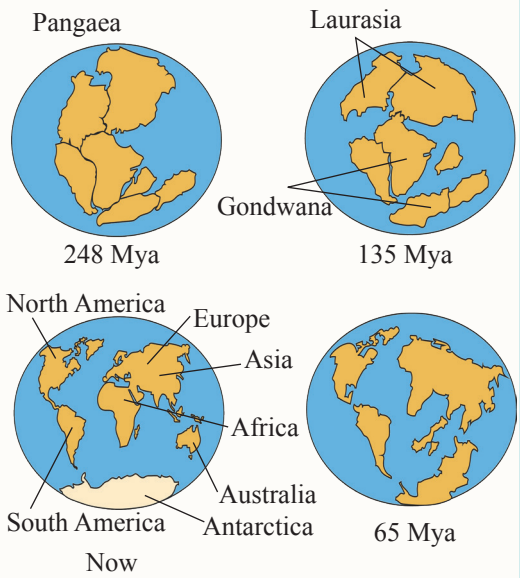
Continental drift is the second theory proposed by Alfred Wegener in 1912 to explain how the continents have shifted from their original position on the earth's surface. The theory was initially developed by F.B. Taylor who postulated about the concept of horizontal displacement of the continents to explain the distribution of the fold mountains. Wegener explained that the earth's continents were once united forming a single super continent land mass called *Pangaea* (Greek word which means 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 2.9(a) and 2.9(b).

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(a) Formation of Gondwanaland and Laurasia



(b) Formation of modern continents

Figure 2.9: *Continental drift*

Different scientists explain various causes of continental drift. Among the scientists include S.B Taylor, A. Holmes and A. Wegener. The proposed causes were centrifugal force, tidal attraction and the force which operate within the Earth or convection and transfer of heat. Wegener proposed three main causes of continental drifting which include centrifugal force, tidal attraction and convection transfer of heat.

Centrifugal force: The rotation of the earth created a centrifugal force towards the equator. He believed that Pangaea originated near the South Pole and that the centrifugal force of the planet caused the proto continent to break apart and the resultant continents to drift towards the equator. Wegener called this the *pole-fleeing force*. According to Wegener the continents after breaking away from the Pangaea moved in two directions namely equator-ward and westward movements. The equator-ward movement of sialic blocks was caused by gravitational force and force of buoyancy. Wegener explained that the lighten sialic materials were floating without friction on relatively denser (SIMA) materials. Equator-ward movement depended on the relation of 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. A. Wegener (1922) complemented F.B Taylor (1910) who had previous proposed that the main driving force possible for displacement of the continent was tidal force. With regard to Wegener

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the attractional force resulted from the sun and the moon which attained its maximum 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 transfer of heat: 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 and arises to the surface until is cooled and sinks again. The repeated heating and cooling results in a current which may be enough to cause such a substance to slightly move. This is associated with the movement of continents.

Evidences of the continental drift

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

Jig-saw fit: according to Wegener there is geographical similarity among various coasts of different continents. This is known as jig-saw fit. It is obvious that some coastlines of continent 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 2.10). The Jig-saw fit implies that all continents were formed from a single landmass.



Figure 2.10: *Jig-saw fit of the continents*

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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 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. Also, fossils of the land reptile *Lystrosaurus* have been found in rocks of the same age in Africa, India and Antarctica (Figure 2.11). Also, the distribution of glossopteris flora in India, South Africa, Australia, Antarctica, Falkland island proves the fact that all landmasses were previously united.

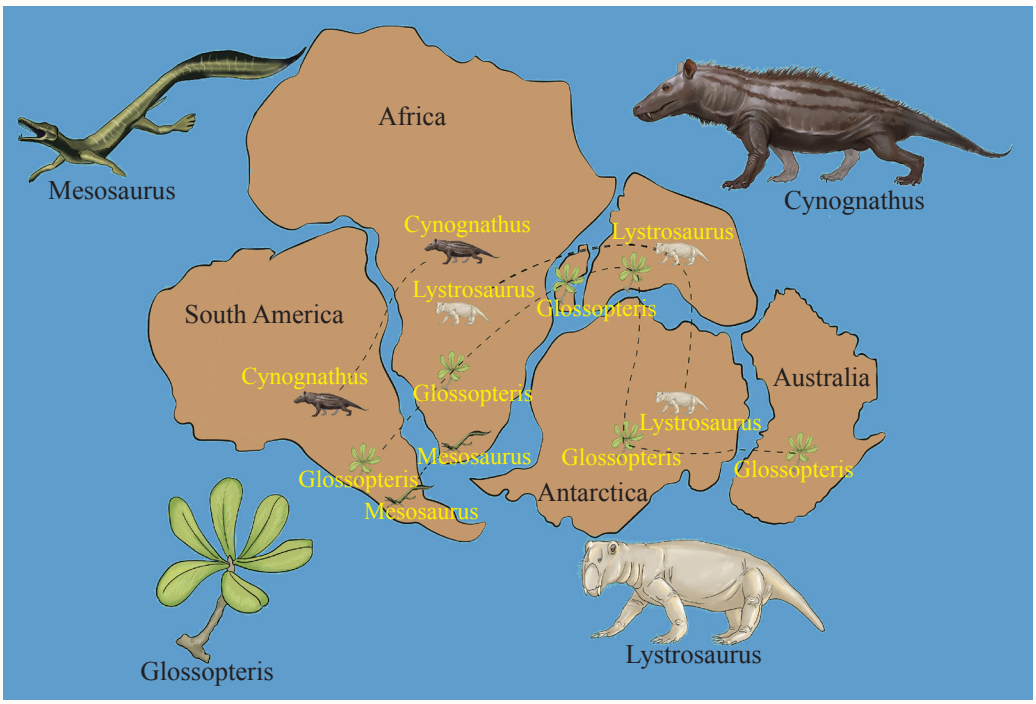


Figure 2.11: *Paleontological evidence of the continental drift*

Geological similarities: There are number of large scale geological features which are matching on different continents. This evidence uses identical rocks in terms of types, structures and ages which are found in both sides of Atlantic Ocean, for example the coastlines of South America and West Africa seem to match up, more particularly the terrains of separate continents conform as well. Similarly, the familiar rock strata of the Karroo system of South Africa matched correctly with the Santa Catarina system in Brazil. Moreover, the mountain ranges with the same rock types, structure and age are now found on 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 latter part of the paregoric era (about 300 million years ago), glaciations occurred

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throughout a large part of the continent in the Southern hemispheres. The deposits left by these ancient glaciers are real 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, used as the evidence that the continents drifted from regions which were cold to currently warm regions. For instance, Africa has been shifted northwards from the south, likewise the presence of coal in Britain indicates that coal was deposited before shifting of the continents, and the condition was warm around 300 million years ago. This is because plants which led to the formation of coal deposits cannot exist in areas where there is very low temperature as the case of today.

Paleomagnetism: The most powerful argument for large scale plate motion are derived from studies of different aspects of the earth's magnetic field. When the rocks cooled, they were magnetized in the same direction where magnetic field (magnetic north) is found. The paleo magnetic dating shows that rocks older than 200 000 years ago 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 to show that the continents drifted at a certain geographical period. This rift valley is formed due to the movement of plates beneath the continents. The tensional force of the moving plates forms cracks which finally form a rift valley (Figure 2.12).

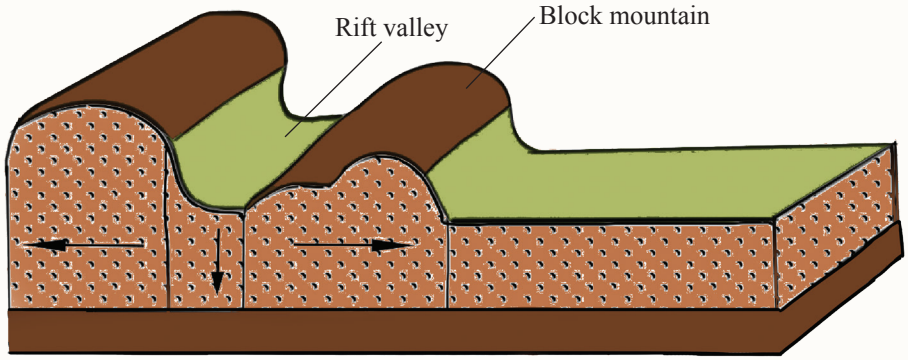


Figure 2.12: *Formation of a rift valley*

The red sea evidence: This began as a rift valley 20 million years ago and now is over 300 km wide. It was formed by divergence between African continent (plate) and Arabian plate (Figure 2.13).

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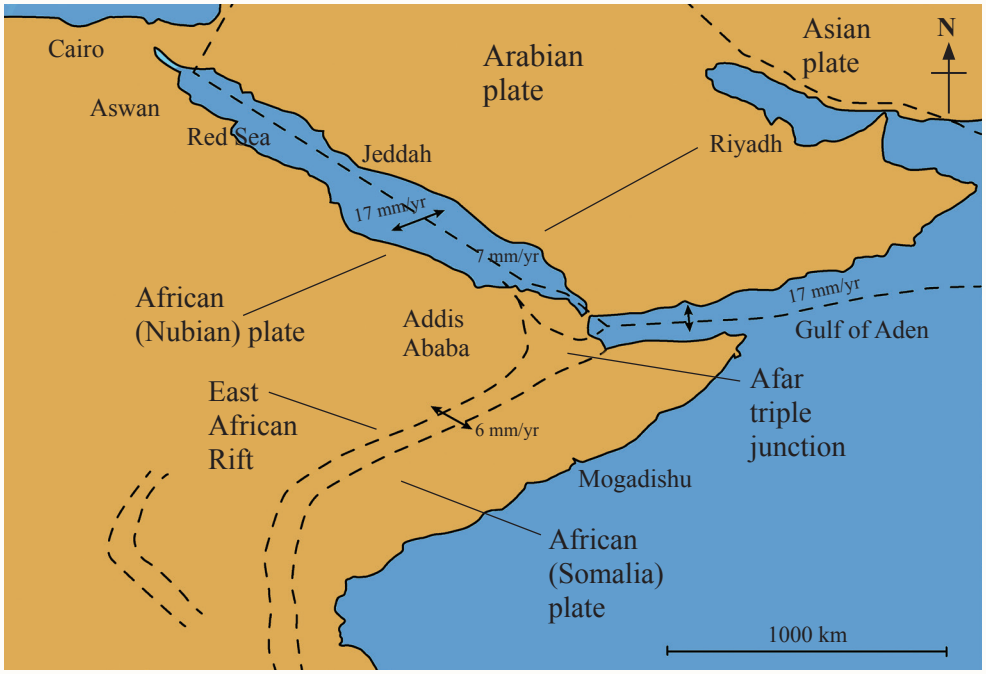


Figure 2.13: *Red sea evidence*

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

Climate similarities and conditions: Also known as paleoclimate. Coal formed under warm wet conditions that were found beneath the Antarctic-ice cap were also noticeable in Tropical Brazil and Central India. Moreover, other minerals such as coal, sandstone, and limestone could not have been formed in Britain having its present climatic conditions.

Geomorphological evidence: This was based on the nature, age, structure and chain of Atlas mountain in Africa and Alps mountain in Europe that seemed to be similar in age, structure and alignment. It is believed that possibly the mountains were formed when Africa moved northward ending up cooling with European continent.

The consequences of continental drift

The consequences of continental drift are highlighted based on the formation of features, climate change, changes in oceanic current pattern, evolution of animals and speciation and crustal deformation. These consequences include:

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Formation of physical features: Drifting of continents led to the formation of various features such as mountains, oceans, seas and the rift valleys. F.B Taylor (1910) hypothesises that fold mountains were formed as a result of movement of landmass. According to Taylor, 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 to 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 changes: 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. Commonly known as net pole-ward movement resulted 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.

Ocean currents pattern change: 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 20^0C at the beginning of Eocene period about 56-53 million years ago to 17^0C during 30–14 million years ago and then cooling to the present to 12^0C.

Evolution of animals and speciation: The rearrangement and displacement of landmasses helped to create the diversity of animals which we are seeing today. Without continental drift, the Earth today would have been very different in terms of animal diversities available in different parts of the world. Continental drift promoted allopatric speciation when the united landmass separated regions that were once connected become geographically isolated. Each separated region becomes an evolutionary arena with plants and animals diverged from those on other continents. For example, the distribution of the flightless running birds or ratites in South America, Africa and Australia is the result of breakdown 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 moved they caused crustal deformation as the applied force exceeded 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.

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Economic activities change: The geographical position changed and have made some of the possible human activities which depend on the nature of the present position of that region. For example, if Africa remained in the Southern pole, some human activities like agriculture would not be possible. Also, continental drift resulted into features like sea, ocean, rift valley and mountains. These features have brought various human activities such as fishing and tourist attraction.

Critiques of the theory of continental drift

Despite the explained causes and evidences, continental drift still faces a number of critiques. Some of the main critiques are; 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 of the revolution of the earth. Another opposition emphasized that from Jeffey (1920) a physicist, 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 scientific community, primarily because the actual force generated by the rotation of the earth were calculated to be insufficient to move the continents. The use of jig saw puzzle analogy as one of the evidences of his theory was not easily accepted. The argument was that, it was not a perfect fit the fact that not all continents can fit exactly to each other whereas 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 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. Geologists could show by using established principles of physics that the proposed mechanism was impossible. Wegener failed to explain on the development of gracier in the hot desert such as Iran's hot desert that exists to the present.

Exercise 2.2

1. With vivid examples, from Africa, support the continental drift theory
2. Explain the forces behind continental drifting.
3. Elaborate the contention that 'continents are restless'.
4. Explain the positive and negative consequences of continental drifting.
5. Discuss the weaknesses of the continental drift theory.
6. Continental drift theory is relevant to African continent. Discuss this statement with supporting example.

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Seafloor spreading theory

Seafloor spreading is one of the modern theories put forward by American geologist Harry Hess in 1960's which supports the idea of continental drift. It provides explanation on the formation of the oceanic mountain ranges called *mid-oceanic ridges* as fundamental results of plate tectonic movements that necessitated continental drifting. Hess stated that new crustal materials are being formed along the mid oceanic ridges as a results of earth's mantle which behave like a giant convectional system in which materials are heated by radioactive elements and rises 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 spreading apart of the seafloor at a rate of 1 – 10 centimetres per year. A good example is Atlantic Ocean which widens at a rate of 1 to 10 cm per year.

Seafloor spreading does not lead to enlargement of the crust. This is because as the new seafloor gains materials at the mid ridge it loses old material elsewhere in the deep trenches where the crust of the new floor is moving downward to the mantle and then melts and becomes part of the mantle which then will be forced out in the form of vulcanicity. By this process the continents carried above are forced to move along it (Figure 2.14).

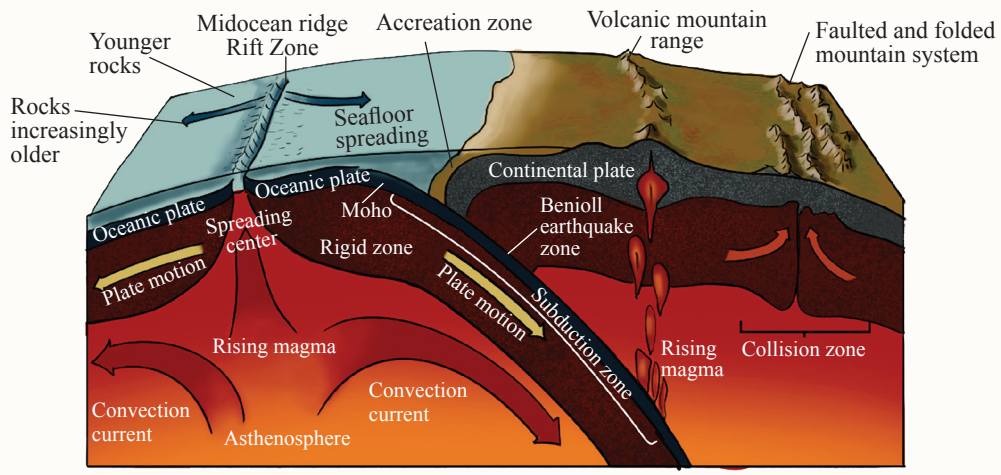


Figure 2.14: *Seafloor spreading*

Evidences of Seafloor spreading

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

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Presence of oceanic ridges: A mid-oceanic ridge is a seafloor mountain system formed by plate tectonics. Typically, it has a depth of 2 600 metres and rises about two kilometres above the deepest portion of an ocean basin. This feature is where seafloor spreading takes place along a divergent plate boundary.

Presence of fractures and rifts at the mid oceanic ridge: The center of the mid ocean is marked by a deep and steeply walled valley. It is believed that this is where molten rock comes up 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 is manifested through the spread of the seafloor of Atlantic and Indian Oceans. The Atlantic Ocean widens by 5 cm per year. The presence of oceanic trenches which form as the seafloor buckles in response to this outward push 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 center are younger than the rocks in the seafloor on either sides. Thus, a move away from the ridge in either direction mark the increase of the age of the rocks of the seafloor. Also evidences 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 solidification iron atoms are locked into place. These rocks of different ages show different directions to magnetic poles. Thus, rocks that hardened in 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, magnetic pole is in the south for a period of time and then in the north for a further period of time and so on. It is claimed that there have been 171 reversals over 76 million years. Thus if basaltic lava formed when the magnetic pole was in the north new basalt iron atoms would be aligned to the north, after the reversal newer lava would be oriented to the south.

The 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. Also, it help us to understand the causes of movement of lithosphere. However, the theory fails to explain the mechanism that would allow continents to move through ocean basins.

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Exercise 2.3

1. With the aid of diagram, explain the theory of seafloor spreading
2. How does seafloor spreading theory connect to previous theories of the movement of continents?
3. Explain how the theory of seafloor spreading is related to the occurrence of earthquakes and volcanoes.
4. Explain the weaknesses of the Seafloor spreading theory.

Plate tectonic theory

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 concept of plate tectonics was brought out in the late 1960's in attempt to address weaknesses of two preexisting theories of continental drift and seafloor spreading. The word *"tectonic"* comes from Greek word *"tekton"* which means a builder. It is of wider implication as it includes the effects of vulcanicity and earthquakes. The basic idea of plate tectonics is that the lithosphere (Earth's crust and the upper rigid part of the mantle) is divided into a number of 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 larger plates

The seven major plates include:

(a) The North American plate - It includes 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) The 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) The Eurasian plate - It is a continental plate, thus it occupies both Europe and Asia continents, include the surrounding areas.

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

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

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

The small plates

The smaller plates are greater in number than major plates ranging to about 13, including Caribbean, Philippine,

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Arabian, Nazca and Juan de Fuca plates (Figure 2.15). These plates are moving over the hot, partially molten asthenosphere, though their speed is low.

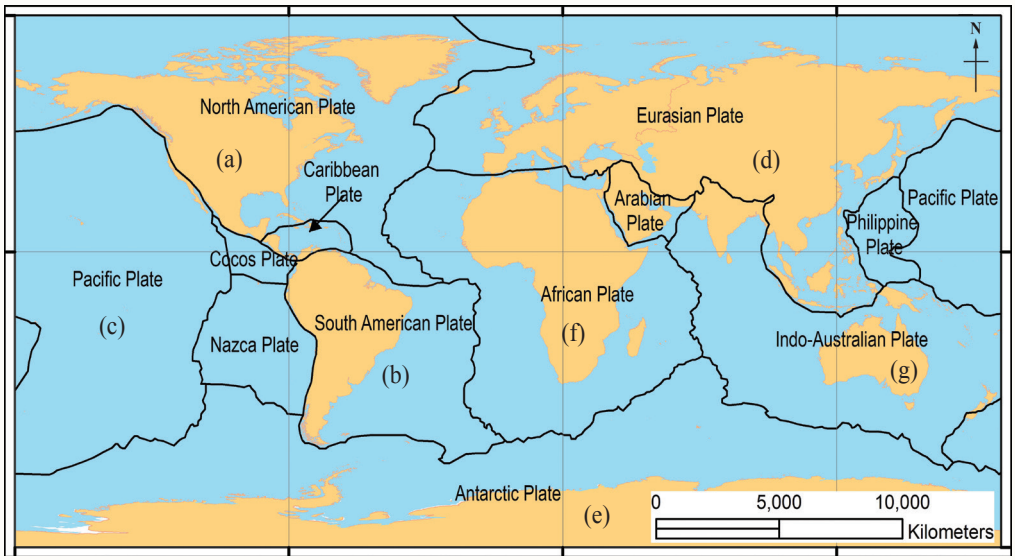


Figure 2.15: *Major and Minor Plates*

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 float on underlying semi molten mantle (the asthenosphere) and are moved by convectional currents. Generally, the theory can also be explained as the study of the movement of the plates and their resultant landforms. The plates are basically divided into two types which are continental plates and oceanic plates.

Continental plates

These are plates which carry the continents above them, hence referred as continental mass. They are composed of sialic older, lighter rock of granitic type. They are dominated by minerals rich in silica and aluminum (sial). They have old rocks mainly over 1500 million years. The continental plate of Africa, North America, and South America are the 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 young mainly under 200 million years. The boundary between the crust (continental or oceanic) and the underlying mantle is known as *Moho or Mohorovicic discontinuity* that was named after a study conducted by Andrija Mohorovicic in 1909.

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Causes of plate movement

The causes of plate movement are mantle convectional current, 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 slowly and contrasts hence, become denser and sinks down again (Figure 2.16). The new oceanic crust gradually cools and thickens with age and is pushed downhill as new magma emerged from the active zones of divergence behind it. This force is regarded as a secondary force.

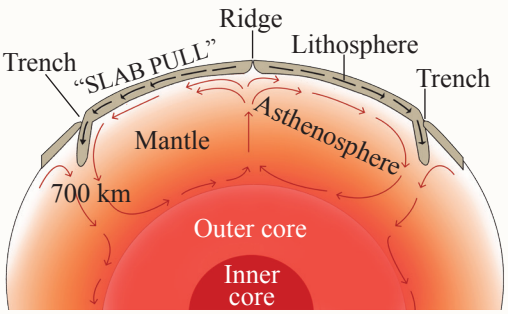


Figure 2.16: *Mantle convectional current*

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, then cools and solidifies. This action causes the plates to move. This 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 of the plates to move. As a new crust slowly drifts away from the ridge, it cools and becomes denser, thus causing the sea bed to sink at 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 to the deep trench hence causing motion of the plates. *Oceanic topography:* Oceanic topography is also known as elevation of the mid oceanic ridges. The loading and unloading theory applies as elevated parts subjected to extra weight resulting into sinking of the materials which in turn lead to plate motion. As plates move, they either collide, move apart or slide past each other resulting to the formation of various landforms such as mountains trenches, earthquakes, volcanoes, and mid oceanic ridges.

Usually, landforms formation occur in plate boundaries, and zones or margins. However, before accounting for the

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formation of these landforms, several aspects should be noted;

(a) Due to its relatively low density continental crust does not sink and so it is permanently floating on denser oceanic plate. Oceanic crust is being formed and destroyed continuously.

(b) Continental plates, such as the Eurasian plate, may consist of both continental and oceanic crust.

(c) Continental crust may extend far beyond the margins of the land masses.

(d) 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.

(e) No 'gap' may occur on the earth's surface, so if two plates are moving apart, new oceanic crust originating from the mantle forms new ocean floor.

(f) 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.

(g) Plate movement is slow (though not in geological terms) and is usually continuous. Sudden movements are detected as earthquakes.

(h) Most significant landforms (fold Mountain, volcanoes, island arc, deep sea trenches and batholith intrusions) are found at plate boundaries. Very little change occurs in plate centers (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: oceanic ridges, Benioff zones, young fold mountains, and transform faults. Plate boundaries can be classified into three main types which includes divergence, convergence and transform/ conservative/shear boundaries.

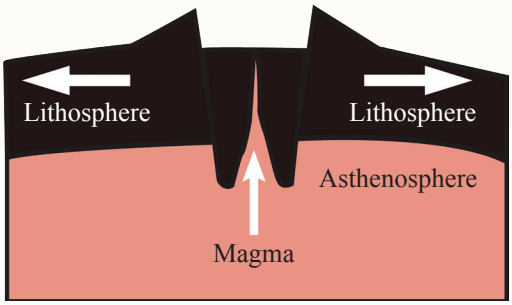
Divergence plate boundary

This boundary (zone) is also known as constructive zone. This is a zone whereby two plates move away from one another. These margins are also called constructive zones because new materials from the interior part of the earth are added to the surface forming some new features like the mid-ocean ridge, island arcs, and new oceanic crust. A divergence zone can be found between oceanic plates, continental plates, and continental and oceanic plates. When divergence occurs in the ocean floor no gap will be left on the ocean floor as new crustal material from mantle fills them. Also, when divergence occurs on the continent (Figure 2.17), the continent

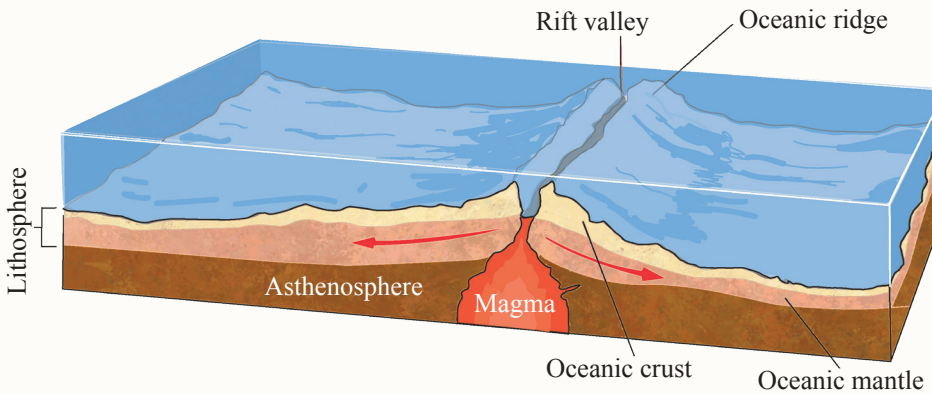
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will break up and drift apart and the central block subside. On the land giant troughs such as the Great Rift Valley in Africa forms when plates moved apart. The continent to continent divergence zones are associated with different features.



(a) Continental divergent plate boundary



(b) Oceanic divergent plate boundary

Figure 2.17: *Divergence plate boundary*

Formation of rift valley occurs if the divergence boundary is on the continental land. For example, the East Africa rift valley. Volcanic features like volcanic mountain are formed as magma forces along the fault. Mount Kilimanjaro is an example of volcanic mountains. 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 is the Mid Atlantic Ridges which are 1000 km wide and 2500 km high. The formation of rift valley at the mid-oceanic ridges happens when the oceanic ridge breaks at the center. The Atlantic Ocean is an example of seafloor spreading. It was formed due to divergence of South America and African plates. Moreover, volcanic islands are formed from the rising submarine volcano at divergence 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 formation of trenches such as Marianas, fold mountains like the Himalaya and volcanic islands like Japan. Convergence

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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 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 2.18). The subduction zone is active in volcanicity and earthquakes zones.

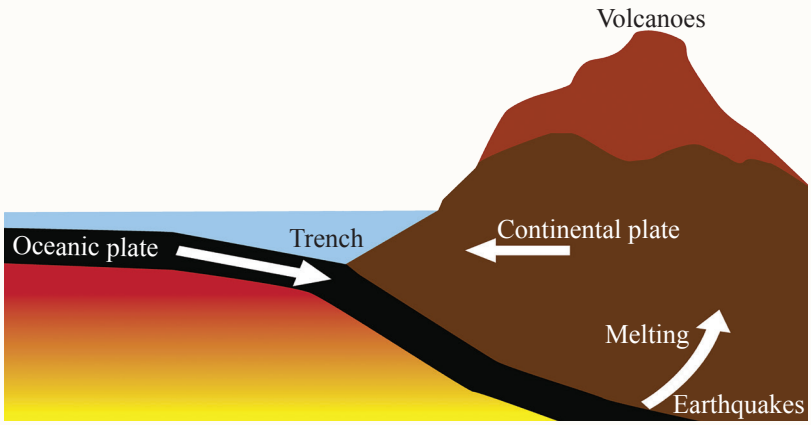


Figure 2.18: *Continental and oceanic convergence boundary*

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 part rather they are forced to bend hence leading to the formation of fold as well as mountains such as the Himalaya, Alps and Atlas (Figure 2.19). Also, it is known as destructive zone because the plates tend to lose the materials at the margins where collision occurs.

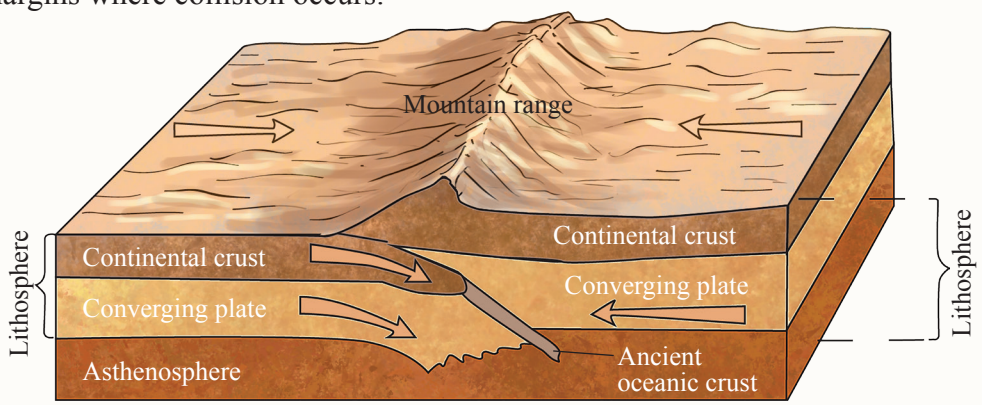


Figure 2.19: *Continental - Continental convergence boundary*

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Oceanic - Oceanic convergence boundary

Oceanic - Oceanic convergence boundary occurs when two oceanic plates converge, one is subducted beneath the other along an oceanic- oceanic plate boundary especially when one oceanic plate is slightly denser than the other. An oceanic trench is formed where one oceanic plate is subducted beneath another (Figure 2.20). 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 of Japan.

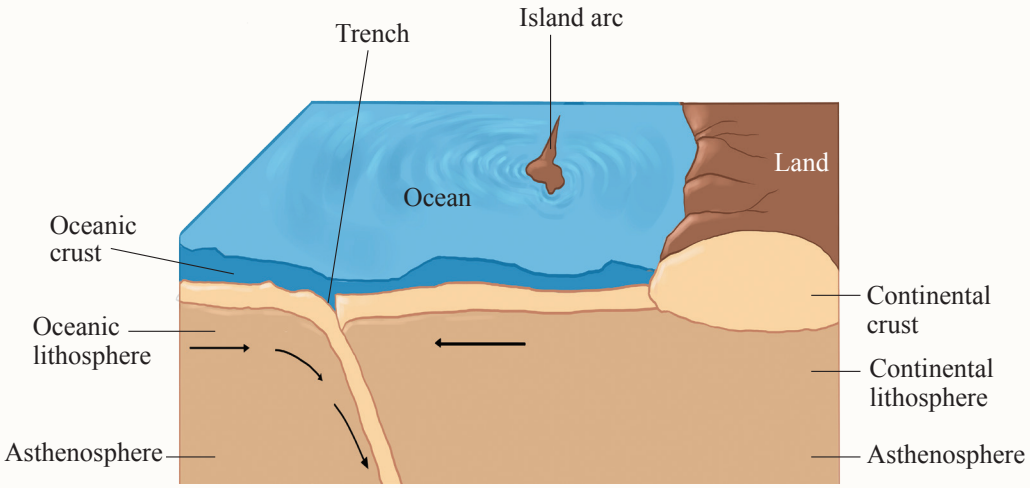


Figure 2.20: *Oceanic –oceanic convergence*

Resulting landforms on convergence plate boundary

Converging boundaries are associated with various landforms. For example, formation of deep trench due to downward movement of oceanic rocks beneath continental rocks or due to collision of two oceanic plates. Some examples of these include Java trench and Mariana trench which were formed when the Philippine plate subducted under the pacific plate. Fold mountains form when a continental plate collides with another continental plate or oceanic plate collides with a continental plate. Such mountains include: Atlas Mountains, Himalaya Mountains, Andes mountain and Rockies mountains. Also, there is formation of an island arc due to volcanism. Examples of island arcs include Japan and West Indies. Formation of volcanoes is due to the rise of destroyed oceanic rocks into mantle. Moreover, due to descending of oceanic crust major earthquakes occur.

Transform boundaries

Transform boundaries are also known as conservative tear or shear plate margins. These occur when two lithospheric plates slide each other along a transform fault (Figure 2.21). During that process

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neither of the plate is created or destructed as a result transform faults which are accompanied with tremors and earthquakes may occur. Examples of transform boundaries are the San Andreas Fault in California and North Anatolian Fault in Turkey. These boundaries are associated with faults and earthquakes.

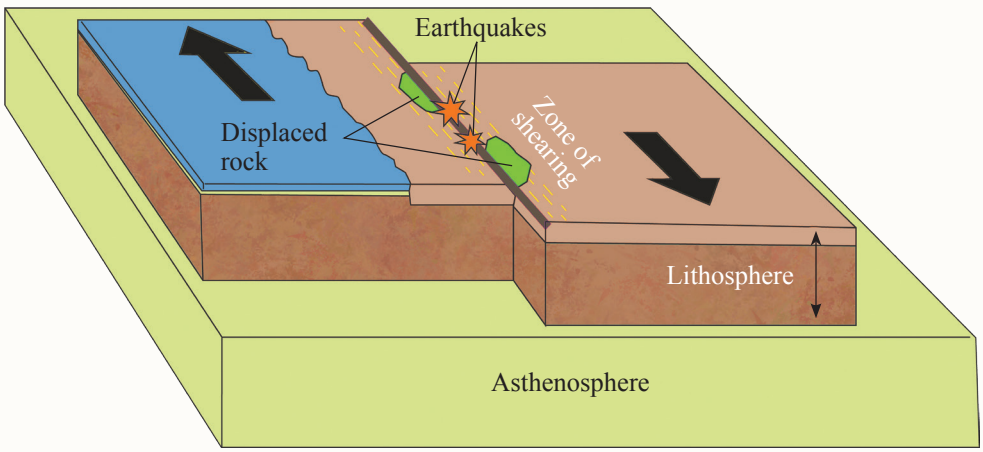


Figure 2.21: *Transform boundary*

Application of plate tectonic theory

The plate tectonic theory provides a global framework that successfully explains many of the structural and geophysical phenomena on the earth's surface from mountains building and earthquakes to continental drift. It explains the formation of island arcs, ocean trenches, mid oceanic ridge and rift valleys. Also, it provides the knowledge that the earth's lithosphere is in a constant motion and changes on the plates are expected. It explains the occurrence of the oceanic floor spreading and its consequences to the lithosphere. It also helps in predicting future trends of geomorphological state especially the occurrence of earthquakes and vulcanicity. Moreover, it gives an insight on the rock cycle.

Critiques of the plate tectonic theory

Several critiques have been put forward on the plate tectonic theory. According to the theory, old rocks like pre- Cambrian rocks cannot be found near the crest of the mid oceanic ridge. The theory has not explained about such aspect. Also, the theory did not explain clearly about some faults which are common in both continents and oceans. Moreover, there is weak evidence on thermal convection in mantle, which is usually considered to be one of the driving forces of the plate motions. Furthermore, the assumption that the solid lithosphere can be pushed down into mantle to a depth of 700 km is highly doubted and is not adequately sustained.

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Activity 2.2

1. In groups, do the following activities;
   (a) Search for appropriate readings from school library and online platforms about plate tectonic theory.
   (b) From the reading, find out the main idea of the theory.
   (c) Elaborate on the applicability of plate tectonic in explaining the formation of landforms in the Earth's crust.
   (d) Present your work in class for discussion in the presence of the subject teacher.
2. In group of five students draw world sketch map and then attempt the following
   (a) Indicate the major and minor tectonic plates
   (b) Submit the task to the teacher for evaluation.

Exercise 2.4

1. Explain the causes of plate movements as explained by the plate tectonic theory.
2. With the aid of labelled diagrams, describe the types of tectonic boundaries.
3. Relate the theory of plate tectonic with landforms formation in Africa.
4. Using examples, differentiate between convergent, divergent and conservative plate margins.
5. Substantiate the contention that plate tectonic theory is a new version of continental drift theory.
6. To what extent plate tectonic theory explains the formation of various landforms in East Africa?

Materials of the earth's crust

The Earth's crust is a thin layer of rock that makes up the outermost solid shell of our planet. It amounts to less than half of one percent of the planet's total mass but plays a vital role in most of Earth's natural cycles. The materials of the earth's crust include elements, minerals and rocks. Some elements are also minerals by themselves for example, gold and diamond. An element is a smallest particle of matter which is combined to form Minerals. It is a substance which cannot be split into simpler substances by chemical means. The most abundant elements on the earth's crust include; Oxygen 45.2%, Silicon 27.2%, Aluminum 8%, Iron 5.8%, Calcium 5.1%, Magnesium 2.8%, Sodium 2.3%, Potassium 1.7%, and Titanium 0.9%.

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Minerals are naturally occurring inorganic solid substances having a definite internal structure, chemical composition, colour and shape. They are formed due to the combination of various elements with the exception of a few which are formed by one element for example, gold, diamond and silver (Table 2.1). There are about 2 000 minerals in the earth's crust but all minerals are formed from one or more of eight main elements. Minerals differ in many ways, for example in shape, size, colour, hardness, density and brightness. All minerals, have several things in common such as definite chemical composition, naturally organic and inorganic, and are crystalline solid. *Definite chemical composition of minerals:* This means that the chemical analysis of any sample of a given mineral will always produce the same ratios of elements for example, quartz has two atoms of oxygen for every atom of silicon (SiO2). It means that all occurrence of minerals has a chemical composition that all occurrence of that mineral have a chemical composition that varies within a specific limited range. For example, halite "rock salt" had a chemical composition of NaCl. It is made up of an equal number of atoms of sodium and chloride. *Naturally organic and inorganic minerals:* Human made crystalline compound are not regarded as minerals nor organic substances which are compounds of carbon, oxygen and hydrogen made by living organisms. Some organisms build shells while others have parts that are considered minerals, for example, Calcite. *Crystalline solid:* A crystalline substance is one whose atoms are arranged in a three-dimensions and are regularly repeating an orderly pattern. A mineral must be crystalline; most solids are crystalline. However, there are some substances existing that are not crystalline but they have the criteria of being mineral. They are not actually minerals but mineraloids, for example, opal.

Table 2.1: *Minerals formed by combination of elements*

Minerals	Elements
Quartz	Silicon and oxygen
Mica	Potassium, Magnesium, silicon and aluminum
Felspar	Potassium, Sodium, Calcium and aluminum
Clay minerals	Complex silicates derived from weathered minerals i.e feldspars.

Characteristics and classification of minerals

Minerals are characterized and classified by their unique physical and chemical properties which are hardness, colour, streak, specific gravity, cleavage fracture, luster, crystalline structure, tenacity and reaction with acid. *Hardness:* Hardness

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refers to mineral resistance to scratching. For example, diamond is the hardest mineral and cannot easily be scratched or broken, while talc is the softest mineral and can easily be broken and scratched by hard mineral. Hardness of minerals has been scaled on Moh's hardness scale, which ranges from one to ten. Whereby one for the softer mineral, ten for the hardest mineral. *Colour:* Minerals have distinctive colours which can be used for identification of mineral types. Colour of the minerals depends on its chemical composition for example gold has a yellow colour, olivine (green), biotite (black). *Streak:* This refers to the colour of the mineral in powder form, for example the streak of metallic mineral tends to appear dark particles which tend to absorb light, while most of the nonmetallic minerals tend to appear lighter because particles tend to reflect light. *Specific gravity:* This refers to the ratio of weight of the mineral in comparison to weight of an equal amount of water. It is obtained by finding the difference between the weights of a mineral in air in comparison to the weight of mineral in water. Streak is obtained after scratching rock mineral on streak plate. *Cleavage fracture:* This is obtained when minerals are hit sharply on smooth surface, by this way minerals will tend to break along the line of weakness. So different mineral break in different ways showing different type of cleavage, for example, mica splits in one direction and forms thin sheets. Halite has three cleavage directions and it breaks into tiny cubes. Diamond may split in four directions forming a pyramid. Other minerals such as quartz do not split clearly but break into pieces with irregular shapes. *Luster:* This is the physical property of a rock mineral which indicates how much the surface of the rock mineral reflect light, hence shiny or dull. Luster is either metallic or nonmetallic. Minerals with metallic luster are generally opaque, chemically they include most of the native metals such as the sulfides, and the metallic oxides. Their refractive indices are 3 or greater. Minerals with non-metallic luster are generally transparent or translucent; chemically, they include minerals of the other classes such as quartz and feldspar. Lust of a mineral is affected by brilliance of light used to mineral surface. *Crystalline structure:* This refers to the shape of rock minerals. Mineral crystals occur in various shapes and sizes. Some minerals have a cubic form like halite (salt), and others are prismatic like tourmaline. *Tenacity*: refers to the toughness or resistance of the mineral to break or being deformed. Minerals such as halite, calcite and fluorite are brittle, as their molecules are held together by weak ionic bonds. Therefore, these minerals shatter when they are struck. Metallic minerals, such as copper and gold, are said to be malleable, as they are easily hammered into different forms. Minerals such as talc and gypsum can be cut into thin sheets or sections and are said to be sectile (like section). Mica is an example of a mineral that is elastic, as

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it reforms its original shape after a stress is released. *Reaction with acid:* Minerals like carbonate react visibly with acid. When a drop of dilute hydrochloric acid is applied on a calcite it gives bubbles releasing carbon dioxide

Rocks

Rocks are natural occurring solid cohesive aggregates of one or more mineral materials. Rocks are made up of eight chemical elements which are oxygen, silicon, iron, aluminum, calcium, potassium, sodium and magnesium (Table 2.2). The rocks vary in degree of hardness, coherence, and permeability.

Table 2.2: *Rocks formed by 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.

The classification of rocks

Rocks have varied characteristics. Some rocks are hard and compact like granite and sandstone, some are made up of loose particles for example, gravels and mud. Similarly, there are rocks made up of organic matters like limestone and coal, thus there is a need of classifying them based on their mode of formation (origin), chemical composition and age.

Classificatio 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 Latin word “ignis” meaning fire. It is a rock formed from cooling and solidification (crystallization) of molten rock materials (magma). This magma can be derived from partial melts of pre-existing rocks in either a planet mantle or crust. The melting of rocks is influenced with one or more of three processes that are increase in temperature, decrease in pressure as well as change in composition. Igneous rocks are also called primary rocks because other types of rocks such as sedimentary and metamorphic owe their origin from igneous rock. 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 includes basalt, granite, gabbros, rhyolite and dolerite.

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Characteristics of igneous rocks

Igneous rocks consist several characteristics. Some of these characteristics are 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. Also, igneous rocks 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 and solidify phase after phase to form layers but these layers are not in strata like sedimentary rocks. The rocks do not contain fossils but rather acidic or basic igneous rocks formed due to cooling and solidification of magma which did not contain fossils because there was no life. Also, the nature of magma is hot, therefore any fossils can be destroyed. Igneous rocks are classified into various ways. The classification is based on various characteristics of the rocks such as form and texture, size, mode of formation, chemical composition. Basing on the mode of formation there are two types of igneous rocks which are intrusive and extrusive igneous rocks.

Intrusive rocks which are also known as plutonic, occur when magma cools, solidifies and crystallizes slowly within the Earth's crust. A common example of this type 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 also are known as volcanic occurs when magma reaches the earth's surface either as lava or fragmental ejecta forming rocks such as pumice or basalt. Generally, extrusive igneous rocks are formed mostly by fissure eruption of volcanoes resulting into flood basalts. Igneous rocks can be further classified based on their texture and chemical composition.

Characteristics of igneous rocks based on texture

This refers to the physical characteristics of the minerals such as grain size. It relates to the cooling and solidification history of the molten magma from which it comes. The texture of igneous rock includes phaneritic, aphanitic, porphyritic, glassy, vesicular and fragmented textures. *Phaneritic texture:* Rocks are comprised of large crystals of 0.5 mm to several centimeters 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 slow cooling and solidification of magma beneath the earth's surface in the

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plutonic environment. *Aphanitic texture:* This is comprised of small crystals which are generally less than 0.5 mm and they cannot be seen by the eye or hand lens. This texture results from rapid cooling 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 termed phenocrysts and the finer grains either matrix or groundmass. Porphyritic rocks usually have undergone two stages of cooling; one at depth where the larger phenocrysts formed and the second near the surface where the matrix grains crystallized. *Glassy texture:* This is non-crystalline whereby the rock does not contain mineral grains. Glass results from cooling that is so fast, and that minerals do not have 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 the result of gas (bubbles) expansion which often occurs during volcanic eruptions. Pumice and scoria are common types of vesicular rocks. *Fragmental (pyroclastic) texture:* During 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.

Characteristics of igneous rocks based on chemical composition

This refers to the rock's specific mineralogy and chemical composition. It is associated with the cooling and solidification history which influences the composition of that igneous rocks. Most of the igneous rocks are extremely compacted in their chemical composition. They range from Acidic (Felsic), Basic (Mafic), Ultra basic (ultra -mafic) and intermediate (Figure 2.20). Acidic igneous rocks are rocks which have more than 50% of silicate and basic igneous rocks are those which have less than 50% of silicate. These type of rocks based on chemical composition are acidic, basic and ultra- basic. *Acidic (felsic) igneous rocks:* These are types of igneous rocks which consist of great amount of silica and feldspar. They have very little or no iron (metallic minerals), 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 are also called Ferro magnesium minerals. They are igneous rocks that consist of large amount of magnesium, iron and aluminum. They are rich in iron and magnesium because of the presence of metallic minerals for example, basalt, gabbro and dolerite. They are of high density of 3.0g/cm^3. The world *"Ma"* comes from Magnesium and "fic" from ferric (iron) such as gabbro, basalt and they are dark in colour. *Ultra basic*

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(mafic) igneous rocks: These consists of a very large amount of metallic minerals like iron and magnesium. It has little amount of silica less than 45% a good example is peridotite. It lacks aluminum and it is high in density of about 3.3g /cm^3. They are very rare on the earth's surface, normally comprise of great bulk of materials found below the earth's crust. Figure 2.22 summarizes chemical composition of igneous rock.

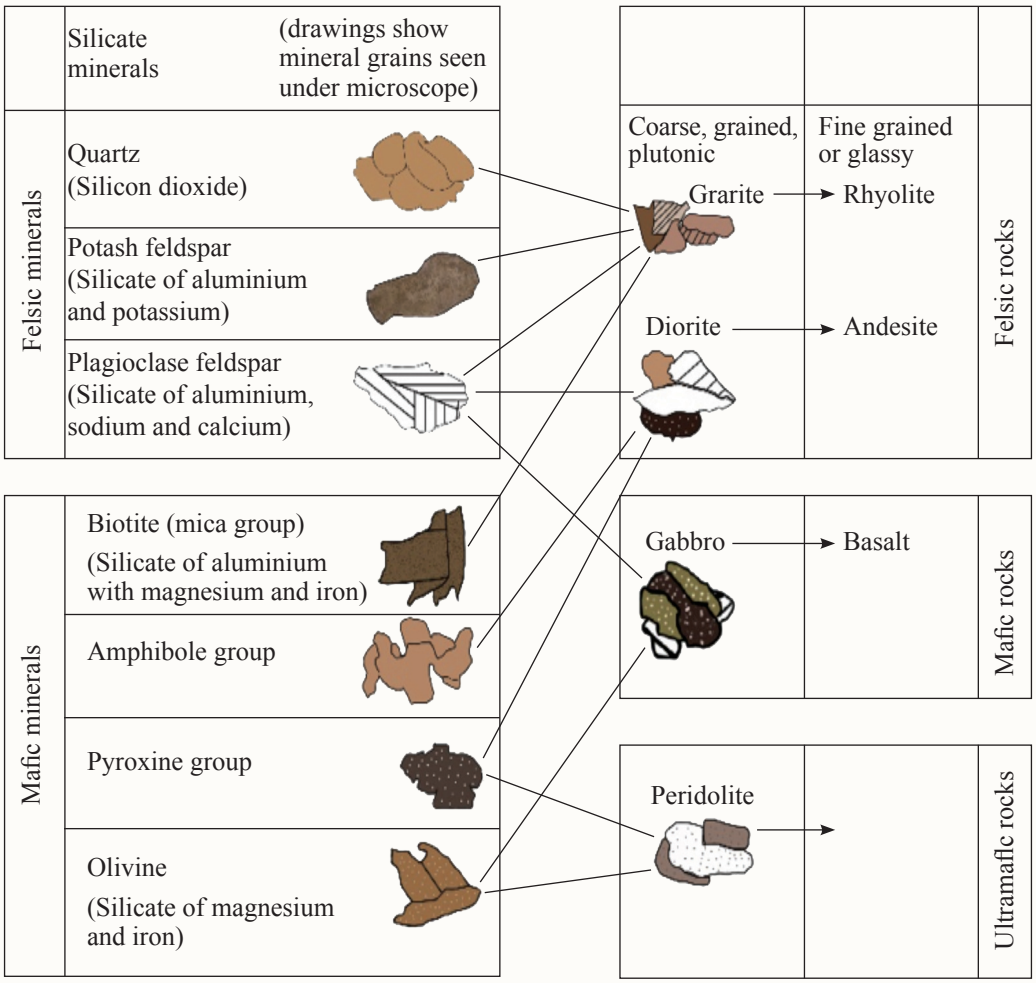


Figure 2.22: *Chemical composition of igneous rocks*

Sedimentary rocks

The word sedimentary comes from the Latin word *"sedere"* which means 'sit" or *"settle"* referring to the types of rocks which have been formed either from sediments or the remains of once lived organisms. Sedimentary rocks are rocks formed at or near the earth's surface by the accumulation and lithification of sediments

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or by the precipitation from solution at normal surface temperatures. They are formed from the remains of former rocks which have been weathered, and eroded and the remains have been transported and deposited elsewhere by wind, water or ice. The deposited sediments are consolidated, compacted and then be cemented in a number of ways to form sedimentary rocks. Sediments can be detrital, chemical or organic sediments. Detrital sediments are mechanically eroded from pre-existing rocks. Chemical sediments on the other hand are fluid precipitates or evaporites deposited in various 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 plants and animal remains. They contain several layers or strata but are seldom crystalline rocks. 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. The sedimentary rocks are mostly formed from 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 rock by influence of heat/ pressure or weathering process. They are formed by accumulation, compaction, cementation, and lithification of sediments

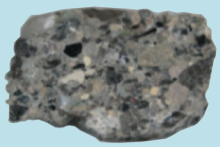
Classification of sedimentary rocks

Sedimentary rocks are classified into two groups based on the size of the rock or mineral grain and mode of formation. Basing on the size of mineral grain, sedimentary rocks are classified as *clastic*. Clastic sedimentary rocks are formed as bits of weathered rock and cemented together. Because all kinds of rocks are subjected to weathering many different minerals can make up this group of rocks. Clays 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 consist of rock and mineral grains, or clasts, of varying size, ranging from clay-, silt-, and sand-up to pebble-, cobble-, and boulder-size materials. These clasts are transported by gravity, mudflows, running water, glaciers, and wind and eventually are deposited in various settings i.e. in desert dunes, on alluvial fans, across continental shelves, and in river deltas. Based on their mode of formation sedimentary rock is categorized into three types which are mechanically, organically and chemically formed sedimentary rocks (Table 2.3).

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Table 2.3: *Types of sedimentary rocks and their characteristics*

Rock name	Description
 Limestone	The rock is classified as chemical or organic sediment depending on how it forms. It is composed primarily of calcium carbonate. The rock can form in two ways either by organically from the accumulation of shell, coral, algal and fecal debris or from chemically from the precipitation of calcium carbonate from lake or ocean water. Limestone is used in many ways. Some of the most common are: production of cement, crushed stone and acid neutralization.
 Conglomerate	This is a clastic sedimentary rock that contains large (greater than 2 millimetre diameter) weathered debris. Environments where large amounts of sand can accumulate include beaches, deserts, flood plains and deltas.
 Sandstone	This primarily a clastic sedimentary rock made up mainly of sand-size (1 to 2 millimetre diameter) weathered debris. Environments where large amounts of sand can accumulate include beaches, deserts, flood plains and deltas.
 Coal	This purely organic sedimentary rock that forms mainly from plant debris. The plant debris usually accumulates in a swamp environment. Coal is combustible and is often mined for use as a 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. Closer to the source, the grains will tend to be larger and more angular. 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*. These classifications are based on transporting agents. 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 mm. They are characterized by having visible layers, contain fossils, those cemented with silicate solution

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contents are tough and those cemented with calcium solution are weak, jointing may develop at 90^0 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 mm, or if silt is included, to 0.004 mm. Some arenites are composed primarily of carbonate particles, in which case they are called calcarenites and grouped with the limestones. *Rudaceous rocks* consist chiefly 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 are cemented, they form conglomerates and breccias.

Organically formed sedimentary rocks

These are the rocks formed from the remains of once lived organisms either animals or plants and 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 rocks formed from the shells and skeletons of once lived animals for example, limestone and chalk or coral reefs. *Siliceous rocks*. These are rocks formed as a result of remains of organisms like diatoms and radiolarians whose skeletons are rich in silica, for example, diatomite rocks. *Carbonaceous rocks*. These are rocks formed from plant remains buried thousands of years ago, under heat and overlying pressure resulting to plants changing into rocks, for example, coal like lignite, bituminous, anthracite, and brown coal. *Ferruginous rocks*. These are rocks formed from precipitation of hydrated iron oxide by some small bacterial organism produced by decomposing vegetable matter composed of high concentration of iron for example, ironstone and ferric rocks.

Chemically formed sedimentary rocks

These are kind of rocks that are formed when rocks undergo chemical changes, whereby 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 by the dissolving original minerals. Not all sedimentary rocks are formed from rock pieces. Chemically formed igneous rock includes gypsum. *Gypsum and rock salt:* These rock form when a body of water which contains a large amount of dissolved minerals evaporates, then the dissolved mineral matter remains as deposit. For example, if water supply to a lake is cut-off, therefore, the water in the lake will eventually disappear and the lake become Salt Lake. If a body of water in the lake contains calcium sulphate dissolved minerals, when dries, usually form gypsum as one of sedimentary rock. On the other hand, rock salt will form if it contains chloride as dissolved minerals. *Carbonation:* Occurs when weak carbonic acid is formed through dissolving rain water as it falls in from

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the atmosphere when it reaches the rocks rich in calcium carbonate like limestone that tends to be transformed to calcium bicarbonate which is easily removed in solution. Limestone landscape, is one of the most noticeable feature. It has very low or almost no vegetation. The reasons for poor vegetation or absence of vegetation is that the permeability of limestone permits rain to soak into it very easily. The rivers from non-limestone region sometimes flow to limestone region, and when this happens, the river, disappears into vertical holes in the surface and continue to flow as underground rivers inside the limestone.

Metamorphic rocks

These are rocks formed either from sedimentary or igneous rock or igneous after being subjected to high pressure, high temperature below zone of diagenesis or both. Any rock can be altered by great heat and pressure including earlier formed metamorphic rocks in the process of metamorphism. In fact, a metamorphic rock means a complete alteration in the appearance of pre-existing rocks due to 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. In this agent when active chemically hot gases and water passing through the rocks changes 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. *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. Therefore, there are four types of metamorphism, namely; dynamic (pressure force), thermal (heat force) thermos – dynamic (combination of heat and pressure) and metasomatic.

(a) 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.

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(b) *Thermal metamorphism*

This involves rocks which are deeply buried and those which come into contact with magma. Hence, it is the type of rock formed only by the influence of heat. Metamorphism occurs at temperature of 100^0C and 800^0C. 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 for example, sandstone – quartzite, limestone – marble. Two processes under this are involved, that is firstly; *by buried metamorphism*, which occurs to deeply buried rocks where temperature reaches 300^0C to cause metamorphism. Secondly, by *contact metamorphism* which occurs to rocks which are adjacent to bodies of hot magma intruded into the cold crust, this is called *aureole metamorphism*.

(c) *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.

(d) *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. *Foliated rocks:* This is a metamorphic rock whose minerals are arranged in parallel layers. This results when minerals are crystallized or are flattened under pressure. Also, they occur when minerals of different densities separate into layers behaving like a mixture of oil and water which result in alternating light and dark bands. Many foliated rocks break into thin sheets, for example, slate and schist. *Non-foliated rock*. This is a metamorphic rock without layers and sometimes they may contain long crystals. These rocks do not break up into sheets, for example, marble and quartzite. Moreover, metamorphic rocks are very hard and resistant than the former rocks mainly igneous and sedimentary and they are formed under high pressure and temperature.

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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 undergo weathering to form sediments that in turn form sedimentary rock. Most of them have wavy like structure.

Classification of rocks according to age

Rocks are classified basing on the age which 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.

The rock cycle

Rock cycle is a concept in geology that explains the transition and transformation among the three main types of rocks which are igneous, sedimentary, and metamorphic rocks. Rocks can change from one type of rock to another. It also describes the processes and forces behind that transition. Rocks are constantly being exposed to various physical and chemical conditions which change overtime. 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 movement of water, ice, and air at the surface. Generally, a rock cycle can be seen as an endless revisable process by which rocks change from one type to another.

Stages of rock cycle formation

The first stage of rock cycle is determined by the presence of magma. When magma is are forced outside via vents, fissures, and cracks, may cool 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 being compacted by pressure of overlying layers of sediments to form sedimentary rocks. The process of sediments to be compacted 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. The cycle loop is completed by this stage in which the metamorphic rocks are subject to greater heat and pressure and become molten and then be converted into magma. However, there is no inevitability about the order of this cycle, for example an igneous

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rock may change, without becoming a sedimentary rock, be transformed into a metamorphic rock by heat and pressure. Equally, sedimentary and metamorphic rocks may be converted to material for new sedimentary rock. Recently the rock cycle as described above has been related to the theory of plate tectonics. Where the cycle starts with the erosion of a continental land, and 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 undergo still greater metamorphism and eventually temperatures and pressures may be so great that melting takes place to generate magma. The magma later on is converted into igneous rocks which may eventually appear at the earth's surface, either as extrusive igneous rocks from volcanoes or by the exposure, by erosion, of intrusive igneous rocks. The igneous rocks are attacked by weathering and erosion, then transported to the continental margin and so the cycle starts again. Generally speaking, rock cycle has neither beginning nor end, but however 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 igneous rock (Figure 2.23).

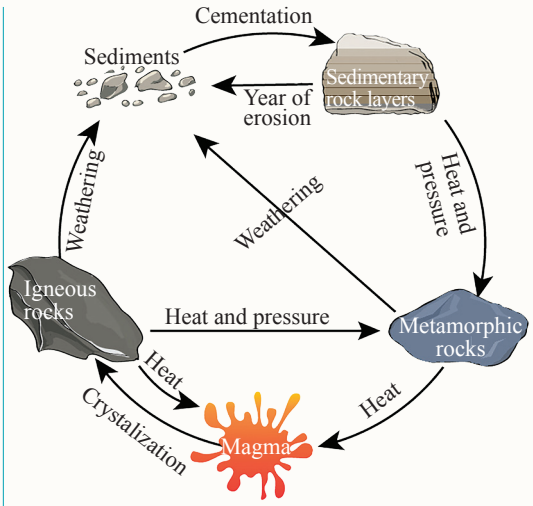


Figure 2.23: *The rock cycle*

Importance of rock cycle

Rock cycle is a good model of explaining the essence source and origin rocks. It support diagramatically the transformation of one type of rock to another. It helps in explain soil formation (pedology).

Determining age of rocks

It is believed that the lowest rocks are the oldest rocks and above ones are younger. There are two methods of determining age of rocks. One way 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 the rock was formed during that particular time period. Another way is to use the *'What's on top?' rule*. When you find layers of rocks in 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

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of rocks in the same two ways which are relative age and absolute age.

(a) 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, law of inclusions, law of fossil succession and the lithology of a rock. *The law of original horizontality,* 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 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. 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*: is based on the fact that the layers of sediments will extend laterally continuous over some distance until they are interrupted by the obstacles or 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 is faulted, intruded, or eroded. For example, the mudstone, sandstone and shale are cut by the basalt dyke, it is obvious that mudstone, sandstone, and shale had to be present before the intrusion of the basalt dyke. That makes the dyke to be younger than the mudstone, sandstone, and shale (Figure 2.24).

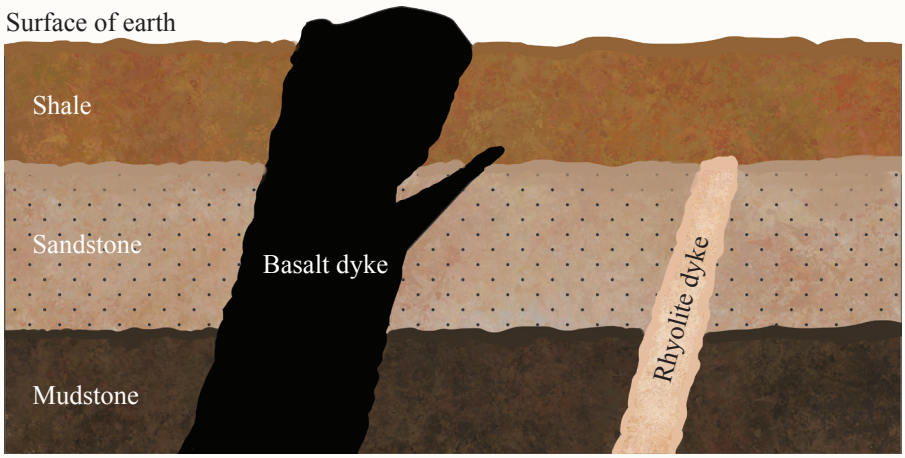


Figure 2.24: *Principles of cross- cutting*

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The principle of inclusion: occurs when the fragmented rock is surrounded with 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:* occurs where evolution has produced a succession of unique fossils that correlate to 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 a 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 refers to determining the age of the rock in comparison with another. It is mostly used on classification of sedimentary rocks. There are three ways to be used on 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 the rock layers become older and older. In other words, vertical arrangement of layers downward determines the rock ages. Basing 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 determine relative ages of rock layers, these are non- conformity, disconformity and angular unconformity.

Non-Conformity: This occurs when the sediments are deposited on top of an eroded volcanic or metamorphic rock (Figure 2.25). This is the gap that occurs where the sedimentary rock over lies 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.

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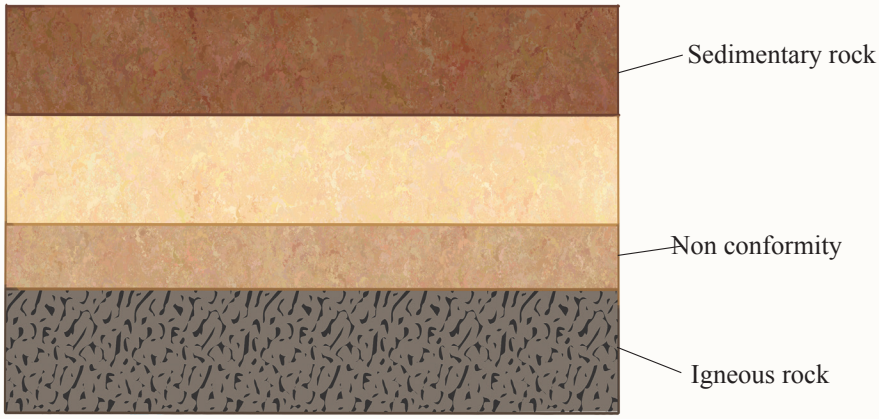


Figure 2.25: *Non conformity*

Disconformity: 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 run-off. Disconformities are much harder to recognize in the field because often there is no angular relationship between sets of layers (Figure 2.26). Disconformities are usually recognized by correlating from one area to another and finding that some strata is missing in one of the areas.

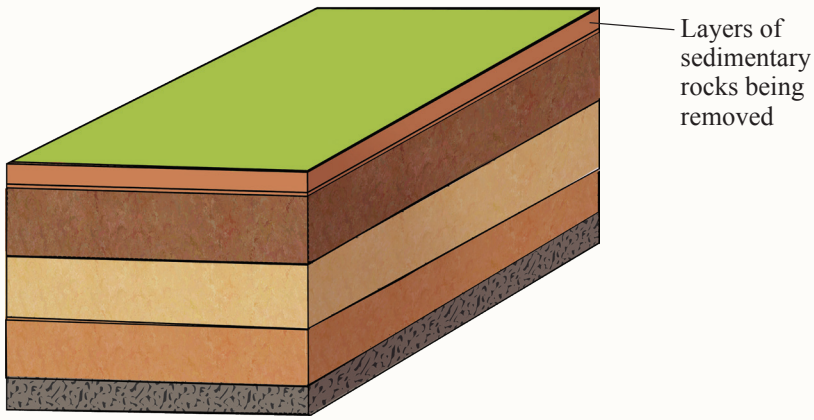


Figure 2.26: *Disconformity.*

Angular unconformity: An angular unconformity occurs where horizontally parallel strata of sedimentary rock are deposited on tilted and eroded layers producing an angular discordance with the overlying horizontal layers (Figure 2.27). It occurs when the folded rock strata (layers) have been eroded and then covered by younger horizontal layers of sedimentary rocks.

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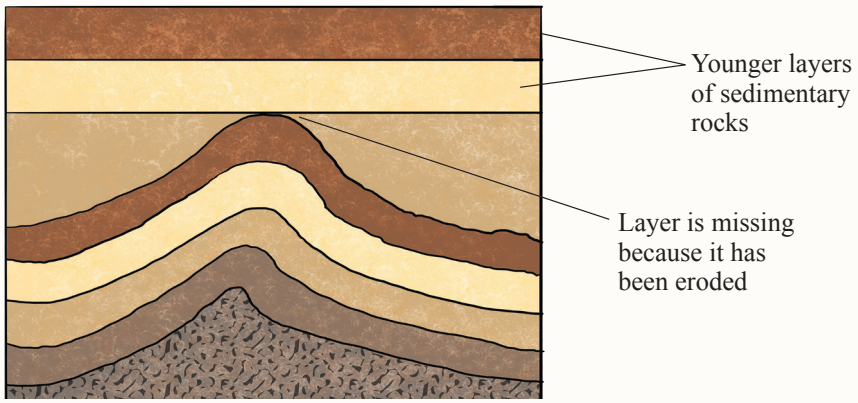


Figure 2.27: *Angular unconformity*

The mineral relativity: This is based on relativity of mineral rocks. By this principle any rock is new or old than the fragments of which is composed. *Fossils index:* This method uses fossils found in rocks which lived on definite order of period. These are remnants or remains of once lived 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 formed on that period. Trilobites are the earliest marine organisms that flourished about 500 to 600 million years ago. Thus by relativity rocks containing graptolites are younger than those containing Trilobites.

(b) Absolute age of rocks

Absolute dating is the process of determining an age of a rock on a specified time scale in archaeology and geology. Some scientists prefer the terms chronometric or calendar dating, as use of the word "absolute" implies an unwarranted certainty of accuracy. Absolute dating provides a numerical age or range in contrast with relative dating which places events in order without any measure of the age between events. They are methods which determine 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. In 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

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substance is one that changes over a period of time. All matter is 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 2.4). Suppose a rock had 100 g of uranium half of it, that is 50 g would decay at 4.5 billion years to form lead. At this time the amount of lead doubles and uranium decreases by half. Due to this very long Half-life, Radioactive Uranium is used to date very old rocks (Table 2.5). Scientists, carefully, measure the amount of uranium and lead in the rocks.

Table 2.4: *Elements used for radiometric dating*

Radioactive Elements	Half-life	Decay elements	Material that can be dated by radioactive element
Uranium - 238	4.5billion years	Lead - 206	Igneous, and Metamorphic
Uranium - 235	713 million years	Lead - 207	Igneous, Metamorphic and Sedimentary rocks
Potassium - 40	135 million 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 2.5: *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

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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.

Radio substance dating: Radiocarbon dating (also referred to as carbon dating or carbon-14 dating) is a method for 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 plant or 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, 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 (GTS)

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. GTS is divided into Eons, Eras, Periods, Epochs and ages (Table 2.6). Eons consists all that span of time from which fossil remains were then known.

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Table 2.6: *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
	Tertiary	Diluvium	Glaciation, invertebrates, large mammals and man	
		Pliocene	Mountain building like Alps, large mammals.	10
		Miocene	Uplift of rockies, grazing animals	25
		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. Coal deposits.	135
	Jurassic		Lowlands widespread: Europe under seas. Mild climates. Mountains rose in Western North America and widespread eruptions. Disappearance of dinosaurs. Pangaea breaks up	180

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	Triassic		Continents mountainous, desert widespread eruption in W, 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	

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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 means '*recent life'* popularly known as the age of mammals. This is the third major era of the earth's history which began about 70 million years ago and has not yet ended. Many of the today's mountains and plateaus were lifted up during this era. At this era ice affected much of the land. This era is referred to as the age of mammals, as mammals were dominant in life forms. Many mammals resembling modern form had appeared by the middle of Cenozoic era, animals like dogs, cats and horses appeared (Figure 2.28). Most of human life fossils have been found in this era. 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 period. Furthermore, periods are divided into epoch, for example, we are living in Cenozoic Era, Quatenary period in the Holocene Epoch.

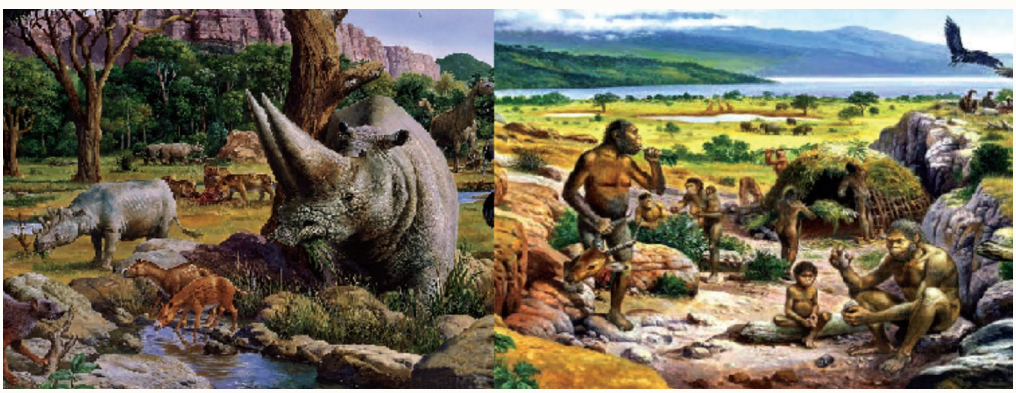


Figure 2.28: *Cenozoic era*

Mesozoic era: Mesozoic means '*middle life'* also known as the age of reptiles. These was due to wide spread of reptiles. This is the second era in earth's history which began about 230 million years ago and ended about 70 million years ago. This era lasted for about 160 million years. At this era continent 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. The climate of the time favored the reptiles to flourish and spread. A good example is the giant dinosaurs meaning 'terrible lizard' that were giant (Figure 2.29). Flowering plants, the family of maple and oak appeared. Birds and mammals eventually replaced reptiles

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that could not adopt the changed condition. At the end of the period dinosaurs disappeared. Mesozoic era is divided into Triassic, Jurassic and Cretaceous periods.



Figure 2.29: *Giant reptiles during Mesozoic era*

The Paleozoic era: Paleozoic means 'ancient life'. This era began about 600 million year ago and 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 close together many types of Invertebrates involved and multiplied. At the late Paleozoic era the first forest appeared (Figure 2.30) and (Table 2.6). The bulk of today's coal formed at this time, insects, amphibian and reptiles appeared, up to its end life was established on land.

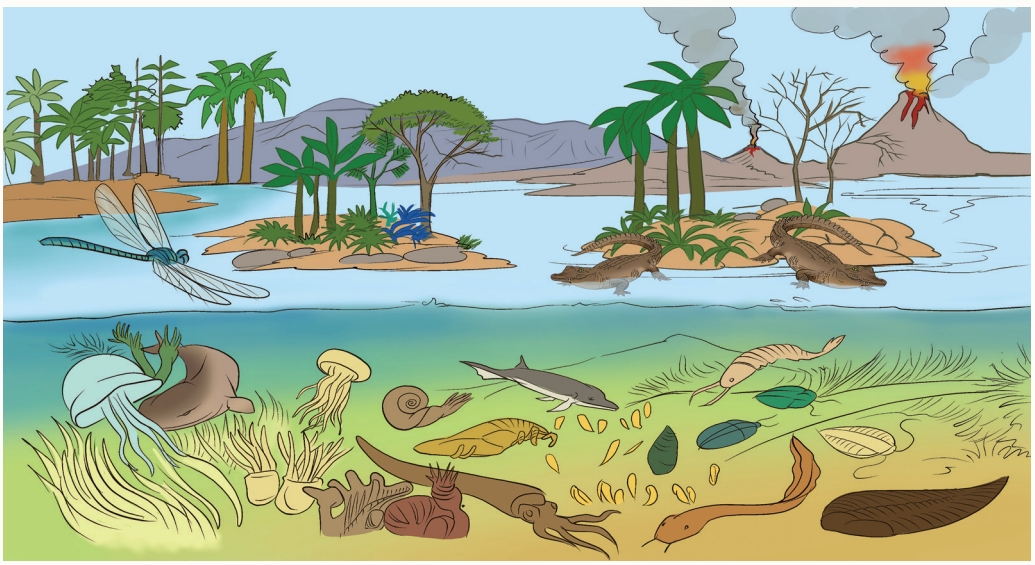


Figure 2.30: *Paleozoic era*

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Pre Cambrian era: This era began with the formation of the Earth and 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 (GTS) was named

Some of the names of rocks were given on the basis of their localities 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 the 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 were formed by glacial deposition and volcanic eruption. Also, it 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 the different mountain building (orogenic) like Laurentian Caledonian, Hercynian and Alpine, Himalaya orogenic, for example, Alps-formed during Miocene 26 million years ago. The Himalayans are said to be formed during Oligocene about 38 million years ago. Furthermore, it 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 already existed and later man emerged. It helps to show the life record of plants and animals, and depict climatic changes which had occurred on 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 rock over 75 000 years ago.

Activity 2.3

In groups;

(a) Discuss the key principles of stratigraphy and explain their importance

(b) Present to class, the principles discussed with their importance.

Improve your findings and write them in you exercise book for further reading.

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Exercise 2.5

1. Mr. Chapakazi told his students that although igneous and metamorphic rocks are all rocks, but they are different. What were the key differences referred by him?
2. On their field trip to rocky city, form five students heard the geologist saying that "Igneous rock is the mother rock". With the aid of well-illustrated diagram describe what do the geologist meant?
3. Igneous rocks are common in our environment. Explain how you can distinguish them basing on their chemical composition.
4. With vivid example, shortlist the importance of rocks to human development.
5. Geological time scale has given a clear picture on the geomorphological and biological history of the earth. Comment on this statement.
6. The geological survey department of Tanzania 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 deposit.

Earthquakes

An earthquake is a sudden shake or tremor shaking of the surface of the Earth, resulting from the sudden release of energy in the earth's crust stored in the rocks beneath that creates seismic waves. Earthquakes can be violent enough to cause loss of people's life and destruction of properties. The seismicity or seismic activity of an area refers to the frequency, type and size of earthquakes experienced over a period of time.

Classification of earthquakes

Earthquake can be classified in various ways including: Classification based on the causative factors can be either natural or human induced, based on area of focus, and rate of casualties. Natural earthquakes are caused by natural processes such as vulcanic earthquakes, caused by vulcanic activity. This involves both the plutonic earthquakes that occur deep in the interior of the earth's crust and the volcanic earthquakes which occur near the surface of the earth with eruptions of both explosive and fissure types. These types of earthquakes occur mostly in volcanic areas. For example, the Mt. Etna volcanic eruption in 1968. Another type is tectonic earthquakes caused by displacement of tectonic plates during faulting activity. For example, in 2001 there was an earthquake of this kind in Gujarat India. Also, isostatic

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earthquake is another natural tremor which is triggered by sudden disturbance in isotactic balance at regional scale due to 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.

Classification basing on the areas of focus earthquakes are grouped into three categories which include moderate earthquakes which refers to the ones whose focus is set or occurs from about 0-50km deep in the earth's crust. Also, the intermediate earthquakes whose seismic focus is located at about 50-250 km deep in the earth's crust. Lastly is the deep earthquakes, including those whose seismic focus occurs deep in the earth's crust between 250-700 km. From earth's surface. Moreover, the classification of earthquake is done basing on the rate or magnitude of human casualties. Through this classification there is moderate hazardous earthquakes which occur and cause human death of below 50 000 people. For example, in Kamakura earthquake in Japan in 1293 recoded the death of atleast 23 024 people. Highly hazardous earthquakes occur and cause human death ranging from 51 000 to 100 000 people. For example, Chimbote, Peru in 1970 at least 67,000 people died. The last type is most hazardous earthquakes causing human casualties above 100 000 people. For example, in 1967 Tang-Shan, China there occurred an earthquake whereby atleast 7 500 000 people died.

Nature of earthquakes

The point at which an earthquake originates is called *Focus*. Focus refers to the exact location within the Earth where an earthquake occurs. It is point within the earth's crust where an earthquake own its origin. It is divided into three categories namely s*hallow*, *intermediate* and *deep* focus. Shallow focus ranges between the earth's surface and 70 km depth, while intermediate and deep ranges between 70 - 300 km and 300-700 km respectively. Most of the earthquakes occur at shallow depth. The point on the earth's surface immediately above the focus is called *the epicenter*. The epicenter is where the shock waves first hit the surface, it is these shock waves which give rise to an earthquake (Figure 2.31). The energy generated by an earthquake is called *seismic waves*.

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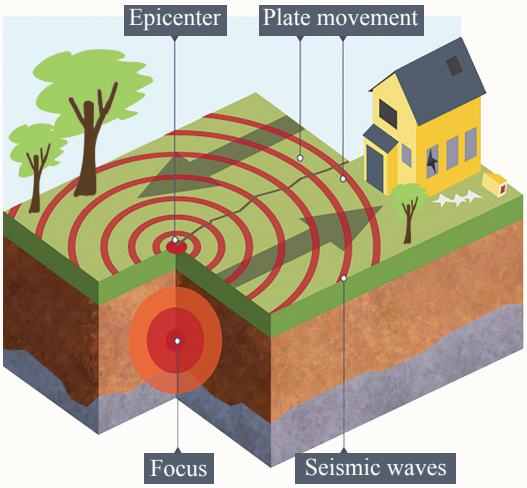


Figure 2.31: *The occurrence of earthquakes*

Seismic waves are the waves travelling 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 P-waves which are type of body wave, that travel through a continuum and are the first waves from an earthquake to arrive at a seismograph. Also, it is called compressional wave because the wave compresses and then stretches the particles of material in the same direction that the wave is moving (back and forth) (Figure 2.32). They are very fast and can travel through both liquid and solid materials.

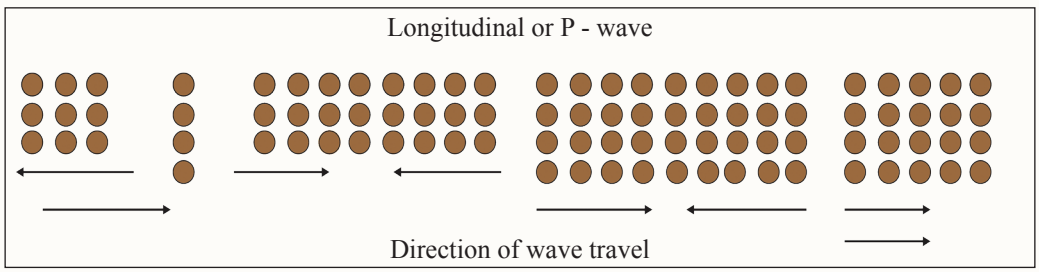


Figure 2.32: *The direction of the P- waves.*

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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 2.33). The vibrating molecules perpendicular to the direction of the wave produces an upward and downward movement that creates alternating high points (crests) and the low points (troughs). The direction of transverse wave motion moves sideways to one another as the wave passes. This motion is called shear movement. They cannot travel in the liquid materials.

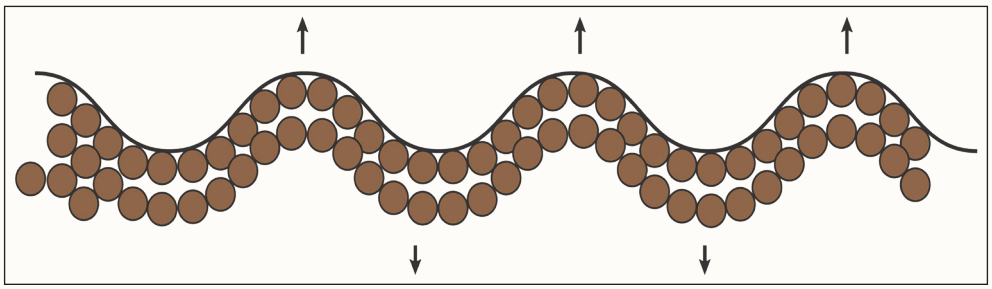
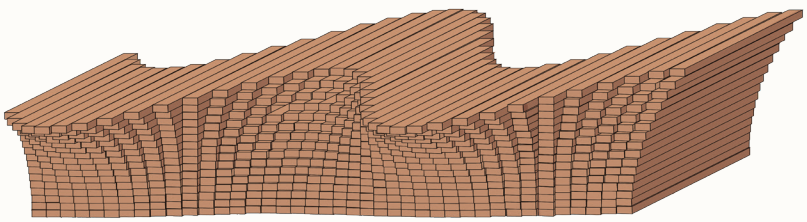


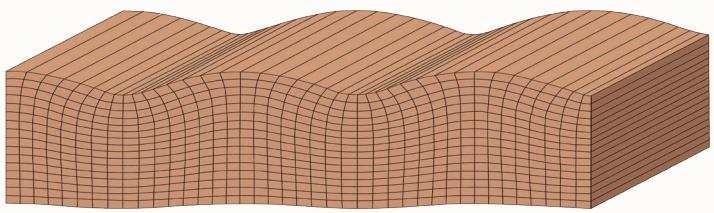
Figure 2.33: *Movements of S- waves*

Surface waves

These are waves travelling through the surface. The surface waves are divided into love (L) and Rayleigh (R) waves. Love waves cause the surface rocks to move from side to side at a right angle 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 (Figure 2.34).



(a) Love waves



(b) Rayleigh waves

Figure 2.34: *Surface waves*

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The causes of earthquakes

Earthquakes are caused primarily by 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 which causes disequilibrium of the part of crust of the earth. Various earthquakes in the earth's crust are associated by plate movements.

The surface of the Earth is in continuous slow motion. The slow motion portrays plate tectonic movement whereby the motion of immense rigid plates at the surface of the Earth is in response to the flow of molten rock material 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. Because of that collision of plates, faults and trenches occur. This is vividly represented by San Andreas Fault in California, Peru-Chile trench and Atlantic ridge. At such places the motion is not smooth, the plates are stuck together at the edges but the two plates continuing to move, so the rocks along the edges are distorted. As the motion continues, the strain builds up to the point where the rock cannot withstand any more bending. With a lurch, the rock 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; when a tectonic plate sliding over another 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 layer slide beneath the other thus the scraps rough surfaces causing the vibration of the earth. Also, sudden faulting which occurs when the forces acting on the crust causing the rocks to bend and finally breaks suddenly which in the final analysis will cause the rocks to vibrate back and forth. Moreover, diastrophic movement resulting from strains in the rocks of the crust on divergent boundary causes shallow earthquakes. Volcanic eruptions cause earthquakes when magma moves below the surface with explosion causing the crust to shake. Furthermore, there are other causes of earthquakes such as mass movement and anthropogenic activities such as quarrying of rocks using explosives like dynamites, nuclear explosion, storage of huge volume of water in big reservoir. Human activities may 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

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three places which are at convergent plate margins, divergent plate margins as well as in the oceanic trenches. In convergent plate margins, earthquake occurs when two plates collide from each other. The impact 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. Also, 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 make new oceanic crust. Moreover, it may occur across oceanic trenches, island arc, and young fold mountain ranges. These are areas prone to earthquakes because they lie in areas of crustal instability. These are the areas where volcanic activities frequently take place.

The common regions where earthquakes occur are the circum-pacific belt. This extends from West Coast of America to West Indies, the East Coast of Asia from the Aleutian Islands, through Japan to New Guinea to New Zealand. Also, they occur in 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. The mid-Atlantic ridge, is a range of submarine mountains from Iceland through the Azores, Ascension Island and Tristan de Cunha and the great African Rift Valley: It runs along the red-sea and through East Africa to Beira. Generally, these zones are categorized as the zone of young fold mountain, zone of faulting and fracturing, zone of active volcanoes and along plate boundaries.

Techniques for 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 considerable loss of life. The earthquake is detected by using an instrument called seismograph (seismometer) (Figure 2.35). This instrument measures, records and determines earthquake waves.

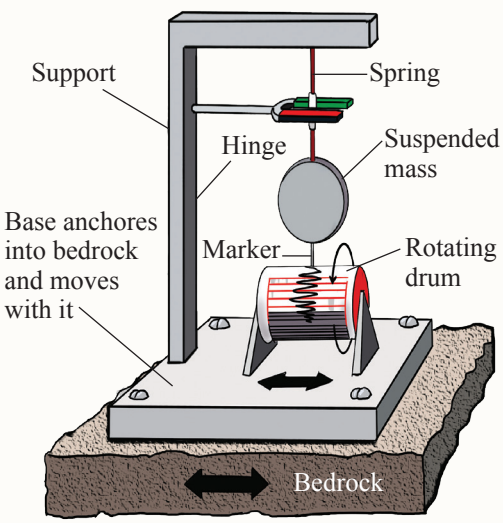


Figure 2. 35: *Seismometer*

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Seismograph records 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 the motionless, the pen records a zigzag line on a paper. This instrument records three distinct types of vibration: 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 hypocenter (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 a number that characterises the relative size of an earthquake. Magnitude is based on 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.

(i) 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 earthquakes sizes and is applicable globally. The scale is based on the total moment release of the earthquake and is derived from modeling recording of earthquake at multiple stations. Moment magnitude estimates the same as Richter magnitudes for small to large earthquakes. But only the moment magnitude scale is capable of measuring M8 (read 'magnitude 8') and greater events accurately. The moment magnitude (Mw) scale is uniformly applicable to all sizes of earthquakes but is more difficult to compute than the other types.

(ii) Richter scale

One way of measuring the severity of an earthquake is by its magnitude on the Richter scale, which ranges from 0 to over 8.6. Richter scale was discovered by an American seismologist in 1935, known as Charles Richter. The magnitude is a measure of the amount of energy released in the earthquake,

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as 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 the year 2003 September 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 on moving 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 epicenter. Intensity is expressed in Roman numbers, for example, V-IX based on the level of observed severity. Intensity is measured through human observations and reports of felt shaking, web based form and recently there are instrumental data at station location used to calculate an estimated intensity. The scale is used to show the intensity of the earthquake and the effects or damage caused by the earthquake. The scale ranges from I to XII. The scale was discovered by Giuseppe Mercalli an Italian Seismologist in 1902.

Factors determining the degree of damage caused by earthquake

The degree of damage caused by an earthquake depends on several factors as follows;

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

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

(c) *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.

(d) *Distance from the epicenter*: The epicenter is the point at the surface where the earthquake originates and is usually the place where the earthquake's intensity is the greatest. Intensity will depend on how far the epicenter is from the population.

(e) *Local geologic conditions*: The nature of the ground at the surface of an earthquake such as loose,

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sandy, soggy soil can have a profound influence on the level of damage. That is why buildings constructed on loose sediments 100 km from an epicenter may experience more damage than buildings built on granite.

(f) *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 building, 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 of earthquakes include structural damage to buildings, fires, damage to bridges and highways, initiation of slope failures, liquefaction, tsunami, trauma, and damage to the life time systems. Usually the types of effects experienced 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.

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: In some cases, earthquakes cause breaking of water and sewage systems. This threatens lives of people. For example, 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. Also, Earthquakes may cause destruction of buildings especially when the buildings are made up of soft sediments, and multi-stone materials. A good example is the earthquake of Kagera, Tanzania in September, 2016 that caused collapse of various buildings made of soft sediments (Figure 2.36). The earthquake measured a magnitude of 5.9 Mw with 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.

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Figure 2.36: *Destructed building by earthquake in Bukoba district, Kagera region in 2016*

Fire outbreak: Fire occurs during ground shake due to the disruption of gas and electrical lines. For example, most of the damage in the great 1906 San Francisco earthquake was caused by massive fires in the downtown area of the city. In that incident, 250 000 buildings were damaged by the fire which were fueled 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. However, 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. Also, earthquakes cause death to both human and animal population. For example, on 26th 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 Indian Ocean coastline in which 11 people were reported to have died in Tanzania.

Stress and panic: During the occurrence of earthquake people usually panic run away, jump out through windows and many more unusual behaviour. Although earthquakes last for a very short time, a large number of people suffer psychological traumatic consequences for many years. Many have lost relatives and a large number have had to move away from their homes. For example, 628 Jurukovski stress had serious consequences since the population

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lost their work capabilities and got psychological problems.

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. These results to economic loss, breakdown of timely food supply, medicines, and equipment which in the final analysis affect human population.

Damage to industrial and other technological systems: Earthquakes cause damage to industrial and other technological systems. Failure of some technological systems that use toxic, explosive, and inflammable materials result into other dangers that include loss of human lives and serious environmental damage.

Precautionary measures to avoid damage from earthquakes

Many of the earthquake incidences occur as a result of natural processes, hence it is difficult to predict their occurrence. Therefore, it is important to look at historical records of earthquakes and conduct geologic field research that can indicate how recently a fault has moved. Also, 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. Moreover, there is a need to construct buildings which have protective mechanisms from earthquake disaster.

Earthquake warning signs

There are several signs that sometimes are observed before an earthquake occurs. 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 the area keeps increasing. Often on the day of an earthquake the temperature of the place may record about 5 to 9^0C above the average temperature of that day. *Water indicator*: About one or three days before an earthquake there is a sudden rise or fall in water level in wells to as high as one meter. The water in a well may turn muddy. At times a fountain appears inside a well or in the ground (occurs few hours before the earthquake). Sudden increase or decrease of water flow in rivers (occur 1 to 2 days before the earthquake). *Seismoelectromagnetic indicator:* Before the earthquake the subsurface temperature rises, this reduces the geomagnetic fields and adversely affects the propagation of the electromagnetic waves. This is experienced on the radio, television (signals are affected), and

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telephone (occurs 10 to 20 hours before the earthquake). Mobile telephones stop functioning about 100 to 150 minutes before the quake. *Animal indicator:* Between 10 to 20 hours before the occurrence of the earthquake the entire animal kingdoms become highly restless. They move in directionless manner and fear. Birds do not perch on trees but move about at low height emitting a shrill noise. Rodents like rats and mongooses go into panic. Domesticated animals like cows, dogs struggle against being tied up and may turn on their owner. *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 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 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 hut, then check the people around you to help.

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

(d) Be on a lookout of fire.

(e) In the process of leaving a building after shaking, use the stairs and not the elevator

(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 in the elevator stop the elevator at the nearest floor and get out immediately

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

(i) In public building, follow the attendant's instruction.

(j) Do not rush to the exit in train, hold on tightly to the strap or a handrail.

Tsunami

A tsunami is a series of ocean waves generated by any disturbance that displaces a large water mass. Such disturbances include earthquakes, volcanic eruptions, earth and submarine landslides which displace large water masses. The word Tsunami is a Japanese word meaning 'harbor wave'. There are various causes of tsunami include, earthquakes, volcanic eruptions and submarine landslides.

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Earthquakes: This is generated by the movement of plates along the fault line. Usually Tsunami in this area occurs when the earthquake magnitude is 7.5 or greater at a subduction zone where oceanic plate slide under the continental plate. There are four necessary conditions in which an earthquake can cause tsunami. These conditions include the occurance of an earthquake in beneath the ocean so as to allow materials to slide. The earthquake magnitude of 7.5 and above richter scale, which must rupture the earth's surface at shallow depth of less than70 km below the surface and be 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 the 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 and elsewhere. The most famous occurrence witnessed on July 9, 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 a 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, and commonly goes unnoticed as they pass beneath ship because they are usually less than 1m high and the distance between wave crest 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 were killed. A tsunami has various consequences to human beings. It causes high rate of mortality, illness and injuries, leads to the spread of infectious diseases as well as creates physiological traumas.

Activities 2.4

In groups, with the assistance of the subject teacher read online sources available about tsunami, and identify 5 areas affected by Tsunami as cases of study. Guide your study on the effects of the phenomenon and ways to overcome it. Present your work in the class and invite comments for improvement.

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Exercise 2.6

1. Using specific examples, explain the causes and effects of earthquakes.
2. Describe the different magnitude scales of earthquakes and how they relate to wave-types and periods.
3. Discuss the impact of earthquakes on human.
4. Assume you are invited as a seismologist in Bukoba district, what are the necessary precautions will you advise the community to take in case they experience another phase of earthquakes?
5. What do you understand by the term Tsunami?

Vulcanicity

The term vulcanicity is a range of processes by which molten, gaseous, or solid rock materials are intruded into the earth's crust or extruded onto the earth's surface. The molten rock materials before reaching the earth's surface are called *magma* while after reaching on 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*. A 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 is made of successive layers of lava. Volcano and lava plateau are extrusive vulcanic features formed onto the surface of the earth after cooling and solidifying 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 into 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 that concentrates along narrow fissures whereas lava explored from the fissure and spread to form lava plateaus. Many fissure eruptions are associated with basaltic lava floor. While, central eruption is the one which concentrates at a central vent and 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 are central eruption and explosive

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eruption or quite eruption. The central eruption is usually violent and explosive eruption of lava, volcanic ashes and fragmental materials through a pipe under the impact of violent gases. Examples of central eruption volcanoes are Mount Kilimanjaro, and Mount Oldonyo Lengai found in Tanzania. Fissure volcanoes also are quiet, in this case lava flows quietly through fissure, fracture on fault due to low pressure. An example of this is Laki fissure eruption of 1783 in Iceland.

Also, volcanoes are classified according to their activities in which there are three categories namely active, dormant, and extinct volcanoes. An active volcano is the volcano which erupts frequently, for example mountain Nyiragongo in Eastern Republic of Congo. A volcano is said to be active only when it has errupted within five hundred years. A dormant volcano is a volcano with an infrequent eruptions. Also, is known as sleeping volcano. Example of dormant volcano are, mountains Kilimanjaro, Meru and Kenya. Extinct volcano is the one which has ceased erupting for a very long time in history, for example Mount Rungwe. Like many other all landforms, a volcano is also attared by weathering and erosion particularly at extinct stage such that with time most of it, if not all of the volcano may have been removed.

Volcanic materials

Volcanic materials ejected during eruption include *lava*. It is known as lava when it is ejected on the earth's surface accompanied by gases. Other volcanic materials include vapour, fragmental materials and ashes. The molten rock is called *magma* when it is below the earth's surface, and lava when it is on the earth's surface. The chemical nature of the materials can either be acidic or basic (Table 2.6). Acidic materials are extremely viscous (sticky) and less mobile because it contains a lot of silica. The basic materials are fluid (less viscous), mobile and flow long distance before solidifying. Basic materials contain low melting point and less silica. Also, lava and magma are classified on the basis of light and dark coloured minerals into felsic and mafic.

Table 2.7: *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. Solidified rapidly at high temperatures over 850° C	Rhyolite
Intermediate	52-66	Fairly viscous. Unable to flow far before solidification.	Trachyte
Basic	45-52	Very fluid and mobile. Able to flow long distances before solidifying.	Basalt

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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. But most of them 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. Also, gas acts as a lubricant so that loss of much gas from the lava will increases its 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 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 surface as lava (the molten magma). The nature of volcanic form, 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 eruption. On the other side basic lava is poor in silica since it is rich in iron and magnesium minerals. It has a lava at melting point which flows at considerable distance before solidifying. Such lavas tend to produce much flatted zones of great diameter and the eruption is quite without much explosive activities, as is the case in shield volcano.

Features 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, solidifies, and form a range of features or landforms. These are often exposed at the surface by later erosion. Intrusive or plutonic features formed within crust, include; batholith, sill, dyke, laccolith, lopolith and phacolith.

Batholith: This is a dome or very large mass of igneous rock which is formed by cooling and solidification of magma deeply in the heart of 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

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irregular shape with side walls that incline steeply against the host rock (Figure 2.37). The most common examples of batholiths include Sierra Nevada Batholith and Idaho Batholith in the United States of America and Aswan Granite Batholith in Egypt and Cape Coast batholith in Ghana.

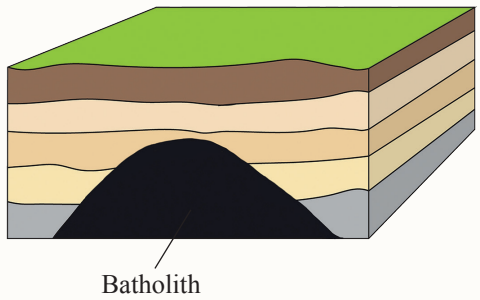


Figure 2.37: *Batholith*

Sill: A sill is a sheet of magma which is formed when igneous materials solidifies horizontally along the bedding planes (Figure 2.38). Usually they are concordant to rock structure and they can be of any thickness and extend for 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 which are simple, multiple and composite sills. Some sills form ridge like escarpments, when exposed by erosion which may give rise to waterfalls and rapids for example, Kink on Falls - Guinea or Three sisters South Africa. Sills are more important ore deposits and other important minerals such as gold, platinum and chromium.

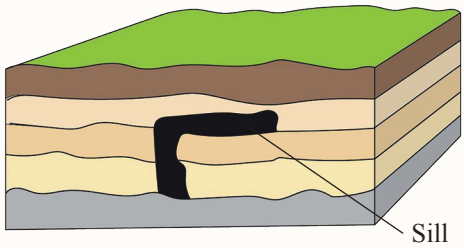


Figure 2.38: *Sill*

Dyke: This is a wall like feature which is formed when magma pushes up towards the surface through cracks in the rock, cools and solidifies across the bending plane (Figure 2.39). Since it is discordant feature, it does not follow the nature of 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 successive injection of different materials into the same fissure.

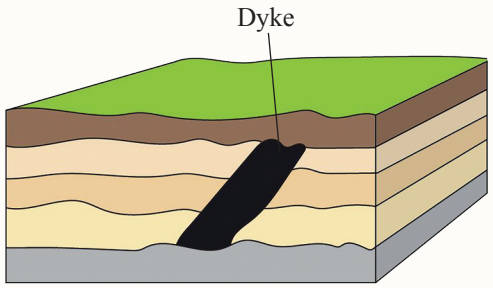


Figure 2.39: *Dyke*

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Laccolith: Is a dome-shaped intrusion feature which is formed within or between layers of a sedimentary rock (Figure 2.40). 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 finally 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 Univukwe Range in Harare, Zimbabwe.

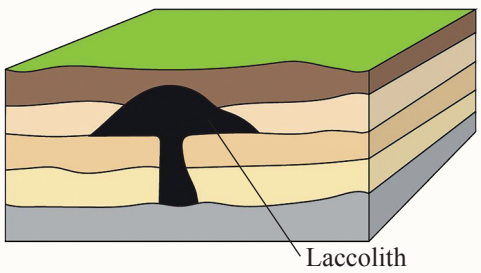


Figure 2.40: *Laccolith*

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 2.41). Examples of lopolith is that found in Bushveld Basin in the Transvaal in South Africa.

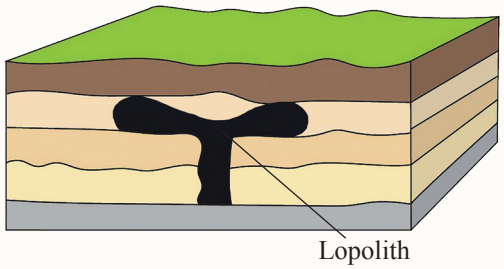


Figure 2.41: *Lopolith*

Phacolith: This is a concordant intrusion of igneous rocks which is formed after cooling and solidification of magma near the crest of an anticline or base of syncline (Figure 2.42). A phacolith can form along the sedimentary bed rock which is concordant by exerting great thickness along the synclines and anticlines.

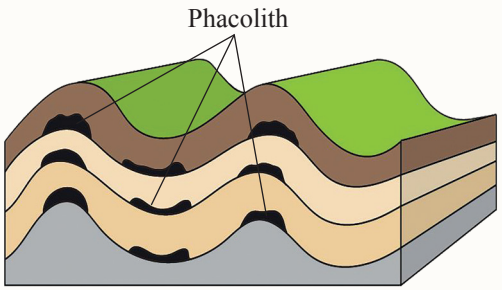


Figure 2.42: *Phacolith*

Extrusive vulcanic features

When a vulcanic activity takes place above the ground and hot molten materials are released onto the landscape, later cools and solidify, such activity is called extrusive vulcanic activity or volcanicity. The materials thrown out include lava flows, pyroclastic debris, volcanic bombs, ash, dust and gases such as nitrogen

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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) are cone shaped structure 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 2.43). The slopes of the cone are always concave due the spreading tendency of lava at the base of the cone while cinder is steep sided. Examples of ash and cinder cone are Sarabwe Fileko in Rungwe in Southern Tanzania and Jos Plateaus in Nigeria.

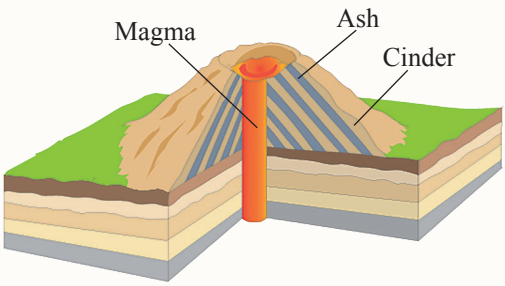


Figure 2:43: *Ash and cinder cone*

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 2.44). The cone has steep slope and it is the most common volcano. Examples of composite cones are Kilimanjaro mountain, Cameroon mountains and Mountain Nyiragongo in the Democratic Republic of Congo.

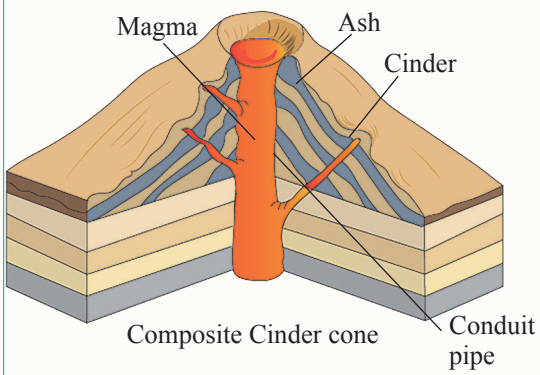


Figure 2. 44: *Composite cone*

Volcanic plug (plug dome): 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 2.45. An example of this is Atakor volcanic area of the Hogger mountain in Algeria.

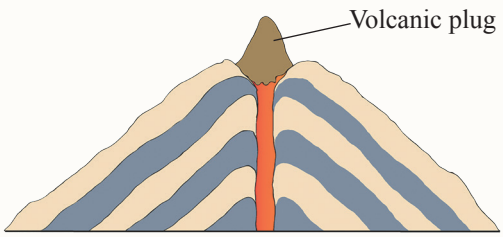


Figure 2.45: *Volcanic plug (plug dome)*

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Explosion crater: The explosion crater is also known as ring crater. It is a shallow, flat floored depression surrounded by a low rim of pyro clasts and local rock (Figure 2.46). Usually less than 50 meters high and often found in groups. A vent is blowing through the local rock by a series of gas explosions.

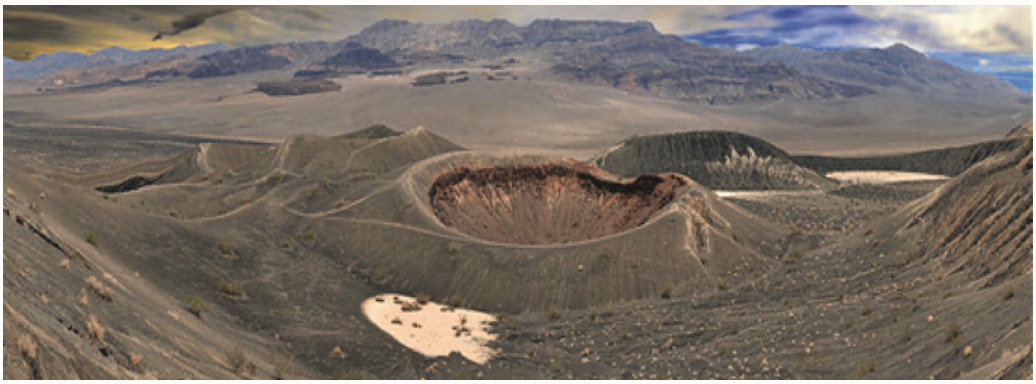


Figure 2.46: *Ring crater*

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 is filled with water from rainfall or melting ice (Figure 2.47). 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, the magma in the vent cools as well and contracts at the same time. This causes it to withdraw into the vent. 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 OlDonyo Nyoike in Kenya. Other examples include Mahavura in 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.

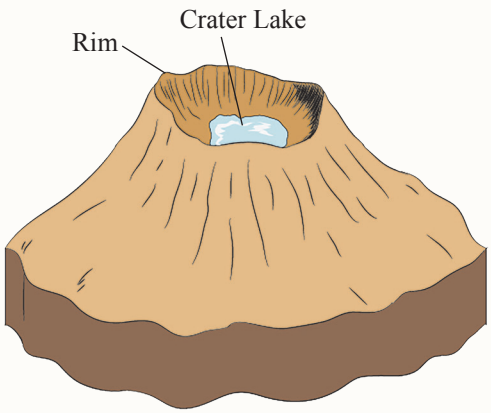


Figure 2.47: *Crater*

Caldera: These are large depression formed when the upper part of the volcano is either blown away by violent eruptions or the top of the cone subsides

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into the crust (Figure 2.48). Basically there are three main types of calderas which are collapse, explosion and erosional caldera. Examples of caldera are Sunda Strait. Collapse calderas are further subdivided into Krakatau-type or explosion-collapse calderas and Glencoe-type or cauldron subsidence calderas, for example, Mokuaweo-weo caldera of Mauna Loa.

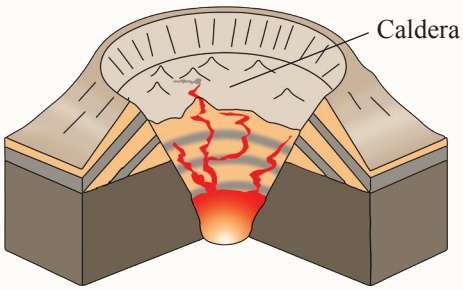


Figure 2.48: *Caldera*

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 2.49).

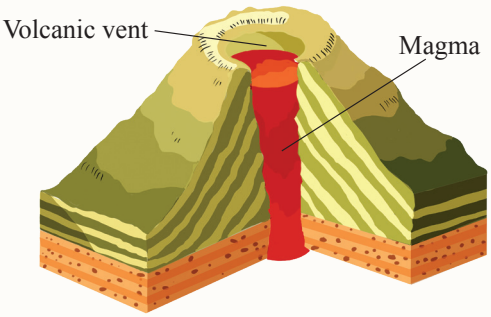


Figure 2.49: *Volcanic vent*

Acidic Lava (cumulo dome): This is a dome shaped volcano with convex slopes formed when acidic lava solidifies around the vent (Figure 2.50). 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 high content of silica and its high melting point. An example of cumulo dome is Ntumbi dome in Mbeya region, Tanzania.

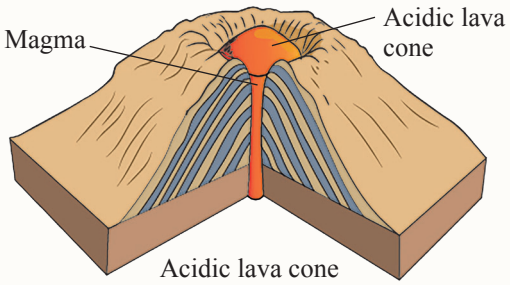


Figure 2.50: *Acidic lava*

Shield volcano: This is broad and extensive domed volcano with gentle slope sides formed when basic lava is poured in the surface and spread to occupy a large area (Figure 2.51). Lava from the earth's interior flows out through a vent.

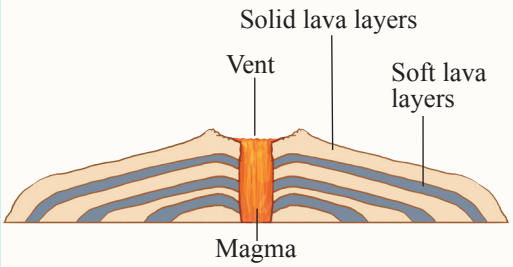


Figure 2.51: *Shield volcano*

Minor volcanic features

There are other minor volcanic features that normally start to take place when volcanic eruption is approaching the

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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 contain mineral substances in solution or in suspension form. They are springs produced by the geothermal heated groundwater that emerged 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 emerged onto the earth's surface it is known as a hot spring. It can influence the production of geothermal power. Example of hot springs are Amboni, Tanga 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 2.52). Geysers are of two types namely pool geyser and nozzle geyser. A pool geyser spout water from open and relatively large pool. A nozzle geyser spout water from very small and contracted vent.

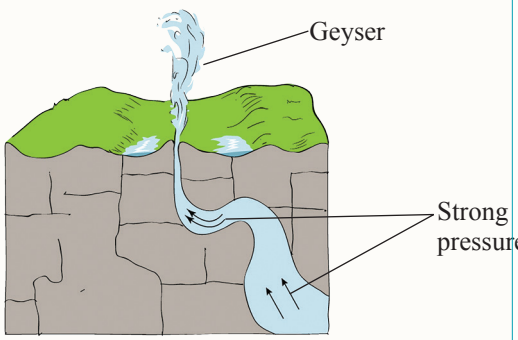


Figure 2.52: *Gaseous materials being emitted through the vent*

Fumarole: A vent through which there is emission of gases and water vapour. Also, it emits smoke.

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 cause great damage to property, houses, crops or livestock (Figure 2.53). 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 2.53: *Destruction caused by volcanic eruption*

Constructive consequences: The lava formed from volcanic eruption leads to the formation of fertile soil when is broken down through weathering process. A good example is the southern slopes of Kilimanjaro in Tanzania. Volcanicity can lead to the formation

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of mineral deposits like copper deposits, diamond of Kimberley in South Africa. Also, some 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 be used to provide geothermal power which can be utilized for electricity generation as the case in Kenya, Ethiopia and USA. Moreover, volcanic eruptions can attract tourists and lead to tourism industry due to the formation of hot springs and geysers.

Activity 2.5

In group of six students, go to the library read books and other online sources about vulcanicity basing on the following aspects;

(a) Causes of vulcanicity.

(b) Major and minor features produced both internally and externally

(c) With the help of subject teacher hold a discussion on the findings collected and write the final findings in your exercise books.

Exercise 2.7

1. Discuss the effects of volcanism to man and his surroundings.
2. Basing on their characteristics, differentiate between active, dormant and extinct volcanoes.
3. Describe the landforms associated with volcanicity.
4. Discuss the importance of vulcanism.
5. With the aid of diagram, explain six intrusive vulcanic features.

Diastrophism

Diastrophism is also known as diastrophic forces. It includes all processes that move, elevate or build up portions of the earth's crust through orogenic processes. For example, 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 center of the earth to the surface. The movement is termed as epeirogenic process as it occurs at a large scale. Upward movement causes uplift of continental parts or coastal areas. This is called emergence. Downward movement causes submergence of part of land mass or coastal area. This is known as submergence.

The process of orogeny, involves endogenetic forces working in horizontal manner. Horizontal movement, involves tensional and compressional forces that act on the earth's crust side by

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side tangentially or horizontally which causes disruption of the horizontal layer strata. It is known as convergent force and movement. Tensional force operates on opposite directions and 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, that is compressional or convergence force. Compressional force causes crustal bending leading to the formation of folds or crustal warping leading to local rise or subsidence of crustal parts. The process of crustal warping affect large areas of the crust either warped (raised) upward or downward. The upward rise of land due to convergent compressional force is called upwarping while the bending of the crustal part downward due to convergent compressional force is known as down-warping. The effects of earth movement can be categorized into two groups namely: faulting and folding.

Faulting

Faulting is the process that involves breaking or fracturing of crustal rocks due to forces resulting from earth movement to form a faults. The movement involved in the formation of a fault may operate vertical or horizontal or in any direction. In faulting, there is 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 as the associated landforms.

Faults

These are fractures in the crustal rocks wherein the 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. *Downthrown side*, is the lowermost block of fault. *Fault dip*, it is the angle between the fault plane and horizontal plane. *Hanging wall* is the upper wall of a fault. *Foot wall*, is the lower wall of a fault. *Fault scarp*, is the steep wall-like slope caused by 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 both the 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 in one side either right or left. They can be vertical or inclined (Figure 2.54). The middle part of the entire fault tends to rise up, while the hanging wall sink down.

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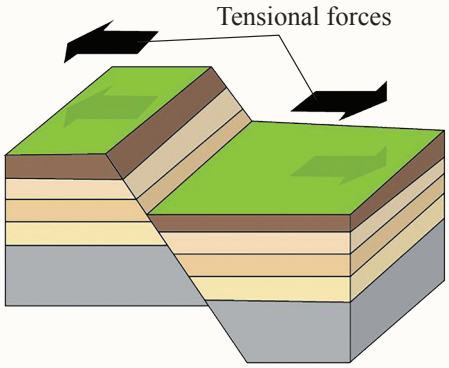


Figure 2.54: *Normal Fault*

Reverse fault: This is a type of fault formed due to compressional forces and occurs when the beds of the rock on one side of the fault plane are thrust over the other side (Figure 2.55). The fault plane in reverse fault, is usually inclined at an angle between 40 degrees and the horizontal (0 degree).

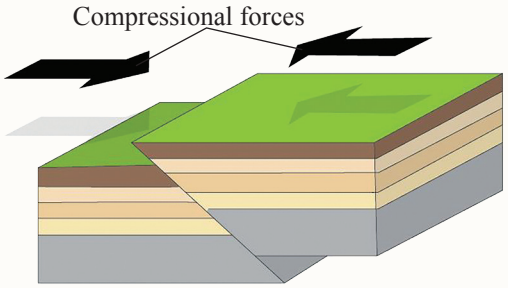


Figure 2.55: *Reverse fault*

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 displaced parallel in opposing direction along the line of fault (Figure 2.56), and a good example is San Andrea's fault of California.

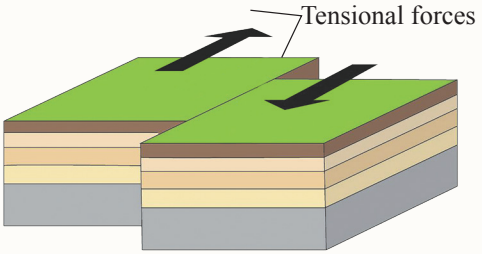


Figure 2.56: *Transform (Tear fault)*

Overthrust fault: Is formed when the top part of the fault overrides the bottom part along a fault plane, because of compressional forces (Figure 2.57).

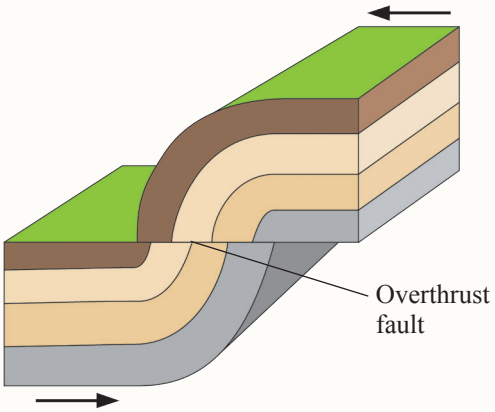


Figure 2. 57: *Overthrust fault*

Monocline fault: Monocline is a tensional fracture in which the strata are bending closely related to the normal fault but the normal fault has horizontal strata (Figure 2.58).

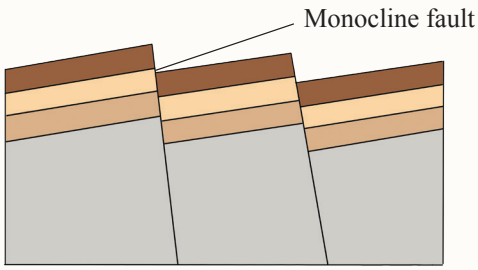


Figure 2.58: *Monocline fault*

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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 in time erosion will modify their outlines. Therefore, these are faults on the basis of fault pattern. The following are some of the direct effects of faulting.

Step faulting: Is the process which leads to the formation of several parallel faults. Therefore, the faults appear as a series of steps on either one side of the rift valley or both sides (Figure 2.59).

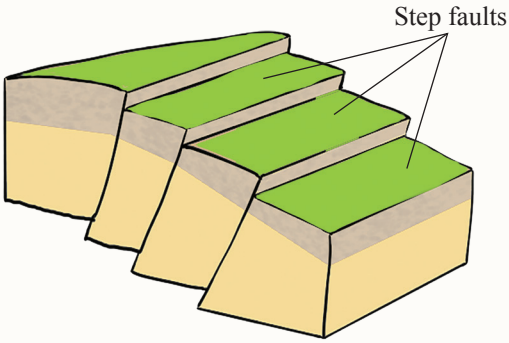


Figure 2.59*: Step faulting*

Fault block: It is also refered as tilted block. This is a block like structure with inclined strata formed due to faulting process. Inclination occurs as the result of one side of the block being uplifted faster than the other side. It is similar to monocline fault (Figure 2.60). This is sometimes known as fault block, if the block has been titled, then they are called tilt-block. In USA they are known as tilt block basin and range countries. Another example is that of Afar Triangle in Ethiopia.

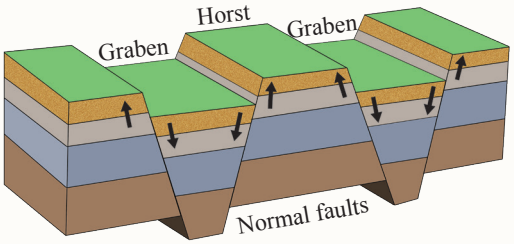


Figure 2. 60: *Fault block*

Horst mountains: The horst (block) mountain is a table like mountain formed by faulting process that result to the rising of the block rock forming table like structure. Block mountain is an upland bordered by fault on one or more sides (Figure 2.61). It occurs either when the land mass subsided between two normal faults or a block remains up stand while on its other side drops. Example of Block Mountains is the Drakensberg range in South Africa.

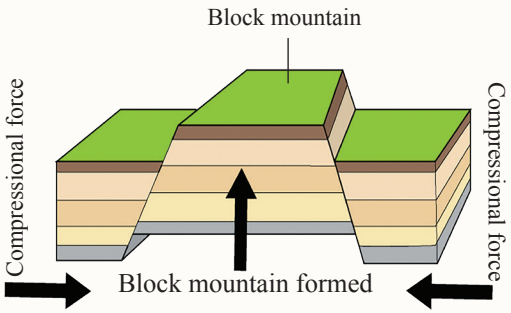


Figure 2. 61: *Horst mountain*

Fault scarp landform: It is an escarpment or scarp which is steep on one side and gentle on the other side (Figure 2.62).

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The steep slope is caused by vertical earth movement along the fault.

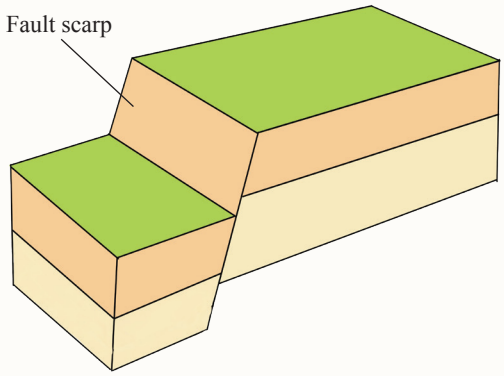


Figure 2.62: *Fault scarp*

Rift valley: It is formed where the Earth's crust, or outermost layer, is spreading or splitting 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, 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 shifting 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 2.63). Many rift valleys have been found underwater, along the large ridges that run throughout the ocean called mid-ocean ridges. Good example of giant rift valleys include the Baikal Rift Valley and the East African Rift Valley.

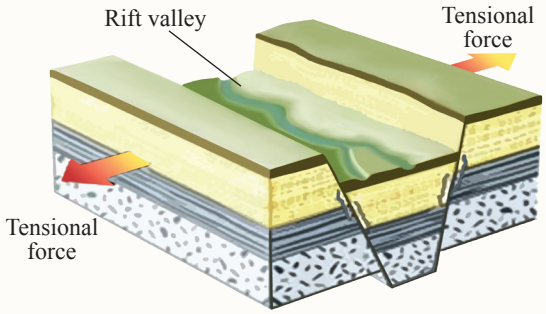


Figure 2. 63: *Rift valley*

The East African Rift System (EARS) forms a narrow (50-150 km wide), elongate a system of normal faults that stretches some 3 500 km in a sub-meridian direction, that runs from northern Jordan Rift Valley 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, which is a volcanic-rich system that forms the Kenya and Ethiopian Rifts. In places the rift system was probably initiated in the early Miocene, but there is also evidence for earlier Paleogene rift activity in northern Kenya and Ethiopia. The rift branch is well exposed at the surface and 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. These

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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 Mt Kilimanjaro, Oldonyo Lengai and Mt 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, Lake Natron in Tanzania, and Lake Turkana in Kenya which is the sole large lake in the eastern branch (Figure 2.57).

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 body of water's 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 off set: 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 for example, Lake Tanganyika, Nyasa and Rudolf.

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

River reverse 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, Lake Victoria, Kagera river and Lake Victoria (Tanzania).

Occurrence of springs: Due to faulting, springs can be formed because the fault provides the 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 which cause rock to be shattered and crushed to the extent that rocks are more easily eroded that those further from faulty. Very common in river valleys, where a valley is guided by a fault line, for example, Santa River in Guinea.

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Folding

Folding is the process that involve the wrinkling of the earth's crust to foam folds. The folding of rocks, like faulting, produces a variety of geological structures such as fold Mountains. When the folding is gentle results in simple up fold (anticlines) as mountains and down fold (synclines) as valleys. If the folding intensity is high results to the over folding rocks which is very common. Rock folding is due to the tremendous compressional forces that develop as the tectonic plate of the crust move towards each other to produce folds. Folds are the wave-like bends that are formed in the crustal rocks due to tangential compressive force resulting from horizontal movement. These bends are caused by endogenetic forces originating deep within the earth. The up folded rock strata which looks like an arch-like form are called anticlines while the down folded structure forming 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 fold or axial plan. To understand 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 refered as symmetrical fold. This is formed when strata are bending into up fold (anticline) and down fold (syncline). The sides of the fold are called the limbs, caused by compressional forces (Figure 2.64). Usually the limbs are similar in terms of slope.

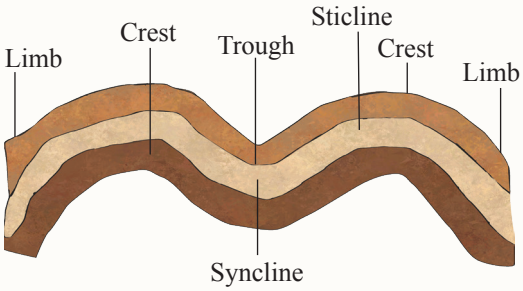


Figure 2.64: *Simple fold*

Asymmetrical fold: Asymmetrical fold is formed when compression continues and simple fold is changed into asymmetrical fold. One limb of asymmetrical fold is steeper than the other (Figure 2.65). A fold whose limbs are unequal in length, and axial plane is inclined, dipping in the same direction as that of the gently dipping limb. Degree of asymmetry is given as the ratio of length of short to that of long limb. 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 termed Z folds or dextral or negative asymmetrical while those in which the axial plane

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is rotated anticlockwise from the normal to their enveloping surfaces are termed S folds or sinisterly or positive asymmetrical. Z and S folds normally occur on the left and right limbs of an antifoam respectively. The photograph is of Z folds from the Ghisauli gneisses of Central India.

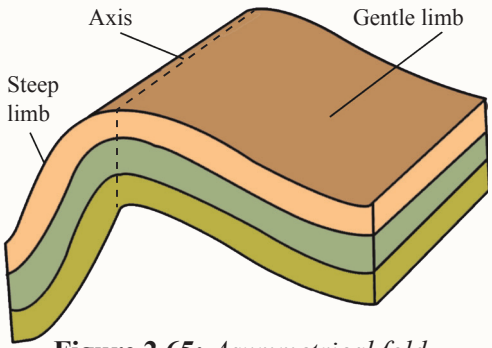


Figure 2.65: *Asymmetrical fold*

Over fold: It is also known as 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 2.66).

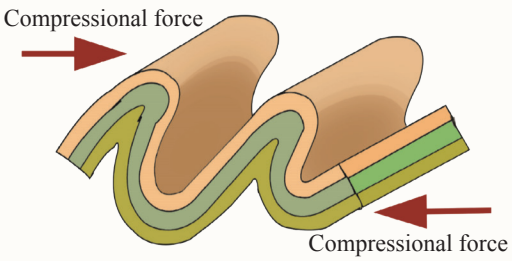


Figure 2.66: *Over fold*

Recumbent fold: This occurs when pressure continues and an over fold is pushed over another limb to a greater distance (Figure 2.67). 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.

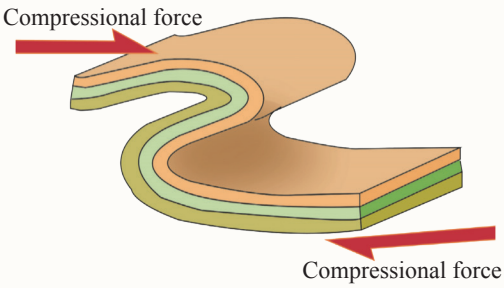


Figure 2.67: *Recumbent folds*

Over thrust fold: The over thrust fold is also refered as Nappe fold. It is formed due to great pressure, the rocks feature and the limb fold is thrust forward over the other limb (Figure 2.68). 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 characteristic of compressive tectonic plate boundaries.

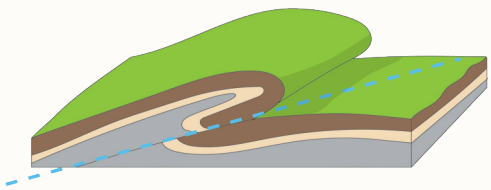


Figure 2.68: *Over thrust fold*

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 Earth (Figure 2.69).

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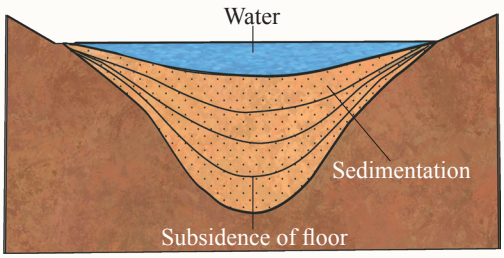


Figure 2.69: *Geosyncline*

Mountain building and classification

Mountain building or mountain formation is the geological processes that underlie formation of mountains. The responsible forces of mountain building are endogenic forces such as epirogenic forces, orogenic forces and volcanism. These processes lead to formation of various types of mountains. A mountain is a large natural elevation of the earth's surface rising abruptly to a given height from the surrounding level. For example Mt. Kilimanjaro is approximately to have the height of about 5895 m.

Mountain building classification is based on several factors including height, location, mode of origin and period of origin. On the basis of height there are *low mountains* which range between 700-1000m, *rough or middle mountains* which range from 1000 to 1500m, and *high mountains* it is from 2000m and above. Basing on location there *are coastal mountains* with examples of Appalachians, Rockies, and Alps. On the basis of location there is *inland mountains* which is formed on the adjacent land mass. For example, the Ural mountain in Russia, Vosges and Black forest block mountains. Coastal and inland mountains are also known as continental mountains.

Also, on the basis of the factor of location there is *oceanic mountains* most of these mountains are below water surface or below sea level such as mid-oceanic ridges. On the basis of mode of origin, there are *tectonic mountains* formed due to tectonic forces. Also, there are *fold mountains* formed due to compressional forces. They are further divided into young, mature and old fold mountains. Another type is *block mountains* which is formed due to tensional forces. Moreover, on the mode of origin there is *dome mountains* originated by magnetic infusing and upwarping of the crustal surface, and *mountains of accumulation* formed due to accumulation of volcanic materials. They are also called volcanic mountains.

Furthermore, on the basis of period, there are pre-cambrium mountains, caledonian mountains, Hercynian mountains and Alpine mountains. Pre-cambrium mountains include the Laurencin orogeny which took place during the pre-Cambrian era, in the Archezoic period 3 000 million years ago. Most of the mountains formed were eroded. Good examples are the pen plain of Canadian shield and Akwapin Hills in Southern Ghana. Also, Caledonian orogeny took place in the Paleozoic era between 500-350 million years ago. Usually it produces extensive mountain ranges which were subsequently eroded and changed by agents of denudation.

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Its remnants include the rugged mountains of the Scottish Highlands and Scandinavia mountains.

Moreover, hercynian orogeny took place between the late Paleozoic and Mesozoic era between 350-240 million years ago. Most of these mountains were modified due to erosion by ice and water for example, the cape ranges of South Africa, the Appalachian Mountains in North America, the Urals Mountains in Russia and Welsh mountains in Britain. Furthermore, alpine orogeny is the recent built mountain formed during Cenozoic era 300 million years ago. These are the highest and most impressive mountains in the world for example, Atlas Mountain, Alps, Rockies, Himalaya and Andes mountain. They developed through the collision of continental carrying plates.

Theories of mountain building

Plate tectonic theory: The theory explains the formation of mountains due to movement of plates in plate margins. Most of the mountain formation occurs in plate zones where the plates converge, diverge or slide, for example, Fold mountains. *Continental drift theory*: This theory explains that when the continents were forming, the Indian continent drifted towards the Eurasia, the crust together with the sediments between were squeezed to form Fold Mountains, for example, Himalaya ranges. This is supported by the presence of Marine limestone rocks at the summit of Mount Everest. *Contraction theory:* This explains that mountains were formed during the formation of the earth, when molten rocks were cooling. The surface rocks cooled and contracted faster than those of interior. Since the interior was cooling at a lower rate the surface rocks started to wrinkle in order to fit on the cooling and contracting rocks of the interior. *Convectional current theory:* The theory states that when the convectional currents in the mantle move horizontally, they cause a fractional pull to the crustal rocks making them move. When the convectional currents are pulled towards each other hence fold mountains occur. *Geosyncline theory:* It is also known as geosynclinal oregen theory. The theory was introduce by German geologist Kober. According to him, the mountain ranges are formed as a result of compression of geosyncline situated on the margin of forelands of ancient rigid land masses. He refered these has border ranges. *Denudation theory:* This explains that, some mountains are formed when resistant mass of rock remain standing after denudation has taken away the surrounding soft rocks. This explains the formation of residual mountains like Sekenke hill in Singida-Tanzania.

Fold Mountains

Fold Mountains are the result of 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 well-developed system of anticline and syncline pattern. Complex fold mountains consist of very complex structure of

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folds caused by powerful compressional forces such as recumbent folds. There is also *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. It is like an elongated dome.

The period of mountain building is distinguished as an orogeny. Fold mountain building process as shown in Figure 2.70 is known as Orogenesis. There have been several mountains building periods during the Earth's history. The periods are classified into old fold mountains and new folded mountains. The old folded mountains originated before tertiary period 3 000 milions years ago such as Caledonian and Hercynian. The mountains have been so greatly eroded. Example of these mountains include Aravallis. The alpine folded mountains of Tertiary period are grouped under the category of new folded mountains formed during Cenozoic era 300 million years ago for example, Rockies, Andes, Alps, Himalayas.

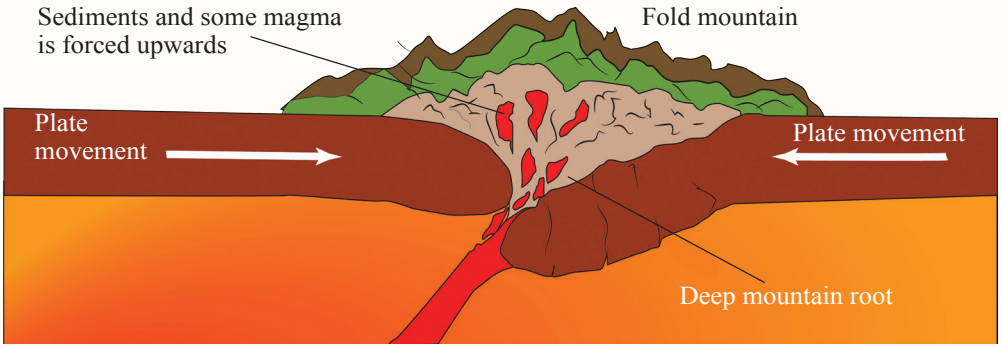


Figure 2.70: *Fold mountains*

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

The distribution patterns of Fold Mountains over the globe 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, formed during Cenozoic era. Most fold mountains on the earth's surface are young fold mountains belt. Young Fold Mountain belts consist of two belts namely; *Circum-Pacific System:* Rings the Pacific Ocean (North and South) America based on the continents for example, Andes, Rockies and Cordilleran ranges. In Western part of the Pacific Ocean, the belts take form of Islands for example, Japan and

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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 meet the circum- pacific belt. The belt includes Alps, Caucasus and Himalayas mountains.

Revision exercise 2

1. Examine the impact of folding and faulting on the landscape. Refer to one landform in each impact.
2. Using specific examples, explain the observation made by A. Wegner to support his continental drift theory.
3. Explain three major types of plate tectonic boundaries.
4. Citing examples, explain volcanos formation, their types and associated features.
5. With an aid of well-illustrated diagrams, describe how the following volcanic features are formed;
   (a) Crater (b) Caldera (c) Ash and Cinder cone
   (d) Batholith (e) Laccolith
6. Using a rock cycle, explain three main types of rocks based on their mode of formation.
7. Using Indonesia tsunami of 2004 as a case study, explain the impacts caused by that phenomenon to the people of South Asia.
8. How does the theory of plate tectonics support the formation of landforms on the Earth?
9. Substantiate the contention that 'isostasy is isostatic adjestment'
10. For several years, Bukoba region has been prone to earthquake disaster. Using the knowledge obtained in the classroom analyse the main cause and possible effects of that disaster to the surrounding community.
11. Differentiate the following geographical terminologies;
    (a) Dynamic metamorphism from thermal metamorphism
    (b) Foliated rocks from non-foliated rocks
    (c) Metamorphism from metasomatic
12. With the aid of a well-illustrated diagram explain the differences between P-waves, S-waves, L-waves and R-waves during an earthquake.
13. Compare and contrast a normal fault and a reverse fault.

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Chapter Three

Exogenic processes of the Earth

Introduction

Some of the landforms seen on the earth's surface are the resultant features of exogenic (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 features. Also, you will learn about the actions of wind and water in desert, glaciation, river, and waves along the cost, and their resulting features. The competencies obtained from this chapter will enable you to undertake various activities that promote environmental conservation and protect the physical environment of the Earth from negative effects of denudation and deposition. Also, you will be able to use features formed through denudation and deposition in promoting tourism sector in Tanzania.

The concept of exogenic processes of the Earth

The surface of the earth's crust is under constant sculpturing due to multiple geomorphic agents which 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 which took place for a long period of time. These geomorphological processes are termed as exogenic (external) forces such as weathering, mass wasting, erosion and deposition. Figure 3.1 is a schematic representation of exogenic processes of the Earth.

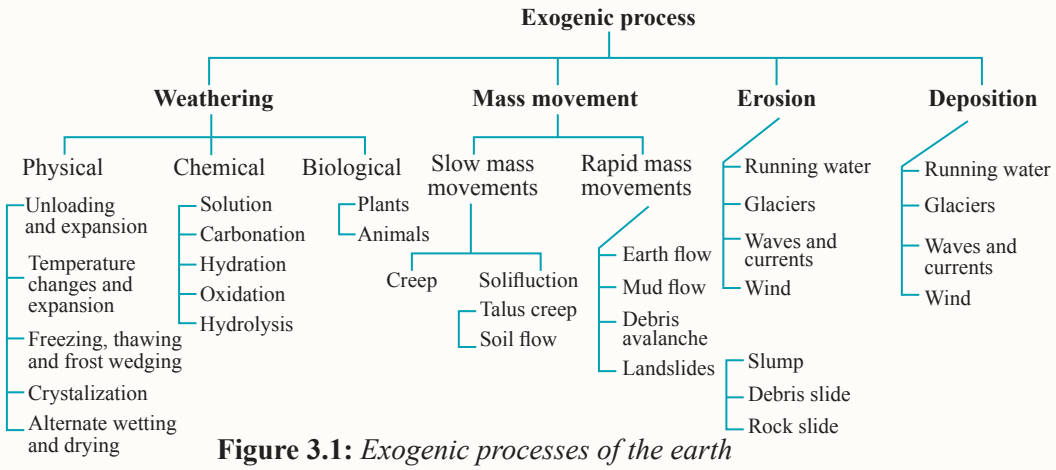


Figure 3.1: *Exogenic processes of the earth*

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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, and humidity which acts as agents of weathering. Weathering as a geomorphological mechanism and process, normally changes hard rocks into fine and soft residuals (the parent matter of the soil). Weathering does not produce new landforms because weathered materials 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, glacier, waves and winds. All rocks, whether soft or hard when exposed on the surface of the earth, they are subjected to change over time due to either pressure release, temperature change or by both. Most of 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 with the conditions on the earth's surface. Hence they are easily attacked, decomposed, and eroded by various physical and chemical processes. Weathering does not involve removal of weathered rocks. Instead the removal of weathered rocks are caused by forces of weather which include rain action and wind. Weathering can also be influenced by organisms, a process known as biological (biotic) weathering. Weathering is a combination of processes of destruction and synthesis. The 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 rock. Usually, it involves the breaking down of rocks into smaller fragments. It is common in desert areas, high mountains and cold regions. The forces that strain and rupture the rock can either originate within the rock or applied externally. The following are different forms of physical weathering.

Thermal expansion: The 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 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 expanding during day and cooling during night. The surface of the rock expands more than the interior part and eventually cause cracks to appear

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extending 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 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 falling of separated plates of rock resulting into the formation of isolated masses of round-shaped rocks called *exfoliation domes* (Figure 3.2*)*. 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 part of the Sahara Desert in Egypt, Sinai and Kalahari deserts.

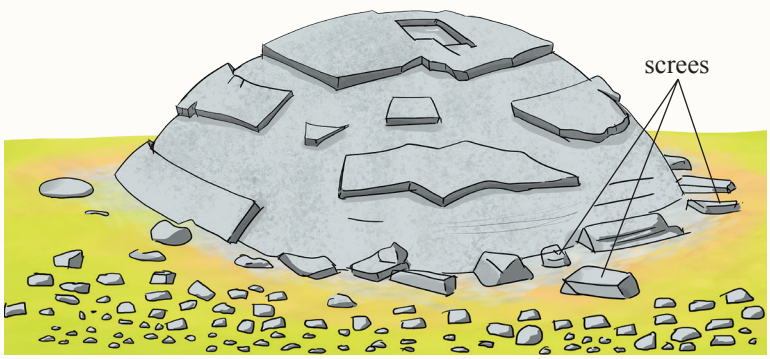


Figure 3.2: *Exfoliation dome with mounds of screes*

However, when coarse grained rock particles of the granular rocks expand and contract 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 3.3). Frost action is common in areas where temperature falls below 0^{o} C and vegetation cover is limited. Such action is most active in temperate regions where freezing and thawing is frequently taking place and in tropics which have high temperature like deserts. Also, it takes place in the arctic region but on a small scale because in this region water is frozen for several months in a year as compared to the period of melting.

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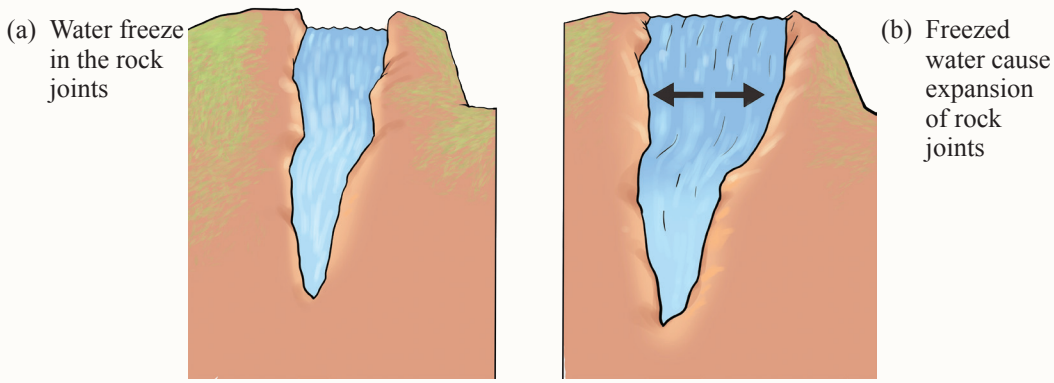


Figure 3.3: *Weathering by frost action*

Salt crystallization: This is common along the coast and in desert areas. It occurs when saline water occupies the pore spaces in the coastal rocks and on evaporation due to high temperature, salt crystals are likely to be formed. Further accumulation and hardening of the salt exerts pressure upon the rocks causing them to fracture and disintegrate (Figure 3.4). 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. Also, the process can 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 3.4: *Weathered rock by salt crystallization*

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Pressure release: This is also refered as unloading process. Many rocks, especially intrusive igneous rocks experienced exertion of considerable pressure for millions of years. The confining pressure strengthens the rocks. On the other hand, the process of erosion however, removes the overlying rock material, in such a way that with time the intrusive rocks are exposed and the pressure on them unloaded paving way to action of other agents and processes. The outer parts of the rocks then tend to expand (Figure 3.5). Over time, the sheets of rock 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'.

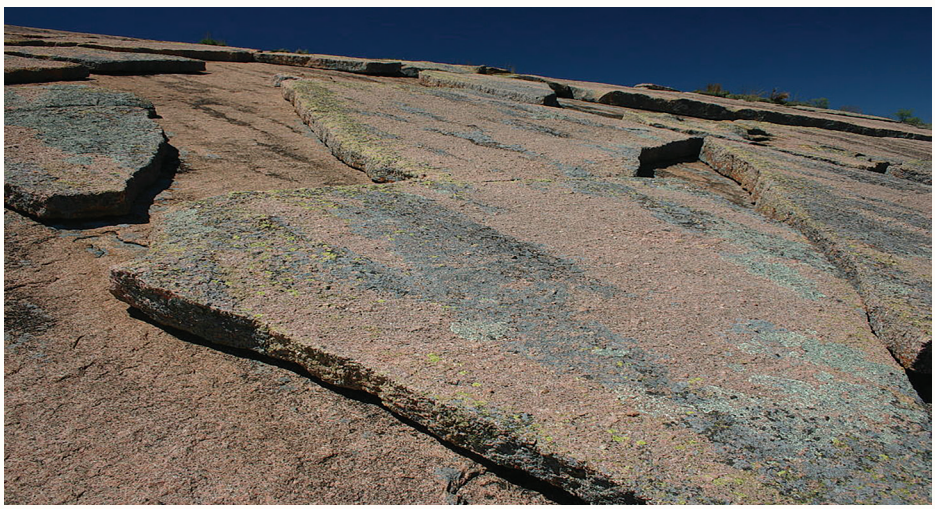


Figure 3.5: *Weathering by pressure release*

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

Chemical weathering

Chemical weathering is the breakup of rocks by being decomposed by chemical reaction. The chemical reaction involves the substances of water, certain atmospheric gases, and certain minerals of rocks. When water is charged by different gases like oxygen and carbon dioxide that penetrates the rocks and make contained minerals decomposed to the ultimate gradual break apart of rocks.

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By chemical weathering; the 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 involves decomposition and transformation of rock and minerals exposed to water and air into new chemical products. A 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 the abundant water to form new mineral. The newly formed minerals are weathering products. The chemical weathering usually takes place on the exposed rock surface, but it can also take place inside the rock in case water can enter via pores, joints or cracks. Temperature is a very important factor as it speeds up the chemical reactions. Also, the composition and strength of soil water, minerals dissolved in the soil water and the soil bacteria are determinants of the rate of rock disintegration. Chemical weathering has several effects on rocks including softening of rocks (minerals) that makes them more susceptible to erosive agents than the original. Also, 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 3.6). 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 carbondioxide gas, reacts with rocks of calcium carbonate minerals. The reaction makes 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, as 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.

$$\underset{\textit{(Calcium carbonates)}}{CaCO_3} + H_2O + CO_2 \longrightarrow \underset{\textit{(Calcium bicarbonate)}}{Ca(HCO_3)_2}$$

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

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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.

$$\underset{\text{(Sulphate)}}{CaSO_4} + \underset{\text{(water)}}{2H_2O} \longrightarrow \underset{\text{(gypsum)}}{CaSO_4.2H_2O}$$

Gypsum is used as a 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 which 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.

$$\underset{\text{(Pyroxine)}}{3FesiO_3} + 1/2\underset{\text{(Oxygen)}}{O_2} \longrightarrow \underset{\text{(Magnetic)}}{2Fe_3O_4} + \underset{\text{(Quartz)}}{3SiO_2}$$

This is more common in iron (Fe) bearing minerals, since iron can have several oxidation states these are 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.

$$\underset{\text{(Orthoclase)}}{4KALSi_3O_8} + \underset{\text{(Hydrogen ion)}}{4H^{+}} + \underset{\text{(Water)}}{2H_2O} + \underset{\text{(Carbon dioxide)}}{CO_2} \longrightarrow \underset{\text{(Potasium ion)}}{4K^{+}} + \underset{\text{(Clay mineral)}}{Al_4Si_4O_{10}(OH)_8} + \underset{\text{(Quartz)}}{4SiO_2}$$

The rate of hydrolysis depends on the amount of H^{+} ions 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 chemical structure.

Solution: This is a process in which the minerals in the rocks directly dissolve in water without their chemical composition being altered, such that it is a direct

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chemical change. This is the process in which some soluble mineral like salt (rock salt) dissolve in 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. Biological weathering is divided into three types namely *faunal, flora,* and *anthropogenic weathering.* Depending on the means of occurrence it can either be mechanical or chemical weathering process.

Flora weathering: This is caused by plants. Mechanical disintegration of rocks occurs due to the penetration of roots. As the roots penetrate due to growth of plants, a powerful force widens the cracks hence breaking rocks (Figure 3.6). Decaying vegetation produces organic acids which cause further breaking down of minerals. Plant roots release chemical substance like acid which then breaks down the rocks.

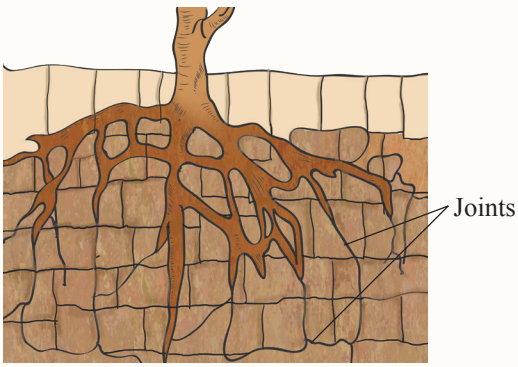


Figure 3.6: *Mechanical disintegration of rocks by plants*

Faunal weathering: It is caused by animals. Animals such as rabbit 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. Chemical disintegration occurs due to the presence of bacteria and burrowing animals in rocks. When bacteria and burrowing animals excrete in the rocks or when they die and decay they release chemical substances in the rocks hence weaken them and easily disintegrate.

Anthropogenic weathering: This is caused by human activities. Human activities such as construction of various structures like roads, railway lines and buildings leads to breaking down of rocks. Also, agricultural activities such as cultivating of the land and mining activities break rocks physically and aid the process of pressure release. Recently, human beings have become the most powerful weathering agent because of further development in modern technologies.

Human activities also contribute through use of agrochemicals such as fertilizers and pesticides in agricultural activities which facilitate chemical disintegration of the rocks.

The interdependence of mechanical and chemical weathering

The essential difference between chemical and mechanical (physical) weathering is that, in physical weathering, there is no actual change involved in the nature of

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rock. The rock is weathered into smaller fragments without occurrence of any chemical change. Chemical weathering reaches greater depths of chemical change of the rock which result in the disintegration/weakening of the rock. However, it should be noted that both types of 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, opening the way for physical disintegration, while fracturing (physical weathering) allows deeper penetration of chemical action.

Activity 3.1

1. In a group of five students visit school library and read books or use internet sources to read on the factors affecting the rate of weathering based on the following aspects:
   (a) Nature of a rock
   (b) Types of climate
      (i) Equatorial climate
      (ii) Tropical climate
      (iii) Desert regions
   (c) Relief
2. Schedule a discussion of the findings, write a report and present it before the class and respond to the emerging questions.
3. Thereafter, incorporate the comments and submit for marking.

Importance of weathering

The process of weathering is a primary source of sediments for erosion and deposition. A number of sedimentary rocks are composed of particles that have been weathered, eroded, transported and finally deposited. Weathering process among other things, contributes to the formation of soils such as clay soil which is suitable for brick making. Weathering contributes to the soil formation by providing mineral particles like sand, silt and clay. The rocks and mineral particles from weathering process supply important nutrients for plant uptake and growth. Through weathering process ions from the terrestrial environment are transported to the sea through leaching and water run-offs and in turn contribute to the salinity of seas. Furthermore, weathering processes loosen the rocks thereby making rocks and the associated products readily available for human exploitations for various developmental purposes. The breakdown of rocks into smaller particles contributes to the soil formation which in turn supports various life forms on earth. The depth of soil horizon extends as far the degree to which the rocks have undergone weathering. Some of the generated features are useful for tourist activities such as the Bismarck rock in Mwanza, Tanzania.

Factors affecting weathering

Weathering is affected by several factors. The primary factors are: climate, physical properties, mineral composition and rock type. Climate determines the kind and

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the rate of weathering. For example, climate under low rainfall conditions, mechanical weathering is more dominant as compared to chemical weathering processes. Availability of high moisture 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 (for example, granite) are easily weathered physically than chemically. In contrast, rocks containing fine fragments (for example, basalt) are susceptible to chemical weathering as compared to physical weathering. Hard and highly cemented rocks disintegrate slowly as 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 decrease in grain size, hence demanding much more energy to disintegrate the fine-grained rocks. Whereas, in case of stratification, the highly stratified rocks like lignite weather more easily as compared to the non-stratified rocks like granite. Differently, the orientation and degree of cementation of rocks has an implication on determining weathering process. For example, 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. Also, 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 as compared to rocks with low clay content. Colour of the rock, rock with dark or black coloured minerals like olivine heat more quickly hence vulnerable to rapid rate of disintegration, wheres rock with light minerals such as quartz and white coloured minerals like limestone heat very slowly, hence slow rate of weathering.

Other factors that influence weathering include gradient, whereby slope in which the weathered material is situated (that is steep slopes versus gentle slopes) which may influence retention of the weathered material or result into being washed away of the weathering products. Organisms influence weathering process based on their physical and chemical interactions

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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 weakens rock structure leading to weathering. Also, small organisms such as worms, rabbits and termites which live and feed in the soil, they release waste products with chemicals which accelerate weathering process. Moreover, plants through penetration of roots accelerate weathering process leading to weakening and disintegration of rocks. Importantly, time is crucial in explaining the rate at which the rock is weathered. Weathering can either be rapid or extremely slow. Thus the time can explain when and at what rate weathering is likely to occur depending on all the factors covered in this section.

Exercise 3.1

1. In which ways does weathering act as a precursor to soil erosion?
2. With examples, explain the interdependence nature between physical and chemical weathering.
3. Explain the difference between weathering and erosion.
4. To what extent can weathering process be regarded as a life support on earth?
5. Explain the mechanisms associated with the following processes as related to weathering;
   (a) Carbonation
   (b) Hydrolysis
   (c) Hydration
6. What determines the resistance of a rock towards weathering process?
7. Examine the role of water in weathering process.
8. Examine positive effects of weathering processes.

Mass wasting

Mass wasting is a movement of rock materials and /or soil 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

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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 weather-able 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 as compared to areas covered by sand. In addition, the large rocks have greater chance to easily overcome by gravity as compared to fine weathered materials. The angle of slope can variably influence mass wasting. For example, the steeper the slope, the faster the movement of the materials. This is because gravity has much effect with increasing angle of the slope. Contrary, the effect of gravity is less active with decreased angle of slope as the case of gentle slope. Climate plays a crucialrole, through rainfall and temperature. Through regarding to rainfall, 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. In contrary, low rainfall have less effect on saturating the material and hence reducing the intensity of landslides. On the other hand, freezing and thawing encourages mass wasting as well. In dry climate, the materials may be loose but they lack water hence the resultant movement is likely to be slow.

The amount of water has an effect to mass wasting depending on the saturation of the materials. The more saturated the material, 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. On the other hand, water acts as a lubricant along the bedding plane thus facilitating the gravity-initiated movements. The availability of vegetation in an area like grasses, shrubs, and large trees, their roots helps to hold rock materials together and thus stabilizing the earth's surface against movement. In this case the bare surfaces have a greater chance of encountering mass wasting as compared to the areas rich in vegetation. However, presence of dense vegetation cover in wet regions fuels the rate of infiltration into the soil and rocks beneath the surfaces. Due to this the rate of saturation to rock materials is fastened hence triggering mass wasting in an area. Anthropogenic activities like cultivation, grazing, mining, clearing vegetation, and road constructions are greatly affecting the stability of the earth's surface. Vibrations from moving trains and vehicles can cause tremors and explosion as well can cause shaking of the ground and ultimately lead to movement of some unconsolidated

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earth material downslope. The tectonic movements generated by earthquake and/or volcanic activities normally generate the 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 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 very 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 3.7). 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 out, it contracts vertically resulting to 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 facilitate soil creep. Soil creep can be recognized by observing bending trunks of trees, broken fences, tilted electricity and telegraphic poles.

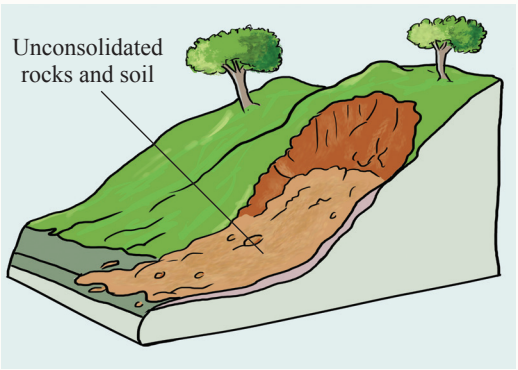


Figure 3.7: *Soil creep*

Talus creep: Talus creep involves a very 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 3.8). A 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, 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

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term talus is often used to refer to the fragments themselves.

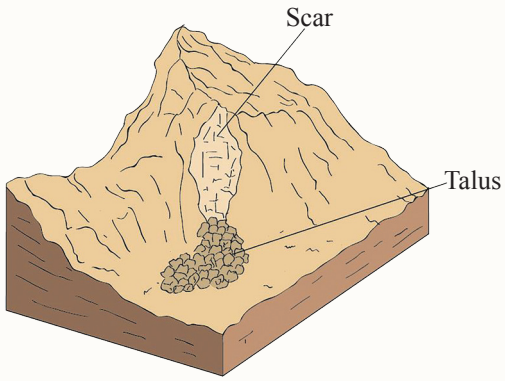


Figure 3.8: *Talus creep*

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 3.9). During the 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. As the melt water cannot infiltrate downwards and the temperature are too low for much 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 m in width and had a mixture of sand and clay formed in valley and at the foot of sea cliffs.

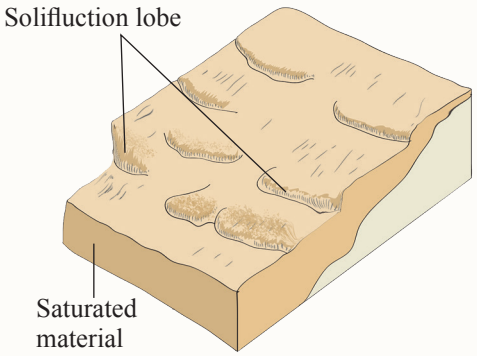


Figure 3.9: *Solifluction*

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

Rapid mass wasting

This is a rapid process of downfall of materials of 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 movement will be. The presence of water is a contributory factor 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, and avalanche provide basic categories of rapid mass wasting.

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Landslide: Landslide refers to the rapid movement of rock materials in form of rock slump, rock slide and rock fall It is one of the natural hazards incidents.

(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 earth flows (Figure 3.10). It is one among the most fluidly super – saturated of earthly materials consist of wetted soil combined with fine boulders and regolith moving down the slope in speed exceeding 1 km 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 crop land and causing mass causalities. Heavy and down pouring of rain in sloped, bare land and less compacted and porous soil may become the prone site for mudflow.

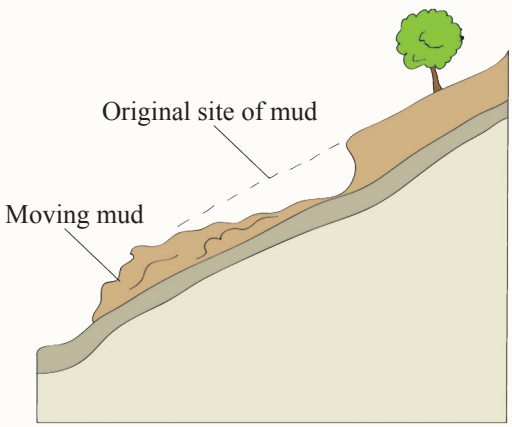


Figure 3.10: *Mud flow*

(b) Rock slump

A slump is a form of mass wasting that occurs when a coherent mass of loosely consolidated materials or rock layers moves a short distance down a slope. The movement is characterized by sliding along a concave-upward or surface. The causes of slumping movement include earthquake shocks, 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 triggers 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 mm fall in one night that caused saturation of soil materials. Also, undercutting of a steep slope by river, sea or the steepening of a slope by human action such as quarrying or clearing of vegetation from a steep slope 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 3.11).

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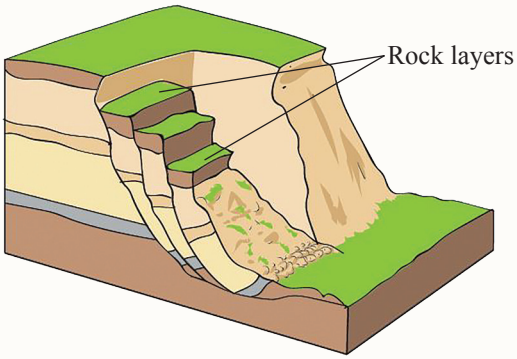


Figure 3.11: *Rock slump*

(c) Rock fall

This is a fall of individual rock from a steep cliff. It is the most rapid movement of all. If rock fall goes on repeatedly for a long time, debris are collected on the slope to form mound (talus). These involve very rapidly falling of huge pieces of boulders and blocks of rock down the hills, cliffs or mountains. 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 the results of rock fall at the base or foot of the mountain or cliff commonly known as scree or talus (Figure 3.12). The rapidity of the rocks downs the hill or mountains depend on the profile and gradient of the slope together with extent of availability of abstraction. This means that the rocks or boulders rolling or bumping on a bare mountain or hill may accelerate into a tremendous speed with possible devastating impacts on the way down the hill compared to those rolling on vegetated slope.

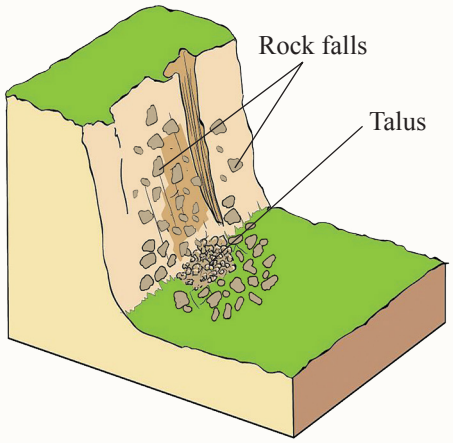


Figure 3.12: *Rock fall*

(d) Rock slide

A rockslide is a type of landslide caused by rock failure in which part of the bedding plane of failure passes through intact rock and material collapses in masses. While a landslide occurs when loose sediment falls 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 the rocks to slide down the hill it is required to have the jointed structure and/or whose bedding planes roughly parallel to the angle of the slope. The rock slide may involve huge size of rock or boulders but in sliding motion down the gentle slope. As the case of rock fall, the rockslide may move for considerable distance

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depending on the nature of the slope and moving materials (Figure 3.13).

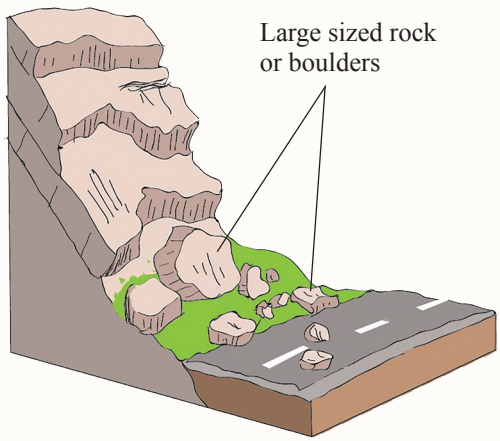


Figure 3.13: *Rock slide*

Avalanche: Avalanche is a sudden and catastrophic movement of snow, ice or rock down the slope (Figure 3.14). It occurs like a landslide when the mass of material is sufficient to overcome friction. There are different types of avalanches grouped on the basis of nature of movement and methods of classification. Avalanches are mainly caused by a heavy snow fall compressing and adding weight to earlier falls, deforestation, low stability and friction on steep slopes and sudden increase in temperature. Also, avalanches are caused by heavy rains falling upon a snow, and very long cold, dry winters followed by heavy snow falling under this condition earlier snow fall will turn into ice while the later will slide.

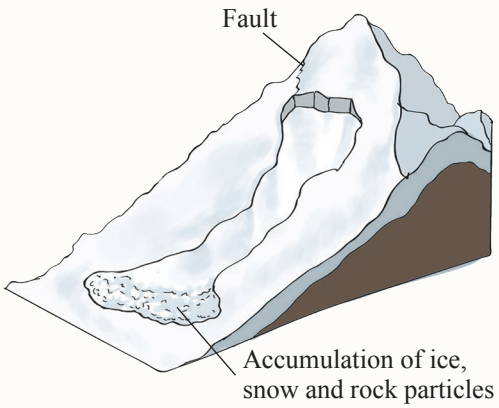


Figure 3.14: *Avalanche*

Precautionary measures to reduce the impact of mass wasting

In order to reduce the occurance of mass wasting on the environment, the following are the recommended measures;

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

(ii) Population control along steep sloped area which would have cut the slope in order to set up residential areas there by increasing the loose material along the slope.

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

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

(v) 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 check access water run-off.

Exercise 3.2

1. Examine the classification of mass wasting.
2. Account for the factors controlling the rate of mass movement.
3. With vivid examples examine the effects of mass wasting.
4. Suggest the measures to curb down mass wasting.

Wind action and desert landscape

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 is however noted that it has a significant effect in the deserts. The wind action in deserts often generates processes of erosion, transportation, and deposition. Ultimately, these processes account for numerous landforms in the deserts. Essentially, the geographical distribution of deserts is largely controlled by global and regional atmospheric circulation patterns. Also, the human activities such as shifting cultivation, overgrazing, unsustainable clearing of forests for different purposes contribute to desertification. Generally, deserts cover all arid regions that normally experience average rainfall of about 250 mm per year. Deserts are persistently dry, have high rates of evaporation, poorly developed soils, and are mostly or completely covered with sparse vegetation. The deserts experience the average summer temperature of about 32^0C to 38^0C while the daytime winter temperature records 10^0 to 18^0C on average. Most of the deserts are located between 15^0 and 30^0 North and South of the equator (Figure 3.15).

Deserts support sparse vegetation cover. The plants are usually small, widely spaced and experience slow growth. Most of the plants have wide, shallow root structure adaptive to absorb the dew. The rate of water loss through evaporation in deserts is relatively higher compared to other regions. The sparse or lack of vegetation cover in

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the deserts exposes the ground surface to denudation and deposition processes by wind. Despite their harsh conditions desert regions support life to a wide range of terrestrial organisms.

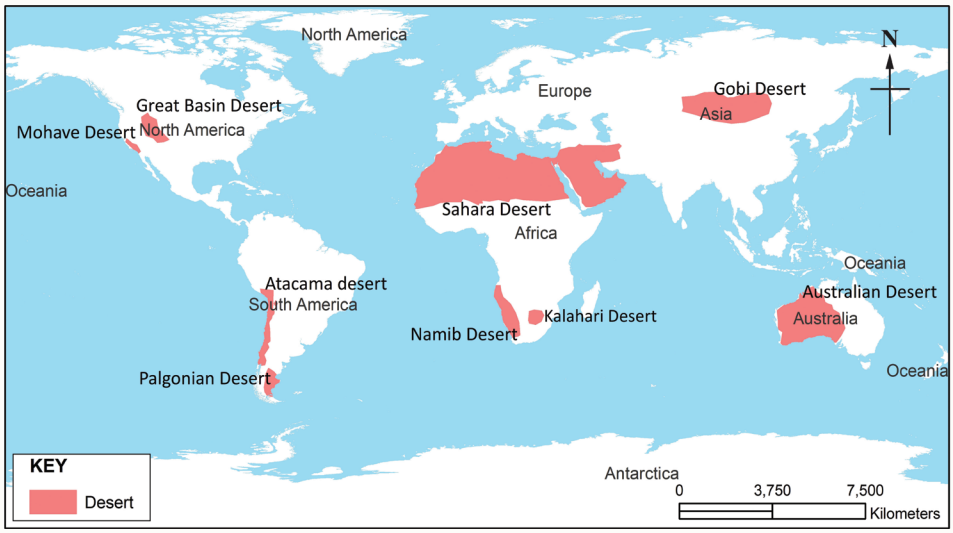


Figure 3.15: *Desert areas in the world*

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, the 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. Also, cold ocean currents explain the occurrence of deserts. Usually these currents do not bring moisture in the areas where they are passing. 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, produces 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 activites.

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Wind action in desert areas

As wind blows in desert areas it erodes, transports and deposits materials from the land surface. Therefore, wind processes in the desert areas involve erosion, transportation and deposition of different materials. These processes result into the formation of different features on the desert area. Transportation by wind in the desert moves away the materials into 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.This materials are generally reffered 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. Also, the nature of regolith is important. Materials are more likely to be moved if there is no 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. Wind erosion in desert areas, can be effective anywhere, depending on its strength. 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 3.16). Deflation causes hollows or depressions due to the blowing away of the fine materials and ultimate by lowering the surface to some depths.

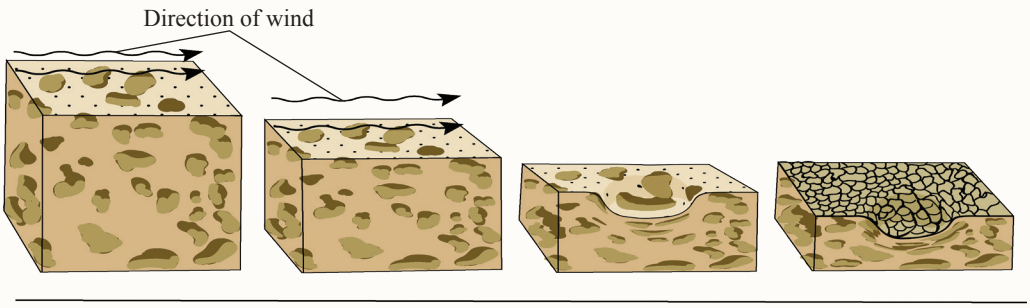


Figure 3.16: *Process of deflation*

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Landforms resulting from wind deflation

The following are features formed by wind deflation. These features are 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. Also, 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 m 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 3.17). A number of assumptions account for the formation of depression.

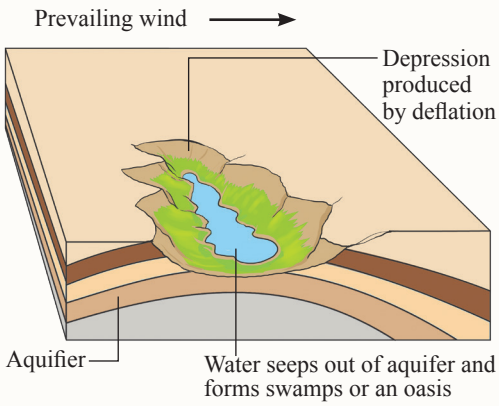


Figure 3.17: *Deflation hollow*

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 it will be 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 meters 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.

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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 3.18). 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.

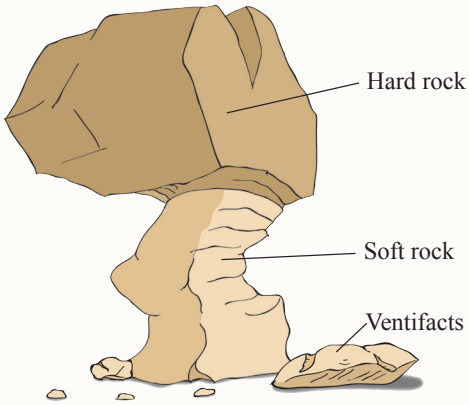


Figure 3. 18: *Ventifacts*

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 3.19). 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.

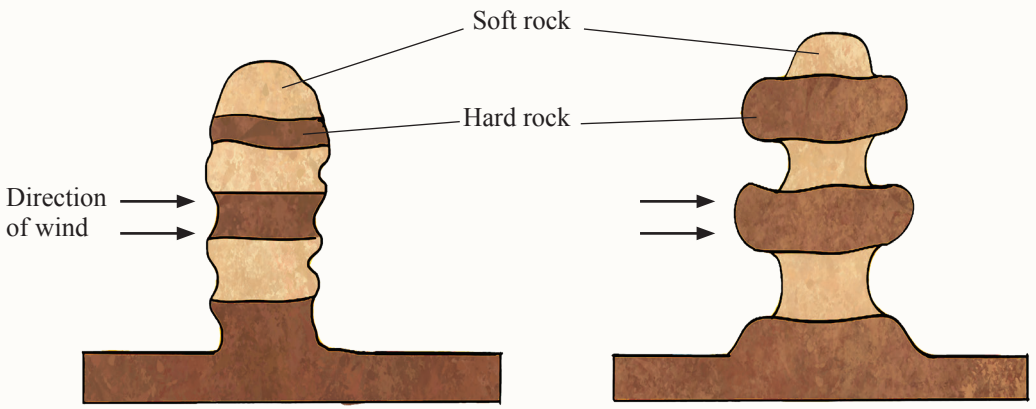


Figure 3.19: *Rock pedestals*

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 structure. 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 as (Figure 3.20). Examples of zeugens can be seen in Bahrain (Middle East).

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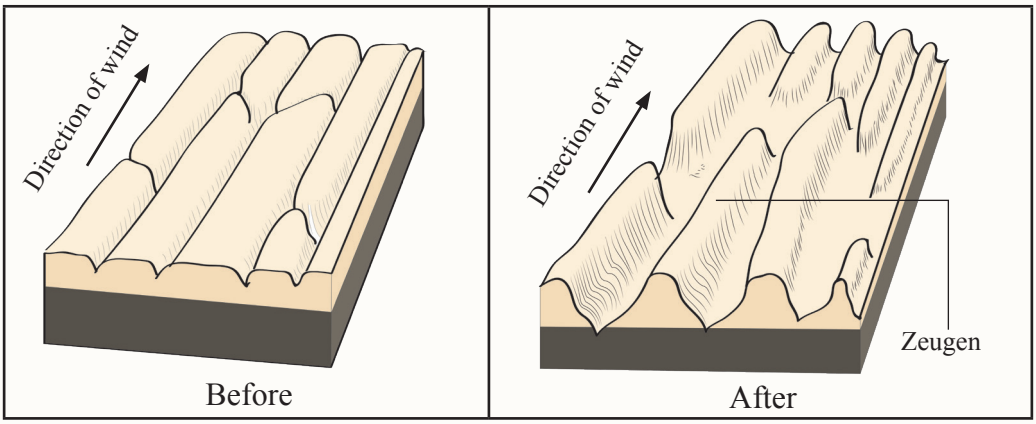


Figure 3.20: *Zeugens*

Yardangs: These are formed when bands of resistant and weak layers of rocks laid vertically and parallel to the preceding winds in the desert as a result wind abrasion produces another type of ridge and furrow landscape. They are usually less than 10 m high and 500 m long but some are more (Figure 3.21). An example of these is the Silsila gap in Egypt North of Kom Ombo.

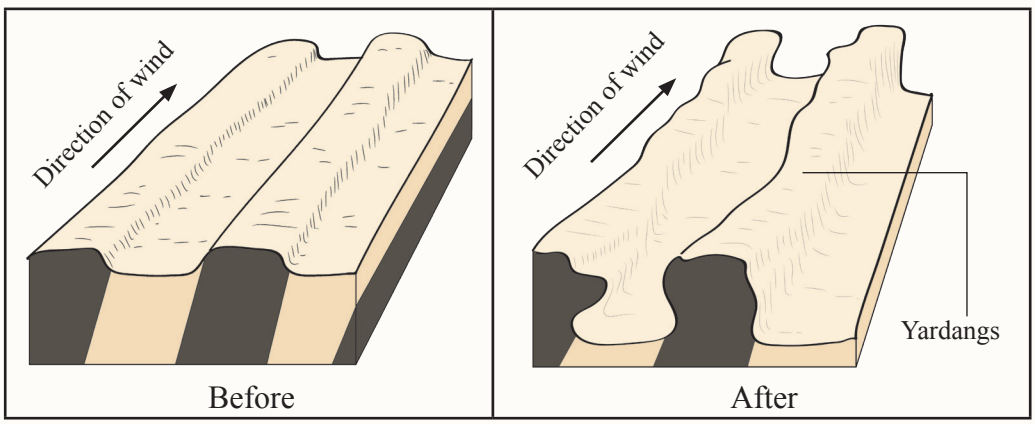


Figure 3.21: *Yardangs*

Inselberg: Inselberg is a German word which means an island mountain. Inselberg is a steep sided hill rising abruptly from pediment which extends on all sides into monotonous plain (Figure 3.22). 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 sheet. Inselbergs are common in Kalahari Desert, parts of Algeria, North West Nigeria Western Australia and Northern Tanzania in Maasai land. Also, inselberg can be described as a residual hill or rock mass rising abruptly from the desert

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floor. When inselberg is smooth and round in shape, it is called *Bornhardt* and when it is characterized with joints with rectangular rock blocks pilled together to produce castellated form, it is called *Kopjes*.

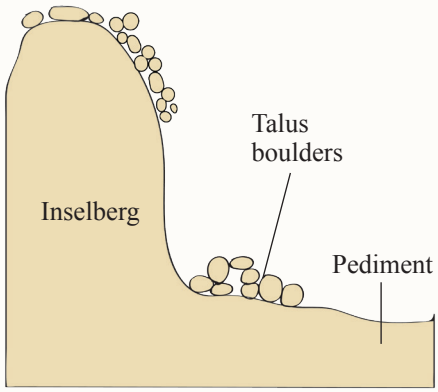


Figure 3.22: *Inselberg*

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. The result is to produce a characteristic of a rounded sand grain (or millet seed). This forms the dominant 'end product" of desert erosion.

Wind deposition

The load carried by wind depends on the size of material and the strength of the wind. The size of material carried by 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 km in length and 200 m 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 3.23). Good examples of seif dunes occur in the Thar.

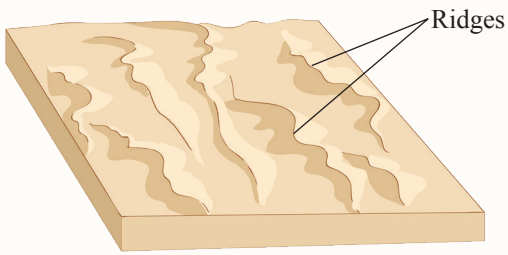


Figure 3.23: *Seif dunes*

Barchan dunes: Barchans sometime known as barkhans, 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

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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 m and is 400 m wide (Figure 3.24). There are good examples of barchans in the Sahara desert and Turkestan.

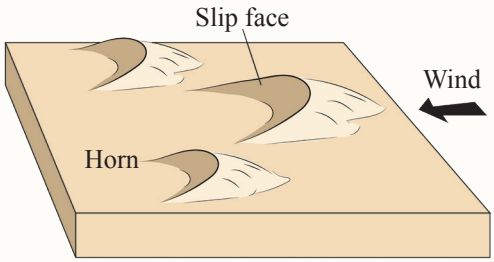


Figure 3.24: *Barchans*

Attached dunes: Attached dunes are also known as head dunes. These are sand drift 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 in huge dune fields, but most are less than 50m high. They are built by light to moderate winds, blowing from one direction only. Wind usually blows perpendicularly to the dune (Figure 3.25). In the Western Sahara, they are known as ankle.

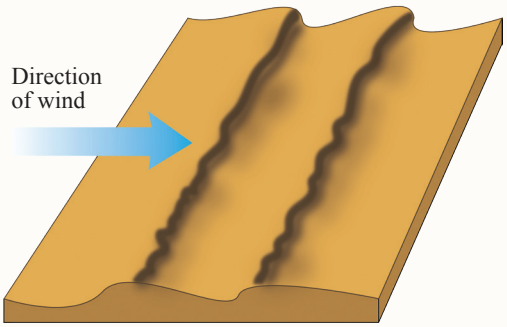


Figure 3.25: *Transverse dunes*

Star dunes: These are complex dunes with a star-shape, formed by winds blowing from several directions (Figure 3.26).

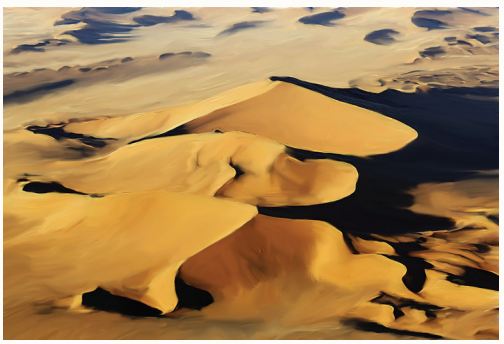


Figure 3.26: *Star dunes*

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 3.27). 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.

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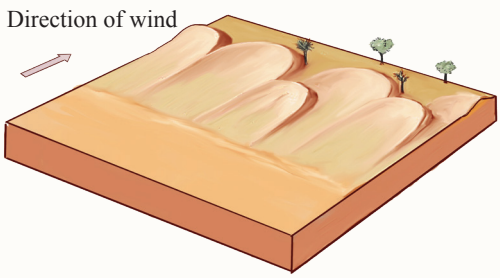


Figure 3.27: *Parabolic dune*

Ripples

These are series of small ridges of more or less parallel 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 Nile river from Sahara Desert. Loess form the fertile soil, for example, Hwang Ho basin that attracts agricultural development.

Activity 3.2

(a) In group of five students, visit your library or use internet sources to read more on wind action in deserts and thereafter write a summary in your exercise book.

(b) With the assistance of your subject teacher, make a presentation in the classroom.

(c) During presentation, allow other students to ask questions and respond.

(d) Improve your work after presentation then submit for assessment.

Exercise 3.3

1. Explain why wind is considered as a major factor of erosion in the desert areas.
2. What are the major land forms associated with mechanical weathering in the desert areas?
3. What are the importance of a desert landscape and its associated challenges.

Water action in deserts

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 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

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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 3.28). The desert surface is washed unevenly by running water through small channels called rills.

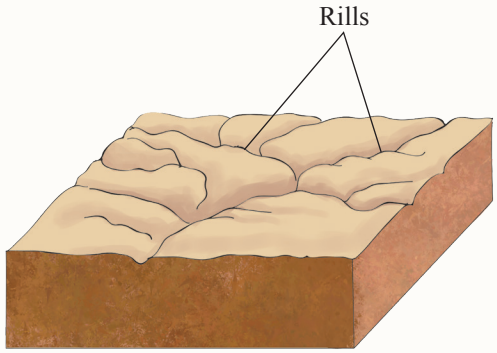


Figure 3.28: *Rills*

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 widen the rills into larger grooves (Figure 3.29).

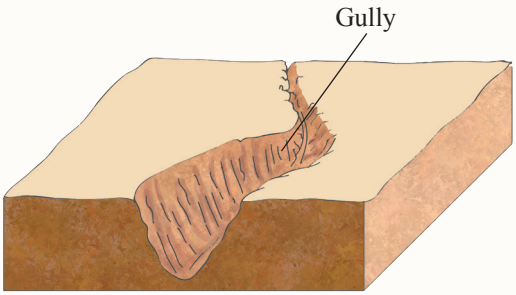


Figure 3.29: *Gully*

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 3.30). 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 3.30: *Wadis*

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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 3.31). 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 Northern areas of Turkana in Kenya.

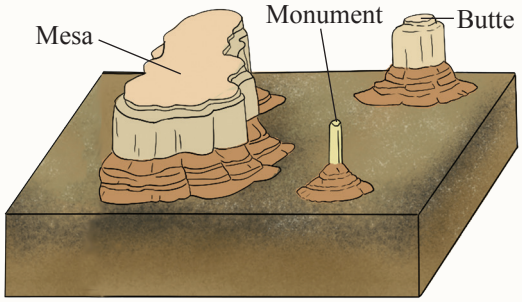


Figure 3.31: *Mesas and buttes*

Water depositional features in the desert area

Water action in the desert results to a different depositional features namely alluvial fans, alluvial cones, bajada, peripediment and sebka. Figure 3.32 and 3.33 present water depositional features in the desert area. The subsequent sections explain the varied features formed by water action in the desert area.

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.

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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 heavy falls 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.

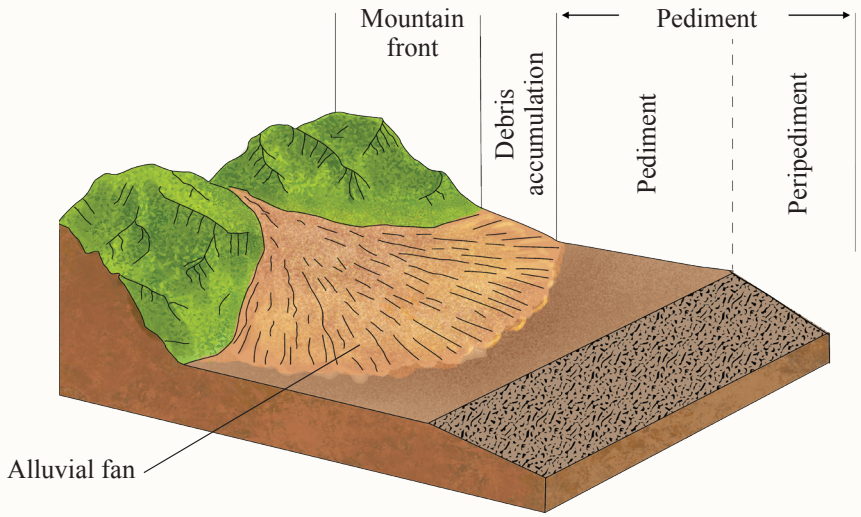


Figure 3.32: *Water erosional and depositional features in desert*

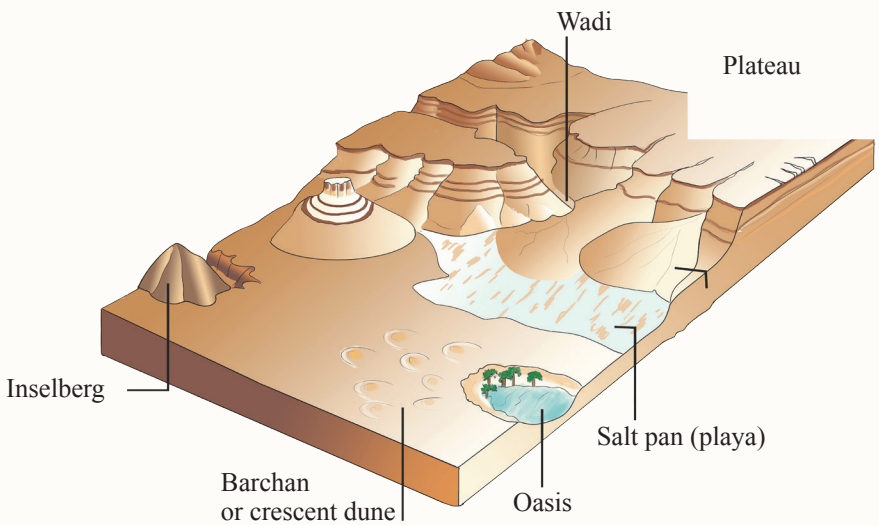


Figure 3. 33: *Water erosional and depositional features in the desert*

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Activity 3.3

With the supervision from your subject teacher, do the following;

(a) On your own, read books and other materials about water and wind actions in desert areas.

(b) Identify features formed due to water erosional and depositional processes in the desert.

(c) Using illustrations and diagrams describe their modes of formation

(d) Share the knowledge you have acquired with your fellow students.

Exercise 3.4

1. With the aid of diagrams, clearly explain the distinctive features formed by fluvial action in the desert.
2. Assess the role of water as an agent of erosion in arid areas.
3. Describe any six characteristics of a desert landscape.

Water action in the karst region

The term *karst* is borrowed from Yugoslavia and means features formed in the limestone regions mostly dominated by limestone rocks. Karst region is a landscape mainly formed water soluble limestone or dolomite to form sinkholes, sinking streams, caves, springs, and other characteristic features. The limestone region characterized with 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. Tanzania is one of places in the world characterised with karst regions. It hosts significant composition of limestone rocks in areas such as Amboni and Nanyala in Tanga and Songwe regions respectively. Also, the karst region is found in Slovenia, Southern Europe.

Characteristics of the karst region

The karst region is characterized with scant vegetation that occur in pocket such as scrubs and thickets. The region has rock outcrop with poor soil in some parts of the region. Rocks in the region 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 as a

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result the reaction between carbonic acid and limestone minerals to form carbonates. 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. There are residual features like scarps and hills consist of resistant rock. Gullies, rills, sink hole and grikes are common land forms on the surface of the entire region. The region largely, supports the growth of grasses as the results of poor soils. These grasses are useful for livestock keeping, as the case of Yugoslavia in which they are used for sheep raring.

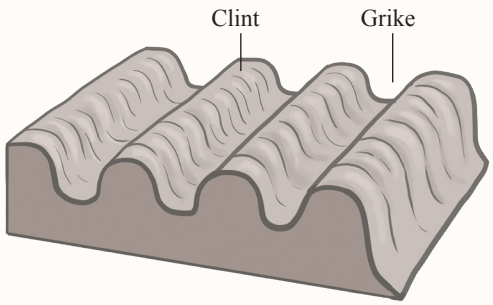
Features formed in the karst region

The 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 3.34). 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.

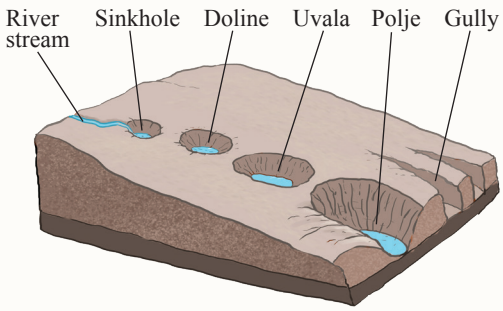
Swallow hole/sink hole/ponor are vertical holes like landforms formed as a result of enlargement of the rock cracks caused by the accumulation of water on the surface of the limestone region. *Doline* which is referred as a shallow depression with gentle slopping sides and generally circular in plain.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



(a)

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(b)

Figure 3.34: *Surface landforms in the karst region*

Sub surface/subterranean 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 3.35). Sub-surface landforms include the following: *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. Also, such river flow is called subterranean river. *Stalagmites* these are finger like structure of rock masses that grows from the floor of the cave upward. Their formation is a results of precipitation of calcium bicarbonate materials that accumulate on the floor of the cave. *Stalactites* these 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* these 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 thread arranged spirals, and they can rejoin the ceiling of the cave.

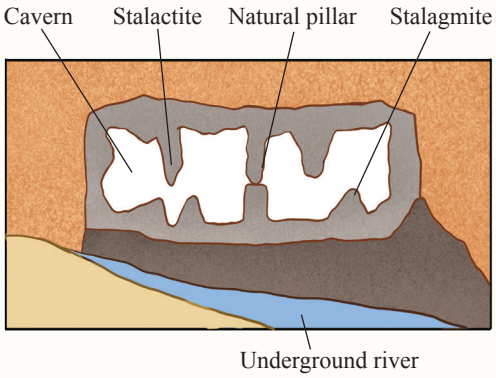


Figure 3.35: *Sub-surface landforms in the karst region*

Importance of the karst region

The karst region has several values or importance, the major ones include: Supporting 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 a fertile soil that can be used for crop production. Such soil includes *toreros soil.* The region provides rocks that can be used for construction activities. Karst

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region provides the basis for availability of raw materials that can be used in different industrial sectors. For example, limestone rocks are essential for the production of cement. Underground features in the limestone region such as cave, stalagmite, stalactites, natural pillars attract tourism which in turns 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 3.5

1. Explain characteristics and significance of karst Scenery.
2. Describe diagrammatically the subterranean landforms formed in the karst region.
3. Describe surface and sub-surface landforms formed in the karst region.
4. Explain the socio-economic significance of the karst region.

Glaciation

Glaciation involves both the moving ice (glacier) and periglacial. Glaciation refers to all processes that take place due to the influence of the moving mass of ice (glacier) or the state of being covered by glacier or ice sheets while periglacial refers to near or at the fringe of an ice sheet, where frost and snow have a major impact upon the landscape. However, the term is often used to explain any area with cold climate such as mountains in temperate latitudes. Also, it includes areas which have experienced severe frost action in the past, for example, some parts of the Congo basin.

Theories explaining the occurrence of glacial periods

The occurrence of glaciers in different parts of the world has been caused by climatic changes associated in the general cooling of the atmospheres. This can be explained through various theories: *Variation of earth distance from the Sun.* This relates to the nature of the orbit of the Earth and its inclination. During the greatest distance from the sun (aphelion 152 million km) on July 4th, the amount of solar radiation is reduced and leads to the formation of glacier because of cooling of the atmosphere. The idea was developed by the former Yugoslavian astronomer and mathematician, Milutin Milankovitch (Between 1921 and 1941). *Reduction of carbon dioxide in the atmosphere.* When carbon dioxide is excessively reduced in the atmosphere, it leads to the cooling on the earth's surface and the falling of snow occurs. This is due to the fact that the absence of CO_2 causes the outgoing radiation to escape freely into the atmosphere through radiation. Carbon dioxide is a very good absorber of solar radiation. Hence if CO_2 content in the atmosphere is reduced

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by a half the temperature go down by 4º C resulting in the occurrence of glaciers. The idea was advanced by Svante Arrhenius, the Swedish scientist. *The increase in the amount of dust in the atmosphere.* When dust, for example, volcanic dust is present in a great amount in the atmosphere it tends to reflect and absorb solar radiation, which is supposed to reach the surface. Therefore, substantial fall in temperature and hence cooling leading to the occurrence of glacier. *Shifting of the position of the continent.* The shifting of continents during continental drifting also accounts for the occurrence of glaciers on the earth's surface. The landmasses, which were shifted to extreme polar regions, assumed very low temperatures that in turn led to the occurrence of glacier because the regions were now located very far from the position of the sun. Some places like Greenland, Antarctica and Iceland are snow covered with ice because of being in the polar regions. *Elevation of the land surface.* Some places have been elevated as a result of diastrophic upheavals. Elevation led to the lowering of temperature due to the principle of lapse rate thus temperature decrease with increase in height, hence formation of glacier. For example, Mt. Kilimanjaro, Alps, and Kenya Mountains are covered by ice and some of them are located in tropical areas.

Accumulation of ice

When the temperature of the air falls below freezing point 0º C, some of its water vapour condenses and freezes into snowflakes that fall on the ground surface as snow. Where snow collects in hollows it becomes compressed by the weight of subsequent fall and gradually develops into a more compact dense form called neve or firn. Firn is a consolidated snow which has experienced one winter freezing and survived one summer melt. When firn is more compressed it may form more solid substance called ice. Once ice has formed it may begin to flow downhill under the force of gravity as glacier. In polar and sub-polar regions extensive areas may be covered by permanent layers of ice (frozen water) called ice sheets (ice cap or snow field). The lower limit of the snow field is called snow-line. This is a point above which snow and ice cover the ground throughout the year. Snowline is the lowest level on the mountains above which snow never completely disappear, it is considered to be permanent level though it varies with latitude, altitude, temperature, humidity, precipitation, aspect and steepness of the slope. There are two types of snowlines namely permanent and temporary. Permanent snowlines are the area where snow does not melt completely throughout the year, for example, polar region of Antarctica and highland areas of very high altitude such as Kilimanjaro and Alps Mountains. Temporary snowlines

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are the area where snow falls on winter seasons, for example, in Britain where snow disappears in August when the temperature rises.

Movement of ice

Ice moves in different forms though its causes to flow is not known exactly. It is stated that the movement is caused by freeze-thaw action. The following are forms of ice movements. *Plastic flowage* occurs when ice moves in a massive nature like a viscous liquid. The movement is caused by deep accumulation of ice on a slope which makes the bottom layers to melt under pressure. The action triggers off the movement of ice down the slope. Such mass of moving ice is called a glacier. *Basal slip* happens when ice slips and slides over the underlying rock. It involves the sliding of glacier over its rocky base. Also, internal shearing is a movement similar to rock faulting which involves differential sliding along plains within the ice body caused by a tremendous pressure exerted by glaciers.

The gradient and the thickness of the ice affect the speed at which ice flows. The movement of valley glaciers is greater than that of ice sheets. Movement on the surface and in the centre of a valley glacier is greater than movement at the sides and bottom. These different rates of movement lead to the formation of cracks called crevasses. These cracks can be transverse crevasses which occur at right angles to the glacier, marginal crevasses that occur parallel to its sides and oblique crevasses which occur obliquely to its sides.

Types of glaciers

Glacier may be classified according to size and shape, the characteristic which are relatively easy to identify by field observation. Based on these criteria, several types of glaciers emerge. Firstly, ice sheets and ice caps that overspread continental or plateau regions where the snow line is low, creeping with a slow massive movement towards the margins, for example, Antarctica or Greenland. Secondly, valley glaciers include large masses of ice which move from either ice field or cirque basin source. They usually follow former river courses and are bounded by steep sides. Thirdly, piedmont glaciers which consist of sheets of ice formed by the coalescence (growing together) of several valley glaciers which have spread out below the snowline like lakes of ice-over a low land areas of wastage for istance, Western Europe and Alaska. Fourthly, ice shelves that form when the ice sheets reach the sea and begin to float. Icebergs form when ice breaks away, a process called calving. Fifthly, corrie or cirque glaciers which include small masses of ice occupying armchair-shaped depressions on mountain sides. They often overspill from their hollows to feed valley glaciers. Sixthly, niche glaciers which are very small and occupy hollows and gullies on North facing slope in the northern hemisphere.

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Factors affecting the rate of glacial movement.

Glaciers can move from one place to another either fast or slowly due to the following factors.

(a) Nature of gradient: This refers to the degree of slope. Along steep slopes glaciers tend to move fast if not blocked by an obstacle on its way. This may explain the limited movement of continental glaciers along plain areas and gentle slopes.

(b) Temperature: Glaciers move fast during warmer seasons. This is because the melting rate or breaking rate is very high. The movement may be in form of avalanches. During low temperature the movement is limited since the freezing rate is also high hence making glaciers to attach to each other.

(c) Thickness and weight of glaciers: The thicker the glacier the fast the movement. This is because the chance for it to be blocked on the way is very low. On the other hand, small glaciers may be blocked while on their way.

(d) Nature of the load: Glaciers are always associated with loads transported. The lesser the load the faster the movement since there is less friction between bedrock, glacier and the underlying valley sides. Therefore, a heavy loaded glacier will have high friction hence retarded to move further.

Glacial erosion

Ice action greatly changes the appearance of landforms. Highlands are subjected to erosion and parts of lowlands are subjected to both erosion and deposition. Some of this glacier is collected in hollows or held back by glacial deposits, where it forms lakes, such as, the Great lakes of North America. Virtually all glacial processes of erosion are physical as the climate is too cold for chemical reaction to take place.

Erosion processes of glaciers

Glacial erosion which predominates in the highland consists of three processes. These are sapping which involves breaking up of rocks by alternate freezing and thawing of water at the bottom of cracks between a mass of ice and the side and floor of a valley or the side of a mountain. Plucking is the tearing away of large blocks of rocks which have become frozen into the sides or bottom of a glacier. It involves the removal of blocks of bedrock which have been loosened by ice. Also, abrasion is the process which involves the scratching and scraping of the valley by debris and other fragments that are frozen or embedded into the glacier. Therefore, the load is used as the tool for eroding the surface. On the other hand, there is another process known as frost shuttering. This process produces much loose materials which may fall from valley sides onto the edges of the glacier to form lateral

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moraine. They may be covered later by snowfall or plunge down crevasses and be transported as englacial debris.

Landforms of glaciated highlands

Features formed on the glaciated highlands include the following; cirques (corries), arête, pyramidal peak (horn), U-shaped valley (glaciated trough), hanging valleys, truncated spurs, benches, col, fiord and rock basin (Figure 3.32). They are also known as Alpine glacier features.

Cirques or corries: These are semi-circular steep sided basins or depressions cut into the side of a mountain or at the head of a valley. They are also known as corries in Scotland and cwm in Wales. During periglacial times, before the last glaciation, snow collected in hollows especially on facing slopes. A series of processes, collectively known as nivation which included freeze-thaw, solifluction and possibly chemical weathering, operated under and around the snow patch. These processes caused the underlying rocks to disintegrate the resultant debris was then removed by summer melt water streams to leave in the enlarged hollow. Sometimes a corrie can be filled with water to form a corrie lake or tarn, for example, Lake Tana in Ethiopia. *Arête*: This is formed when two adjacent cirques erode backwards or sideways towards each other such that the previously rounded landscape is transformed into a narrow-rocky, steep sided ridge. *Pyramidal peak:* This is also known as horn which refers to a steep-sided angular horn formed by the steepening of the back wall of corries, when several corries develop on the sides of the mountain. *U-shaped valley:* A U-shaped valley is also known as glaciated trough. It is a steep-sided, flat bottomed, wide valley which contain features produced by both glacial erosion and glacial deposition. Most of the U-shaped valleys were originally river valleys. The valley is straightened and any projecting spur are planed off or truncated. Thus the former interlocking spurs are turned into truncated spurs. *Hanging valleys:* Hanging valleys resulted from differential erosion between the main glacier and its tributary glaciers. The floor of any tributary glacier is deepened at a slower rate, so that when glaciers melt it is left hanging high above the main valley, and its river has to descend by a single or a series of waterfalls. *Truncated spurs:* A truncated spur is formed due to abrasion by englacial and sub glacial debris and plucking along the valley sides which remove the tips of pre-glacial interlocking spurs leaving cliff-like structure called truncated spurs. Also, it may be formed when glacier flows through interlocking spurs with the ability to straighten the valley by cutting the projecting spur. *Benches:* Benches are also known as alps. These are upper slopes of the river valley, lying above the glacier surface and after the

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glacier melts they form benches. *Col:* Col is a narrow notch on an arête between opposite cirques. It is produced by the process called headwall recession due to plucking. The two cirques meet and create a notch or gap on the arête. *Fiord:* Fiord is a submerged glaciated U-shaped valley (sea inlet) when the glacier eroded its path by undercutting and later plunged into the sea, which then is flooded by sea water after the rise of the sea level which causes submergence of the coastal areas. *Rock basin:* A rock basin is formed by unequal glacial erosion of the bed rock. This is an irregular depression in the floor of a U-shaped valley. This feature often develops when the thickness and weight of a glacier increase, such as, at the junction of two glaciers (Figure 3.36).

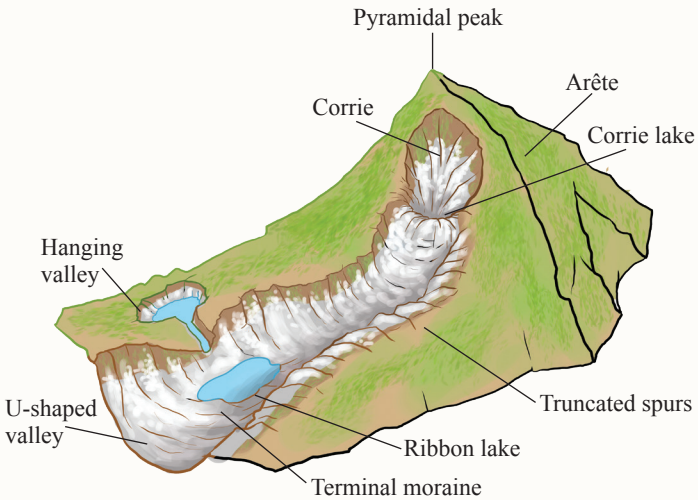


Figure 3. 36: *Landforms of glaciated highlands*

Landforms of glaciated lowlands

The glacial erosional features in the lowland areas are largely caused by the influence of ice sheets. An extensive area covered by an ice sheet smoothen off the original landforms to give a rounded topography known as ice-eroded plain. On these plains there are roche moutonnee and crag and tails.

Roche moutonnee: A roche moutonnee is an outcrop of resistant rock smoothed by ice on the upstream end into a gentle slope and plucked on the downstream end to give a steep jagged slope (Figure 3.37). Also, the rock moutonnee occurs in glaciated highlands.

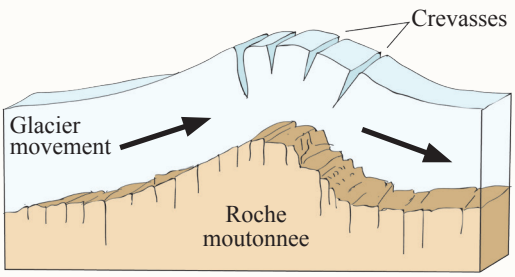


Figure 3.37: *Roche moutonnee*

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Crag and tail: Crag and tail consists of a larger mass of resistant rock. It is formed by less resistant rock which protect the lee-side rocks from erosion, thus forming a gently sloping tail (Figure 3.38).

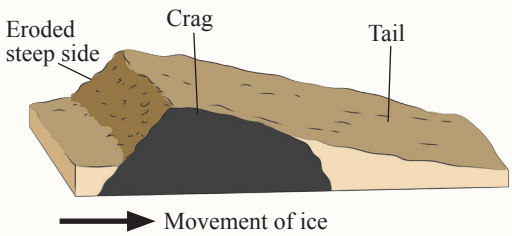


Figure 3.38: *Crag and tail*

Glacial deposition

The deposition of materials by ice can be achieved by stratified and unstratified materials. Stratified materials are sorted and stratified clays, silt sands or gravel deposited by melt-water streams while unstratified materials are unsorted fluvial-glacial. Such materials consist of a mixture of rock fragments ranging in size from clay to boulders and are deposited directly from ice, without water transport. Glacial deposition landforms include boulder clay, erratics, drumlins, moraine, varves, kames, eskers, kettles and braided stream.

Boulder clay plain

Boulder clay is an extensive area of a monotonous relief. Former valleys and hills are buried by thick layer of till deposited beneath the ice sheet and plastered onto the sub-glacial surface by the pressure of the ice. The plain contains other features like erratics, drumlins, and moraines (Figure 3.39).

Erratics: Are large boulders of varying sizes deposited by glacier or ice sheet as they melt. Erratic blocks are composed of materials, which are different from the materials of the surrounding rocks. It helps to know the direction of ice movement. These features can be found in South Wales in Britain.

Drumlins: Are elongated oval shaped low hummock (small glacial hills) made up of boulder clay and it is about 1km long and 25-100m high. The upstream sides are usually steeper than the downstream sides, and they occur in swarms, usually oval and shaped like half an egg.

Moraine: A moraine is a boulder clay deposit (till) laid down in the lowlands to form ridges. It consists of debris mainly boulders and fragments, transported and deposited by glacier. There are different types of moraines (Figure 3.39). The common ones include; lateral, medial, terminal, recessional, and ground moraines. *Lateral moraines* are formed when glacier melts and leaves a ridge of material along the valley sides. Also, it consists of debris derived from frost shattering of valley sides and carried along the edges of the glacier. *Medial moraines* refer to rock fragments deposited in the middle of the valley, after two lateral moraines merge. *Terminal moraines* are formed when debris is transported at the front of the glacier and deposited when glacier melts. It is regularly series of mounds extending across a valley or lowland area. Moreover, recessional moraines

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refer to a series of roughly parallel terminal moraines that mark the step by step retreat of the glacier. Furthermore, ground moraine refers to the materials deposited at the bottom of the glacier after ice melts. They form a fairly thin extensive layer or blanket of till.

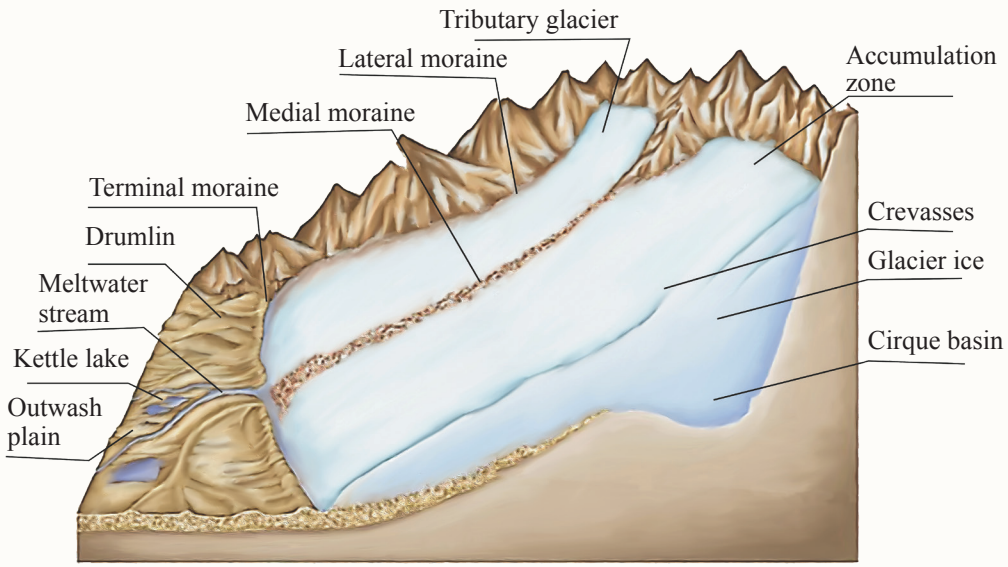


Figure 3.39: *Glacial deposition landforms*

Fluvioglacier landforms

These are landforms molded by glacial melt water. Unsorted material deposited by ice, melt water transport and deposited sorted materials of gravels and sand. Wherever there is a decrease in discharge a group of depositional feature are formed. These features include the outwash plain, verves, kames, kame terraces, eskers, kettles and braided streams.

Outwash plain: Materials such as sand and gravel formerly deposited by glacier are later picked, sorted and dropped by running water (melt water) beyond the maximum extent, of the ice sheets. They form a plain of sorted materials (Figure 3.40). *Varves:* A varve is a distinct layer of silt lying on top of a layer of sand normally deposited annually in lakes nearby glacial margins. Two layers of sediments representing one year's deposition in a lake. The light coloured layer consists of slightly coarser sediments (silt) deposited during the warmer part of the year when the nearby glacier is melting. The darker layer is finer sediment (clay), materials that sink down more slowly during the winter after the lake surface freezes and the supply of fresh, coarser sediments stops due to lack of melt water. Each band of light and dark materials represents one year's accumulation. The dark colour is attributed to fine organic matter mixed with clay.

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Kames and kame terraces: Kames are steep sided hills formed by a sorted sand and gravel deposited by melt water. They are deposited unevenly similar to a series of deltas along the front of a stationary or slowly melting ice sheet. They vary greatly in size and shape and occur in groups. Kame terraces are also mounds of sand and gravel along the valley sides. They are deposited by melt water between the glacier and the valley walls. Kame terraces are distinguished from lateral moraine by their sorted deposits. *Eskers:* These are long, sinuous ridge of water deposited material composed of sorted course sand and gravel. Eskers can be up to 50 meters high and several kilometers long. They develop in areas of stagnant ice where rivers maintain sub-glacial tunnels. Water flowing through such tunnels is under hydrostatic pressures making it impossible to carry heavy or large load, much of which is deposited within the tunnel, when the ice melts it leaves long, winding steep sided ridges. *Kettles:* These are formed when the ice block melts to form a depression. Melting water builds thick deposits of outwash alongside and in from of a retreating glacier. Blocks of stagnant ice may be surrounded and buried by sediments. These depressions often fill with water to form kettle lakes (Figure 3.40).

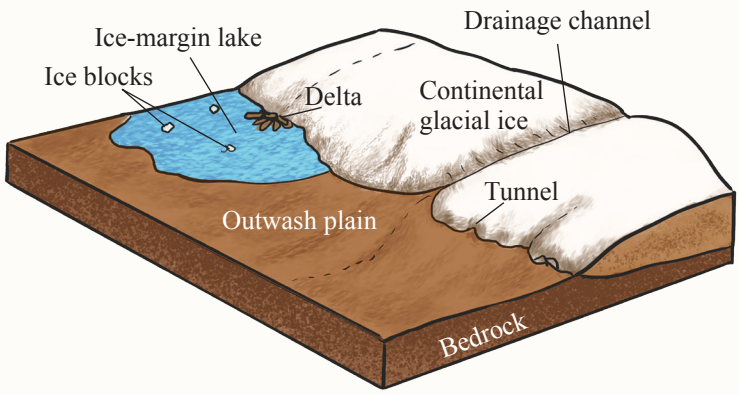


Figure 3.40: *Features on the outwash plain*

Braided streams: Seasonal variations in discharge make the channels of melt water to become chocked with coarse materials. The streams channel themselves into several minor channels through deposited materials. Such melt water rivers are termed braided streams.

The importance of glaciated regions

Glaciated regions generate ranges of values which include;

(i) Fertile land for crop production. The landmarks left by the whole process of glaciation results to the fertile land which is suitable for crop production.

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Glacial deposit such as till and outwash plains are good areas for crop production because of their fertile soil (boulder clay), for example, East Anglia in Great Britain, the American and Canadian Pralines producing vast amounts of wheat.

(ii) Glaciated highlands and lowlands are good grazing lands. Cattle are grazed on the alpine pastures during summer and are brought down to their shelter valleys and cotton postures during winter. This movement of animals up and down the mountains periodically, is called transhumance. It is common in Switzerland, Norway and other mountainous countries.

(iii) Glaciation produces various types of lakes such as cirque, ribbon, moraine dammed and kettle lakes. Some of these lakes have proved to be excellent route ways across rugged terrains. For example, the Hudson Mohawk Gap leads down to New York. The lakes also are good sources of water for domestic as well as for industrial use.

(iv) Glaciation produces beautiful sceneries which attract tourists, that is a source of national income. These features include pyramidal peaks, cirque lakes, drumlins and moraines, for example, the Kilimanjaro Mountain in Tanzania. The peak of Kilimanjaro mountain has an ice cap which is very attractive to tourists from all over the world. Switzerland and Norway also receive millions of tourists every year because of their glaciated highlands and lowlands.

(v) Glacial deposits are good sources of building materials such as sand, gravel and pebbles. These are used for building houses and construction of infrastructure such as roads and railways.

(vi) Fiords are glacial troughs which were flooded after the rise of sea level. These submerged glacial valleys are good water ways which simplify transportation of goods and passengers in various countries such as Norway, China, Switzerland and several other countries in the higher latitudes areas.

(vii) Glaciated mountains are good for sporting. Every summer and winter times, people from different countries visit such places for sports such as skiing and skating as well as mountaineering. This is common in Switzerland, Norway, Sweden and other European countries that conduct summer supports competitions.

(viii) Waterfalls at their junction with glacial trough are suitable for development of hydroelectric power (HEP). Both Norway, Sweden and Switzerland produce a large amount of HEP from such waterfalls.

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(ix) Ice caps and ice sheets are excellent sources of rivers. Thus, they are storages or reservoirs for fresh water. For example, rivers flowing downslope the Kilimanjaro Mountains are valuable to people living along the slopes and downslope of the mountain. The water is for domestic, industrial and agricultural (irrigation) use.

Negative influence of Glaciers

Glaciers have negative influence on the environment. These include accelerating floods whereby melting glaciers may initiate flooding which can be detrimental to the lives and properties of neighbouring societies. Moreover, glaciers mass wasting, frost, and shattering avalanches may spark off rock falls as it disintegrates valley sides which may be disastrous if the rocks tumble reach the lowlanders.

Activity 3.4

With the supervision from your subject teacher, do the following;

(a) On your own, read books and other materials about glaciers.

(b) Identify features formed due to erosion and deposition processes.

(c) Using illustrations and diagrams describe their modes of formation

(d) Share the knowledge you have acquired with your fellow students.

Exercise 3.6

1. Elaborate on the mechanisms of glacial erosion.
2. Explain the mechanism of the formation of fluvioglacial landforms.
3. In which ways the glacial landscape features can be exploited economically?
4. With the aid of diagram explain in details the types of glaciers.
5. Write short notes on the following terms as used in glaciation
   (i) Braided stream
   (ii) Eskers
   (iii) Roche Moutonnee
   (iv) Arête
   (v) Benches
   (vi) Corries
6. "There are many erosive and depositional features in the Alpine glaciation, some of which are important to man" Justify the statement.
7. Explain diagramatically the Alpine glacier features.

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River action and resulting features

River is the a natural outflow of water from the source to the mouth. Rivers are among the major agents of denudation and deposition. They involve land sculpturing as they flow 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. However, erosion by runing water is known as fluvial processes.

River erosion

In the works of the river, erosion is one of the main geological functions of a river. It involve 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, pushes water into cracks in the river. The air in the cracks is compressed, leading 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 bed and 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 is taking place mostly in the upper course and middle course of the long profile of the river. *Attrition:* Attrition is a 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 one another, angular rocks become smaller and smaller to fine sizes, while others are increasingly rounded in appearance from irregular shape. *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 minerals that are soluble in water, and which can then be carried away in solution.

Effects of river erosion

These four processes of a river erosion in their combinations, enable the river to erode its channel in three ways, vertically, laterally and head ward.

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Head ward erosion: Is the erosion which takes place at the origin of a stream channel, which causes the origin to move back away from the direction of the stream flow. This erosion causes the stream channel to lengthen. It occurs when the river cuts back at its source and so increases its length (Figure 3.41).

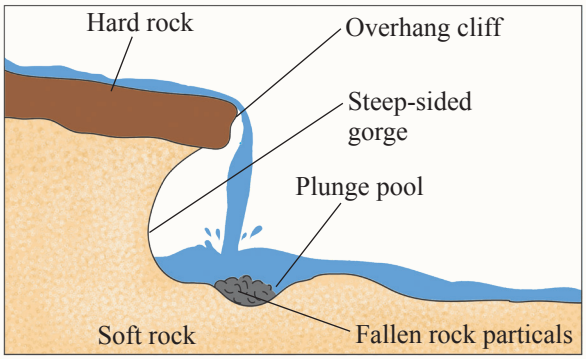


Figure 3.41: *Head ward erosion*

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

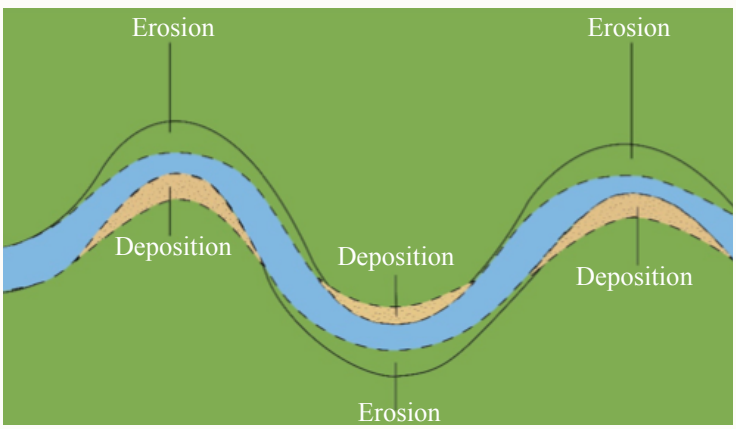


Figure 3.42: *River erosion*

Lateral erosion: It erosion is the wearing away of the sides of a river channel. This is mostly effective along outside meanders (Figure 3.42). This form of erosion makes a river wider and it is most common in the middle and lower stage 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 is 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 by striking against one another or against the channel sides. In general, the load is transported by four main processes namely: suspension (grasses, leaves), solution (mud), saltation and traction

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(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 the turbulence of the water. *Solution* occurs when dissolved material is carried by a river. The movement of materials dissolved in water and this often happens in areas where the geology is limestone and is dissolved by slightly acidic water. Minerals are dissolved in water and 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 which influence the rate of river transportation. These include the following;

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

(ii) The size of the load: the bigger the size compared to the volume of water of a river, the lesser is its ability to transport.

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

(iv) Climate of the area: Equatorial region with heavy rainfall will encourage transportation due to their greater supply of water than arid or semiarid regions.

(v) Size of the river: the bigger the size of the river the greater the energy, hence the higher the ability to transport load. That means larger river have greater energies to transport.

(vi) Speed of water (velocity): The higher the velocity of water flows the higher the chance to pick up larger materials, hence the higher the chances to transport them. Therefore, rivers with high speed can transport more than low flowing rivers.

River deposition

Deposition occurs when a stream's energy is insufficient to carry the entire load. Also, deposition is the function of river which is determined by the failure of transportation. Large boulders and other heavy particles are deposited first, followed later by finer debris. Material deposited by a river is

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given the general name of alluvium. Deposition is greater in the lower course, especially during floods, for example, inside meanders. The channel is normally too small to hold all the loads hence flood discharges, that is water spreads out on the adjacent flood plain (Figure 3.43). Thus together with limited gradient, speed is reduced and the river is no longer competent to carry all its load, so deposition takes place.

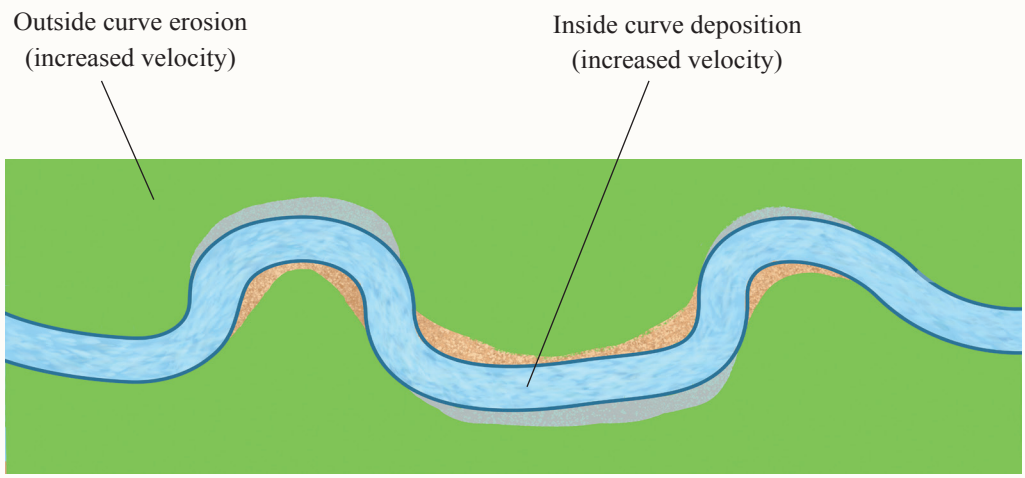


Figure 3.43: *River deposition*

Deposition is contributed by decrease in water volume, velocity, presence of obstacles and stagnation of water when it enters a lake or sea. Deposition occurs locally whenever speed is reduced, for example, on the side of meander or where there is 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 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 whereby it is steep at the youth stage, gentle in the middle and almost plain at the old stage (mouth) of the river (Figure 3.44).

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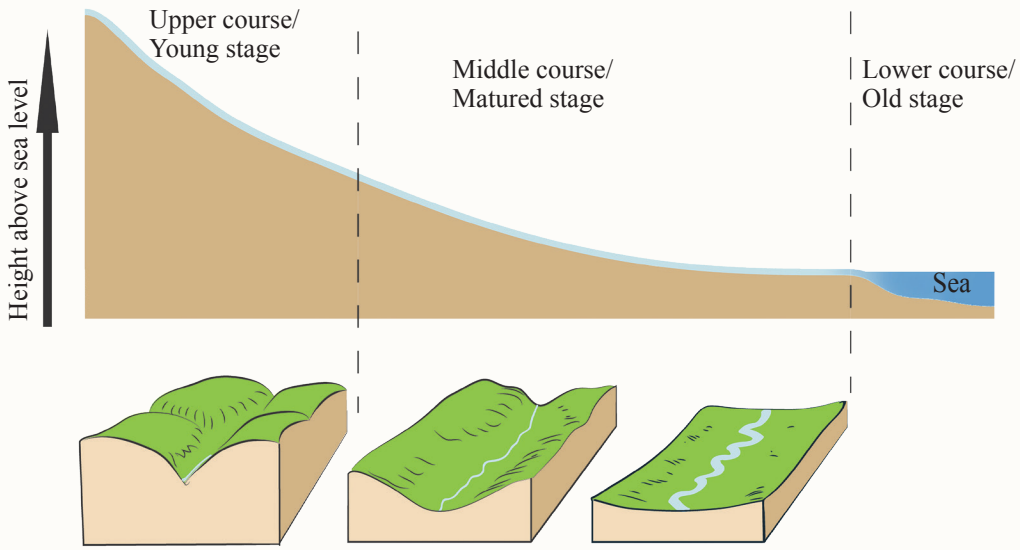


Figure 3.44: *Long profile and cross profile of the river*

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 balance with the rate of deposition. This means that 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 rate. 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 upper and lower stage.

Critiques against 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 within a river basin. As the volume of water raises even the velocity, erosion and load of the river increase. Ultimately, extra load carried by the river leads

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to extra deposition further down the valley or out at sea. Grade is mostly affected by changes in precipitation and glaciations therefore cannot affect 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 resists. Therefore, erosion and deposition rate will differ especially to the areas with minimal amount of rainfall with alternate layers of hard rock and soft rock. In hard rock 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:* Also, the power of a river to renew its erosive power can affect the adjustment due to the fact that instead of undergoing deposition to balance the rate of erosion and deposition, a river starts eroding again hence the balance becomes impossible. Mostly this is affected by sea level changes (sea level fall), faulting and abrupt increase in the amount of rainfall. Thus, the state of dynamic equilibrium is not easily attained. *Mass wasting:* The supply of materials down the slope by the gravitational pull like landslide may affect the equilibrium especially on the rate of erosion and deposition. This is in the sense that as deposition exceeds erosion no point of balance may be attained.

Stages of the development of a river valley

A river, like an animal or a plant, has a life cycle. In the beginning when it is in the youth stage, it flows turbulently in a narrow, steep sided valley, but as it moves down slope denudation widens the valley and lowers its floor. As it continues moving down, the slope is reduced and the erosive energy is reduced too, eventually it portrays in the stage of maturity. 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 is built, known as flood plain. The river is now in the old stage. Deposition within the mouth of an old river sometimes builds up a triangular shaped piece of land called a delta**.** Youth stage is often called Torrent stage; mature stage is valley stage whereby old stage is referred to as plain stage. Erosion by running water is referred to as fluvial erosion. The river is subdivided into three main stages, namely the upper, middle and lower stage. These stages are characterized by different features depending on the rate of erosion and deposition processes (Figure 3.45).

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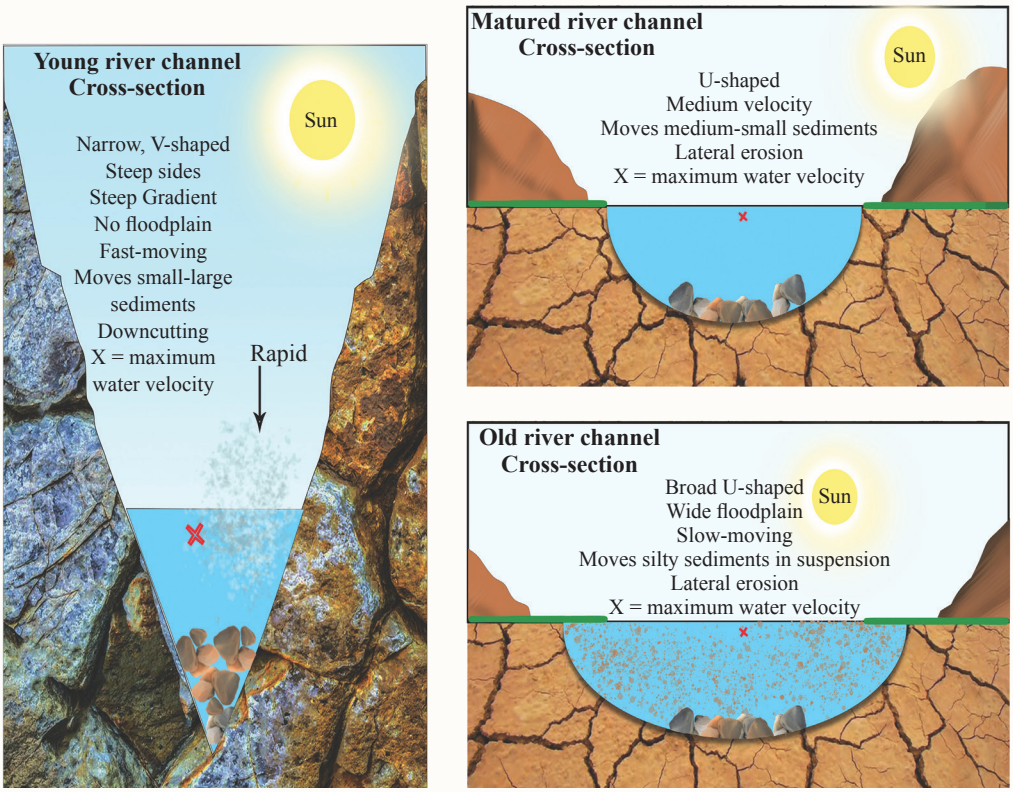


Figure 3.45: *Stages of river valley development*

Upper course of a river

In the upper course, 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 poor, 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 deeper and wider respectively (Figure 3.46).

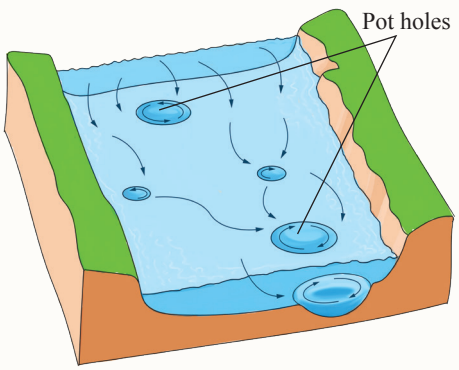


Figure 3.46*: Pot holes*

Waterfalls: Is a place where water flows over a vertical drop in the course of the 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

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over the soft rock, it can also occurs where a dyke has cuts across the bending plane. Moreover, waterfalls can occur when hard rock dips gently upstream, and when hard rock 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 3.47).

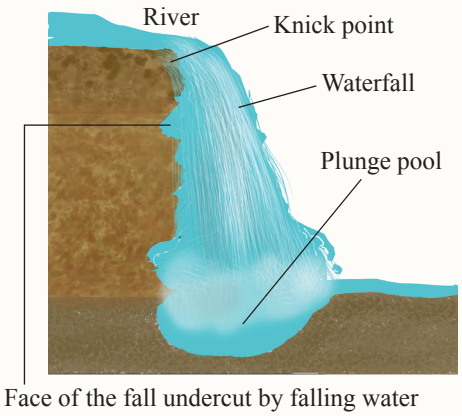


Figure 3.47: *Waterfalls*

Plunge pools: It is a depression formed at the base of waterfall created by the erosion force of falling water (Figure 3.43).

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 3.48).

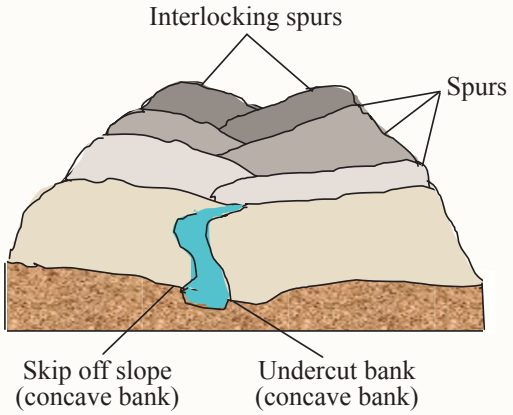


Figure 3.48: *Interlocking spurs*

Gorge or canyon: 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, cause the vertical erosion to be active while lateral erosion to be inactive because of resistant rocks (Figure 3.49).

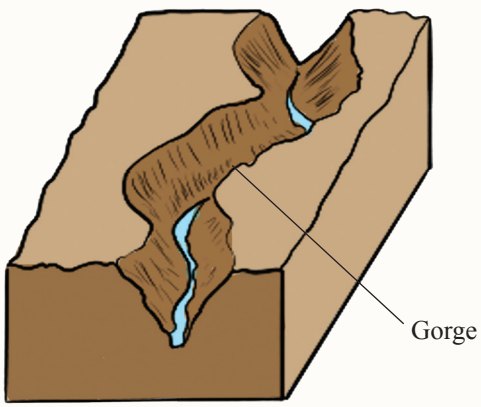


Figure 3.49: *Gorge*

A canyon is a deep and wider gorge with steep sided valley. The Yarlung Zangbo Grand Canyon in Tibet is the deepest in the world which extent to about 5300 meters deep. It is a gorge that looks more impressive in appearance such that it can even attract tourists (Figure 3.50).

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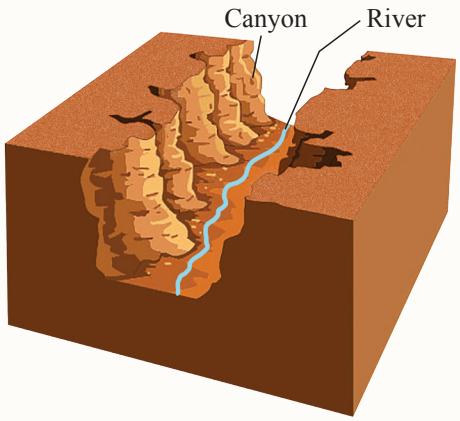


Figure 3.50: *Canyon*

V-shaped valley: This is the 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 the 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 3.51).

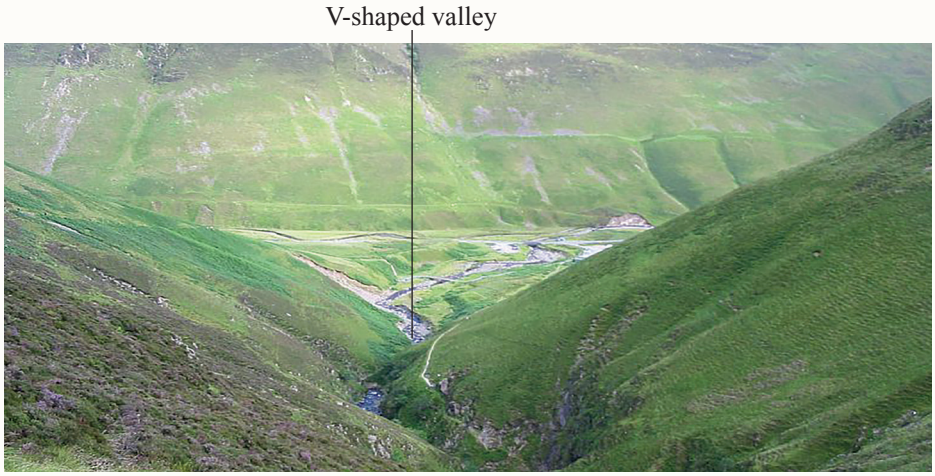


Figure 3.51: *V-shaped valley*

Rapids: These are formed when the water flows on the steep slope area. The rapids develop if the face of the rock is steep but not vertical (Figure 3.52). It is the sudden descend of water without forming waterfalls.



Figure 3. 52*: Rapids*

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Middle course of a river

At this stage lateral erosion is more active than vertical erosion, hence the valley has developed an open U-shaped valley. The volume of water increases as more tributaries join the main river. Also, the load carried by a river also increases, as gradient is gentler than in young valley minimal deposition starts taking place. Also, 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 bank.

Riffle and pool: Natural streams are never absolutely straight, even where they have steep gradients. They tend to develop bends. Erosion is greater in the outsides of these bends, and the eroded material is carried downstream, where it is deposited as bars in 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 3.53). In straight streams beds 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 the bed materials in riffles are noticeably coarser than in pools. For a stream that is in equilibrium, the gravel bars remain in the same location for years known as riffle, although the materials composing them may change from year to year. Therefore, a riffle is a rock area in 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.

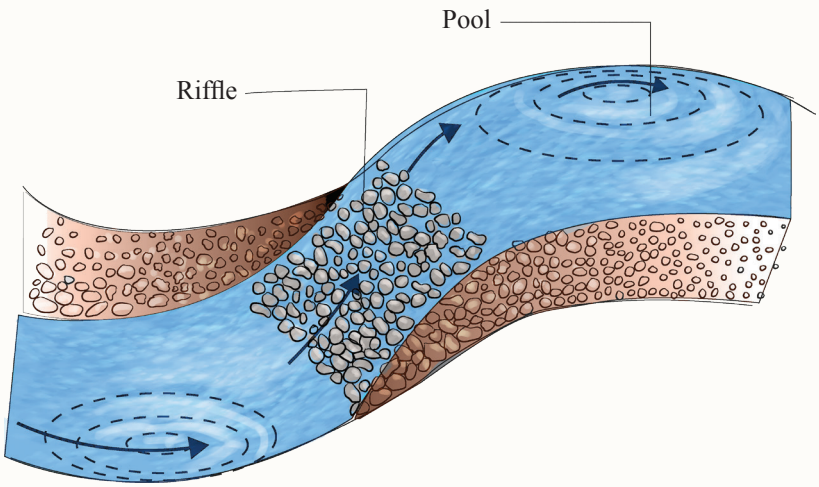


Figure 3.53: *Rocks along the river (riffle) and pool aside deep bank*

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River cliff: This is a steep face of river bank of considerable height. Sometimes it is referred to as undercut concave banks often stand 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 of a river valley, the river is now closer to the sea and deposition becomes the dominant process. Lateral erosion continues eroding (push) 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 coarse of the river is that its gradient is lower than in middle coarse 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 flood plain.

The features which are common on the plain stage or old stage are pronounced 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 3.54).

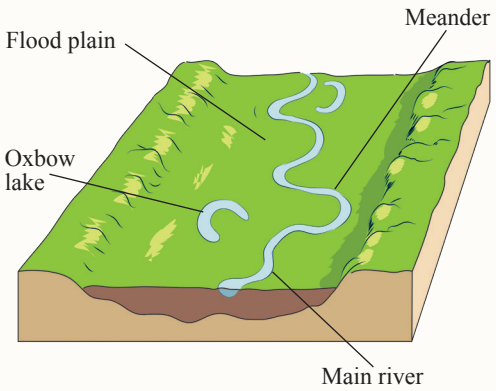


Figure 3.54: *Meanders*

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. Most of the flood plains are marshy with several swamps and small lakes (Figure 3.55).

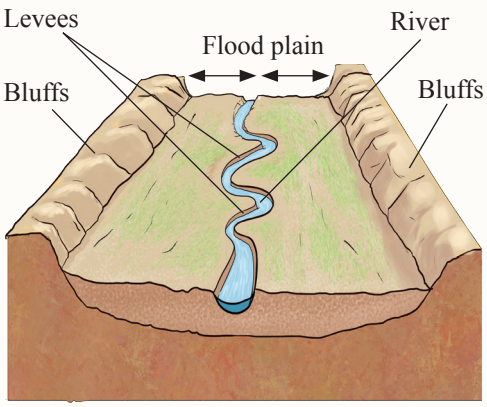


Figure 3.55*: A flood plain*

Braided river: Is a river stream which split into several channels, rejoin and split again as it flow from one point to another.

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Braid channel are separated by sand bars or island of alluvium (Figure 3.56).



Figure 3.56: *A braided river*

Ox bow lake: This is the crescent (curved) shaped lake formed on a river floodplain in an abandoned meander channel. It is a lake formed as the results of the cut-off of the loops of the neck of the river meanders. Sometimes is referred to as horse shoe shaped final section of a once very pronounced meander which is separated from the main stream (Figure 3.57).

Stages in the formations of ox-bow lake

Stage 1: When a river flows over flat land it develops large bends called meanders. At this stage the river is now eroding sideways into its banks rather than downwards.

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

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

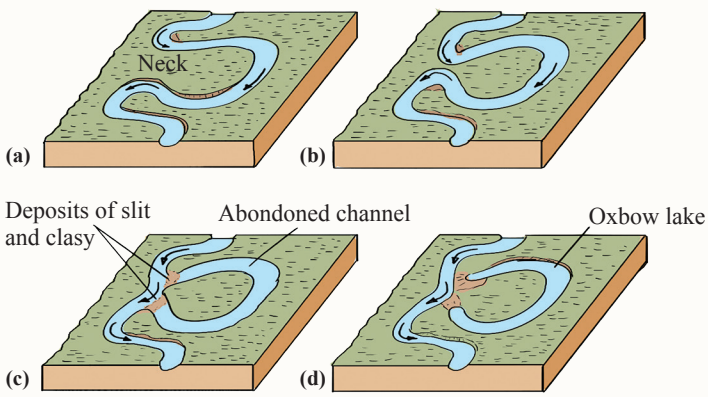


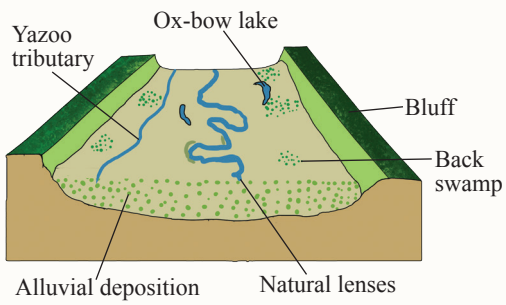
Figure 3.57: *Stages for the formation of ox-bow lake*

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

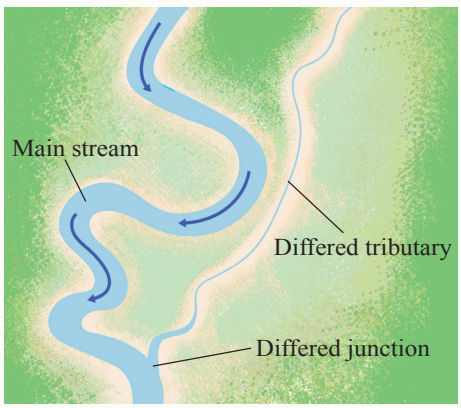
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Deferred tributaries: A deferred stream is also known as a yazoo stream. It refers to a river or stream that is forced to flow alongside the main river for a long distance before joining the main river. The point at which the deferred stream joins the main river is called the deferred junction. This is caused by a levee across the original confluence of the two rivers which act as a barrier (Figure 3.58).



(a) Differed tributaries



(b) Differed junction

Figure 3.58: *Differed tributaries, ox-bow 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 slowing 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 delta is dominated by several streams called distributaries. Under the right conditions, a river forms a deltaic lobe. A mature deltaic lobe 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 lobe, heavier, coarser material settles first. Smaller, finer sediments like alluvium or silt is carried farther 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. The subaerial part of a delta is above water. This part which is known as lower delta is influenced by waves and tides while the upper delta is influenced by the river's flow.

The condition necessary for the formation of delta

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

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and currents. There should be a gently sloping land along the coast where the materials can be deposited.

Stages for the development of delta

There are four stages for 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 the distributaries. These are small channels that divide the river leading their ways into the lake, sea or ocean that facilitate the formation of the delta. Spits and bars arise and lagoons are formed in this stage. The levées of the river extend into the sea via the distributaries (Figure 3.59).

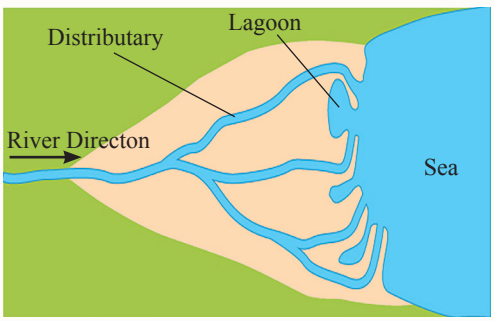


Figure 3.59: *Formation of the distributaries*

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. The delta begins to assume a more solid appearance (Figure 3.60).

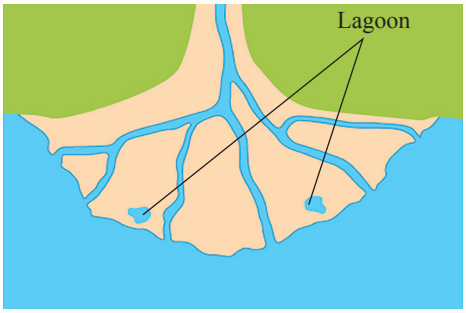


Figure 3.60: *Formation of lagoons*

Fourthly, extension of a delta after a lagoon is covered with alluvium deposits (silts). The filling of lagoon with silts cause further division of distributaries into smaller one and completely being covered with vegetation. This stage is considered as old part of the delta which is colonized by plants and its height is slowly raised. Swamps gradually disappear and this part of the delta becomes dry land (Figure 3.61).

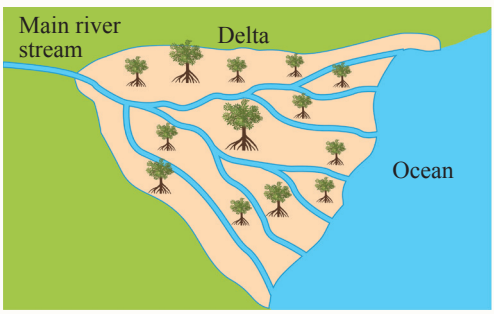


Figure 3.61: *Extension of delta*

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

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(Figure 3.62). Such delta usually has a shape of triangle-like structure. A good example includes the Rufiji delta in Tanzania, the Nile delta in Egypt, delta of Niger, Ganges, Indus, Irrawaddy and Hwang Ho rivers.

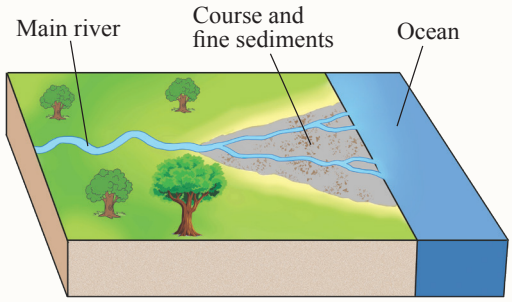


Figure 3.62: *An arcuate delta*

Digitate delta: Is a type of delta which looks like the foot of the bird with its claws, 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 can be observed in the Mississippi delta in USA (Figure 3.63).

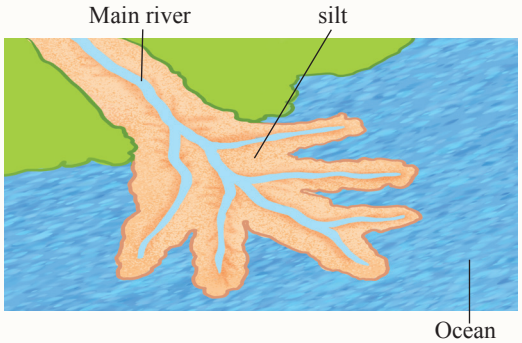


Figure 3.63: *The digitate delta*

Estuarine delta: 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 3.64).

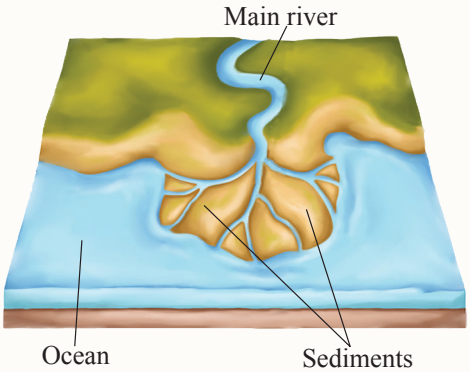


Figure 3.64: *Estuarine delta*

Cuspate delta: 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 lagoon is absent (Figure 3.65). This feature is found in Ebro River in Spain and Tiber in Italy.

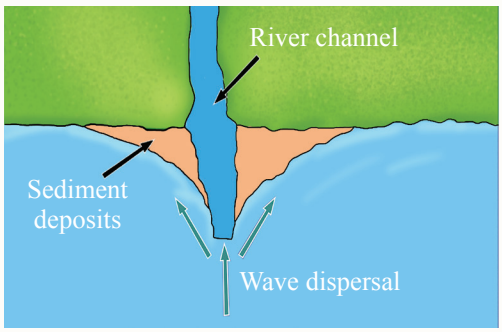


Figure 3.65: *Cuspate delta*

Importance of delta

Deltas are incredibly diverse and ecologically important ecosystems. Deltas absorb runoff from both floods

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(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 delta. 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 renewed erosive activity in a river valley and usually it results from a negative movement of base level, caused either by a fall in sea level or a regional uplift of the land. River rejuvenation is caused by several factors such as fall in sea level (Eustatic change) due to diastrophic forces for example, earth movements. Another cause is the land uplift and subsidence (Isotactic change), which occurs when the land is uplifted in the upper section or subsides in the lower section resulting to new base level formation. Moreover, river rejuvenation is caused by increase in the river volume; which may be resulted 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 landscape with river uplifted by tectonic activities. *Static river rejuvenation* occurs without significant change of water flow gradient it occurs due to the increase in water volume. The increase in the volume of water 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.

Effects of river rejuvenation

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

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Knick point (rejuvenation head): Is a break of slope in the long profile of the river valley, the point where the river bed falls sharply hence leads to the formation of a waterfall or a rapid. Examples can be seen in Congo River and Charlotte fall in Sierra Leone (Figure 3.66).

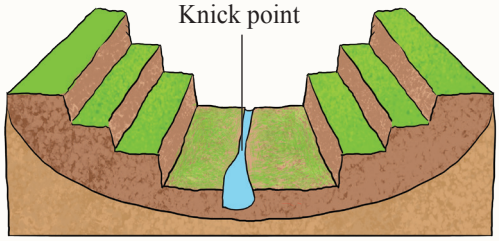


Figure 3.66: *Knick point*

River terraces: River terraces are steps or bench like features on either side of the river valley. They are produced if the flood plain especially in the lower course 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 3.67).

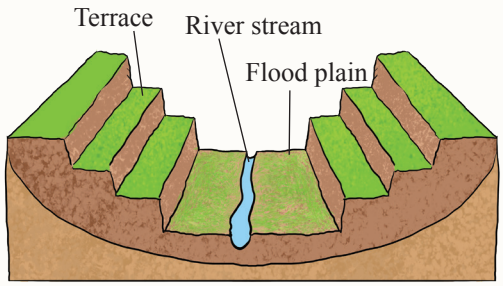


Figure 3.67: *Paired terraces*

Incised meanders: Are steep sided curved bends of a river valley produced as a result of 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 3.68). An example of this feature is found on the river Mkomazi between Mgwasi and Kifungiro in Usambara mountain in Lushoto, Tanzania.



Figure 3.68: *In-grown incised meanders*

Entrenched meanders: 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 3.69). An example of this feature is found on River Tyne in Northern England.



Figure 3. 69*: Entrenched incised meanders*

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Valley within a valley: Is a steep sided rejuvenation gorge formed within the former valley due to fall in base level which leads to river rejuvenation.

Waterfalls: Usually formed due to water in the river valley dropping sharply from the knick point.

Canyon and 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 neighbor. 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. Also, it should be flowing at a lower level than its victim and should have greater power of headward erosion. There should be a layer of less resistant rock between the two rivers that allow easy erosion to take place It should be able to erode its valley more rapidly than its weaker neighbor (Figure 3.70).

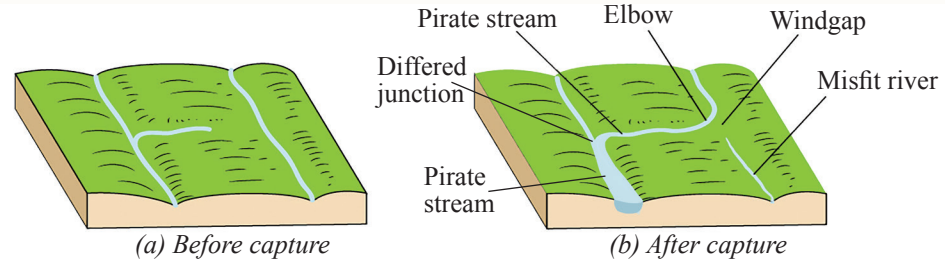


Figure 3. 70: *River Capture*

Features formed due to river capture

Possible evidence of river capture can be seen due to several features formed such as: *An elbow of capture* which is the sharp change in 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* is the valley of the beheaded stream below the point of capture. It may be left as a dry valley. *A misfit:* is the beheaded stream having 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 like Tiva river capture in Kenya and Cunene river capture in West-central Angola.

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Activity 3.5

Visit the river in your locality, then critically analyse its formation and development from young stage to old stage.

Exercise 3.7

1. With examples explain the processes involved in the erosion by rivers.
2. Describe the following terms as used in describing river erosion;
   (a) Headward erosion
   (b) Vertical erosion
   (c) Lateral erosion
3. Explain the main characteristic features of the lower course of a river.
4. With the aid of a well labelled diagram explain the features formed by fluvial deposition in the different parts of the world.
5. Explain the geological conditions required for the occurrence of waterfalls.
6. By using clear illustration, explain the process of river capture.
7. By using diagrams, explain the stages of ox-bow lake formation.
8. With the aid of a well labelled diagram explain the landforms associated with river rejuvenation.
9. Explain stages and conditions necessary for the formation of a delta.

Waves action and 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 thus the highest water level of the wave while the lowest water level is known as the *wave trough.* The vertical distance

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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 3.71). The time it takes for the two crests or troughs to pass the same point is the *wave period* (*T)*. This implies that longer waves move faster than shorter waves. Moreover, wave is also characterised by *wave speed* which is concerned with the rate at which the wave moves through the water, and is measured in knots. Lastly, there is *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 reveals 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.

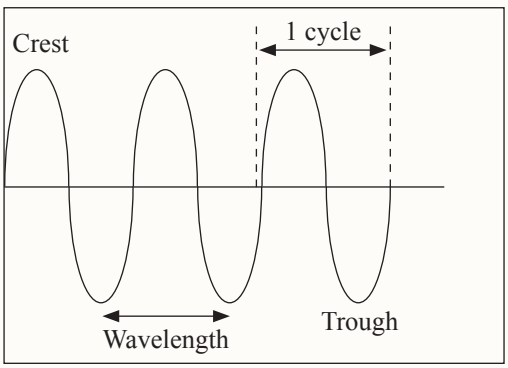


Figure 3.71: *Motion of waves*

Swash and backwash movements

There are two different movements associated with waves. These movements are swash and backwash (Figure 3.72). *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.

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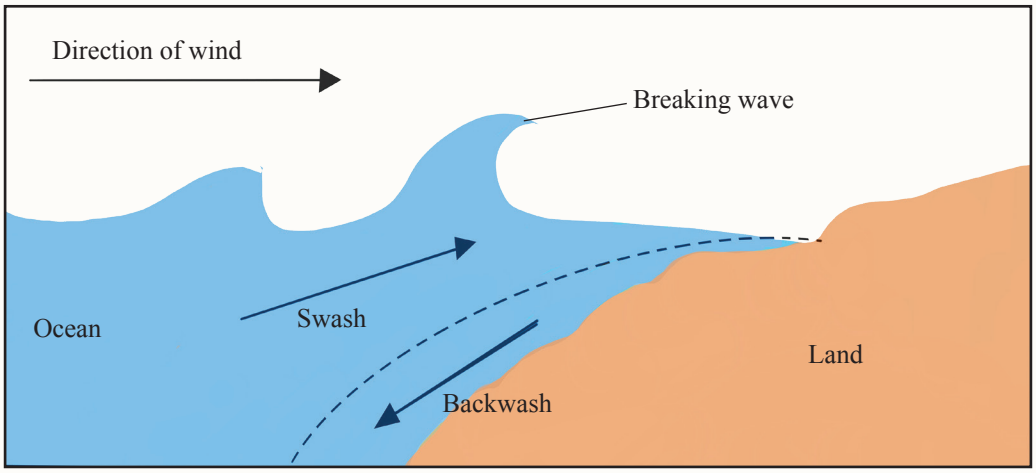


Figure 3.72: *Swash and backwash waves*

Types of Waves

Basically, waves can be categorized as **c**onstructive waves 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 such features due to deposition has made this wave to be referred to as a constructive wave.

Destructive wave

It is the waves 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.

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.*

Factors that determine height and power of the wave

There are several factors that determine the height and power of the 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

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maturity and vice versa. Moreover, *depth of water* is another factor such that when wave passes into shallow water, its crest steepens and then breaks, and mass of broken water rushes to the beach as a swash. Therefore, shallow water reduces velocity of waves. 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 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 bottom of the oceanic rocks they tend to break, transport and deposit rock and send materials of different scale 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 word, waves are the outward manifestation of kinetic energy propagating through seawater. In reality, the water in waves doesn't travel much at all. The only thing waves do is transmission of 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 involves the following processes; hydraulic action, abrasion, attrition and solution.

Hydraulic action or hydraulic pressure

As waves move forward, hits against the cliff directly and loosens the interior of joints and bedding planes. The compressed air expands with explosive violence. Such action if repeated again and again enlarges the cracks and rock fragments break apart. The striking waves exert enormous pressure on the air trapped in crevices, cracks, hollows and joined rocks. Such 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 huge load of rock materials weighting several tones.

Abrasion (corrasion)

This occurs when the waves which contain large fragments hit and erode

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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 dissolve in water mostly carbonic acid, and are removed from one point to another especially on cliff forming beaches. The global shorelines and continental are formed or characterized with different forms of rocks (soft and harder, easily dissolved and impermeable). When the seawater reacts with soluble rocks 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. But waves which break before hitting the cliff have minimum erosive effects. Also, depth of the sea 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. Moreover, the length of the fetch affects wave strength. When the fetch is long the wave tends to be strong since it had enough duration to collect energy from the prevailing wind. The strength and direction of prevailing wind are other factors that affects wave erosion in which the stronger the wind the more powerful the wave is, and the weaker the wind the less powerful wave is. Also, where the winds blow perpendicular to the coast, wave erosion becomes more effective than when the wind blows parallel to the coast alignment. Furthermore, the nature of rocks affects wave erosion. When the

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rock is hard the rate of wave erosion is low but where the rock is soft the rate of erosion is high. Also, the rocks which are well-jointed or have been subjected to faulting undergo erosion at a faster rate due to an increased vulnerability to erosion. Moreover, human activities along the coast such as building on cliff tops and removal of the beach material 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 3.73 and 3.74).

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 3.73).

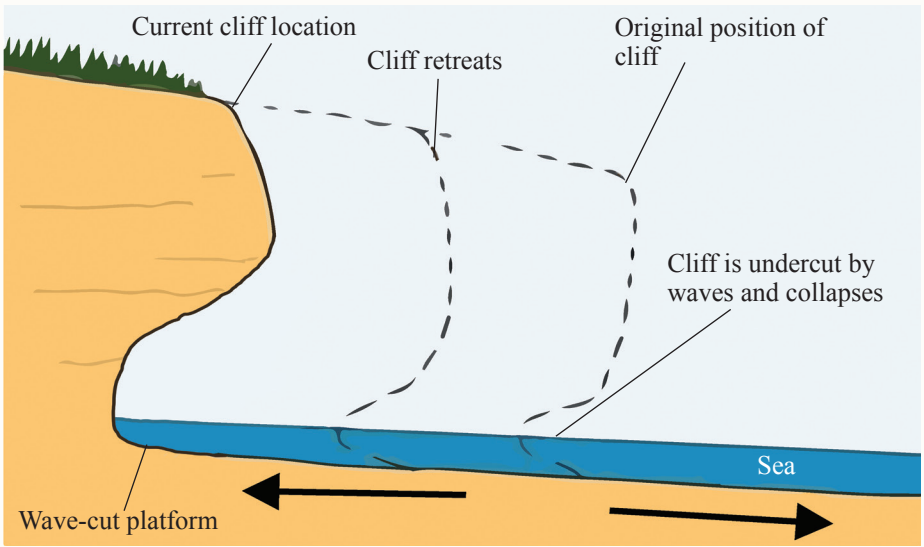


Figure 3.73: *Cliff erosion and wave-cut platforms*

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 3.73). Another category is straight cliff which is formed along the coast composed of rocks with uniform resistance. Also, there is an indented

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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 the 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 3.73). Normally, waves cut platforms are formed as the results of excessive erosion of the surface of cliffs such that 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 on the coast (where the water is shallow) they are steepened and have 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 from few to several meters, and 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

Arch is the feature formed when two caves approach one another from either side of a headland and unite to form an arch.

Stack

This is an isolated portion of headland sometimes can be formed from an isolate portion of the 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 remnant is called a stump.

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Stump

Refers to the remains of eroded stack or rock pillars.

Blow hole

This is the hole formed at the top of the roof of a cave. This is the 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

Geo is a long narrow in-let formed after the collapse of the roof of a cave.

Headland

Headland is the hard part of coast land extending into the ocean. The extension of the headland may be influenced by different rate 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 the inland water called bay.

Bay

A bay is the 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 rate of erosion and configuration of the coast itself. The bay is a kind of recessed coastal body of the water when it extended further is called a gulf which can extend hundreds of kilometers.

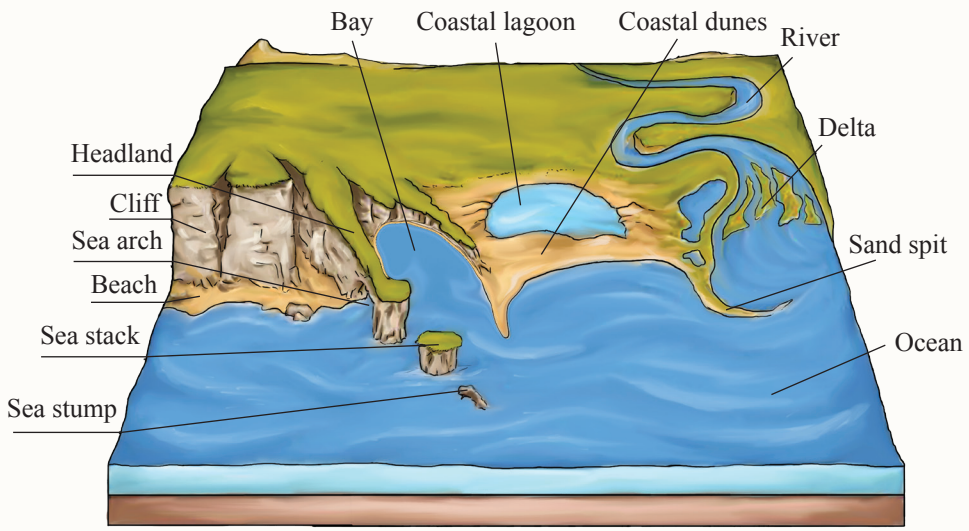


Figure 3.74: *Wave erosional features*

Wave deposition features

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

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Beach

A beach is the wider strip of sand or shingle deposits with water along the sea coast. It is the land bordering the sea coast in between high and low tide. A beach is formed when materials carried by waves are accumulated along the coast line (Figure 3.75). 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 includes Coco beach, Bagamoyo and Mikadini, Nungwi beaches in Tanzania.

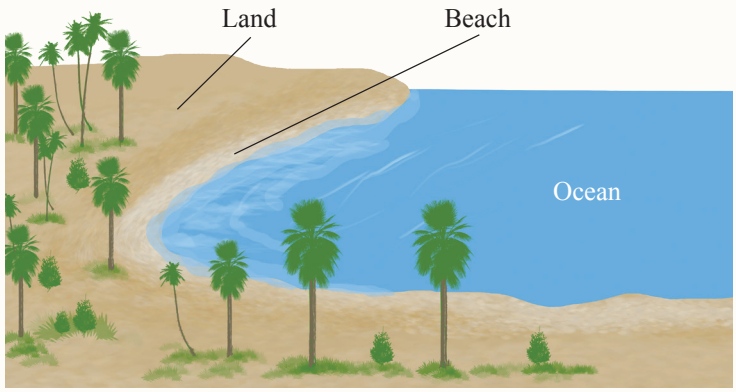


Figure 3.75: *Beach*

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 3.76).

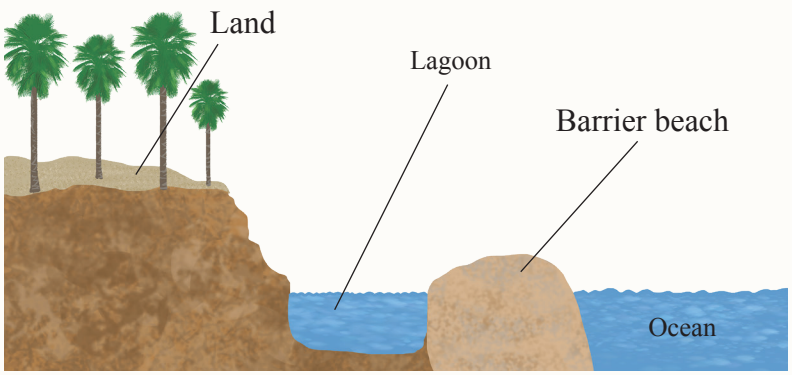


Figure 3.76: *Barrier beach*

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 3.77).

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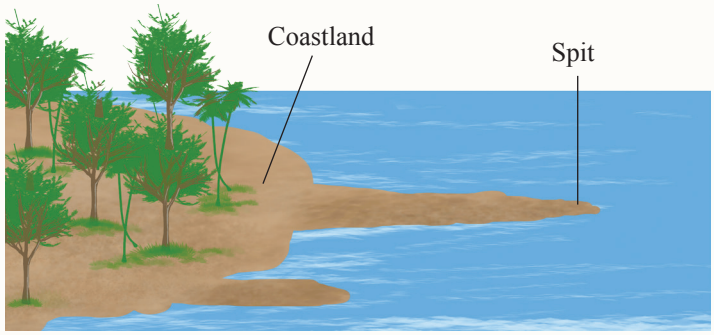


Figure 3.77: *A spit*

Bar

Bar is a ridge of material usually sand which lies parallel or almost parallel to the coast or across the estuary or bay 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 to the south of mainland Britain (Figure 3.78).

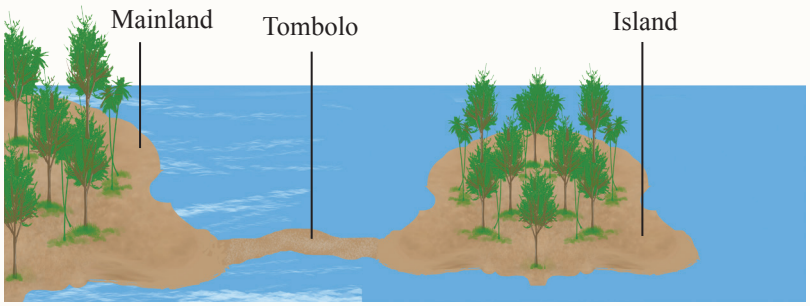


Figure 3.78: *A tombolo*

Bay bar

Bay bar is the bar that runs across the bay. Good example is that one occurring along the coast of Poland. Bay bar is associated with the occurrence of lagoon.

Lagoon

Lagoon is a shallow body of water separated from the main body of water by a sand bar. Lagoon can either be coastal lagoon or atoll lagoon (Figure 3.79).

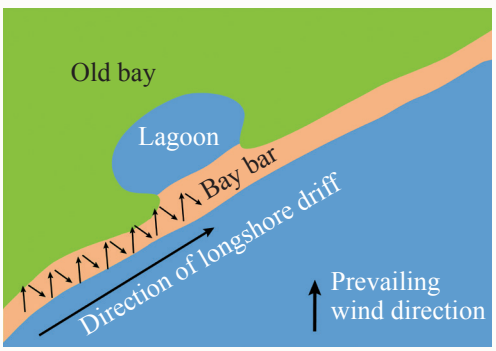


Figure 3.79: *Lagoon*

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Offshore bar or long-shore bar

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 Northern America along the Southern part of the Atlantic Coast.

Mudflats

Are coastal wetland saturated with mud deposited by tides or rivers.

Cuspate foreland

A cuspate foreland is a triangular extension of the shore line. The formation of cuspate foreland is called long-shore drift. When waves approach the coastline at an angle, this cause the movement of sand or sediments in the same direction toward the sea to the right or left as seen in quatsap point near Ducka bush river in Jefferson.

The importance of wave action and associated features

(a) Waves are potential for production of tidal power which is also a safer and environmentally friendly energy as compared to thermal or nuclear energy sources;

(b) Most of the erosive and depositional features produce different marine to graphical features ideal for tourism and other developmental projects;

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

(d) The coastal areas offer natural harbors and creation of attractive features such as bays, headland, stack and stump, beaches, cliffs, and carves which can actract tourist to visit and enhance economic development of a country;

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

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

Tides

The periodical rise and fall of the sea level, once or twice a day, mainly due to the attraction of the sun and the moon, is called a *tide*. Tides (tidal waves) are caused by the gravitational pull of the moon and the sun on the Earth. Tides have a predictable daily and monthly cycle. 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

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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 of all, there is *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. The second category is *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. The third category is *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 form 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 full moon period and another during 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.

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Furthermore, high tides are good for bringing fish at the shore enabling the fishermen get plenty of fish.

Exercise 4.8

1. Basing on their modes of formation, explain the types of ocean movements, waves, tides and currents.
2. Examine the causes and importance of ocean movements.
3. Discuss the importance of tidal waves to the livelihoods of communities living along the coasts of East Africa.

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 *coast line,* which is the border between the land and Sea. It can be a cliff line or gentle slopping. The second is *shore*, this is the land between high tidal water level and low tidal water level. The *shore line* 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 (geology), 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.

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Human factor: These involves 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 uplift or depression of the land, such that coastal regions becoming depressed and others becoming uplifted.

Organisms: Organisms especially coral polyps influence the change of the coast by being developed by coral reefs like that of 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 impacting agriculture, urban and natural coastal systems.

Eustatic change: This is concerned with the change in sea level by either increase or decrease of the amount of water in the oceans. This is a result of either melting of ice or freezing of water (Figure 3.80).

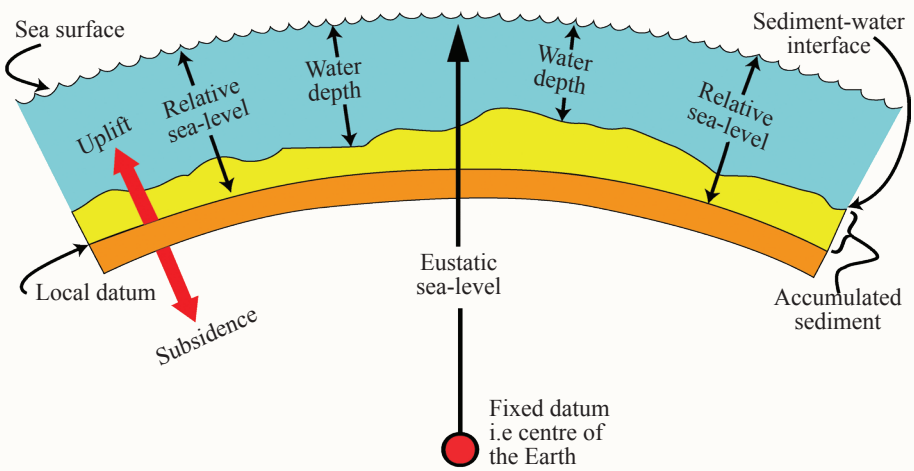


Figure 3.80: *Eustatic change*

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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 the 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 m 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 mm 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 ever increasing human activities such as burning of coal, oil, forest and cutting down tropical forest have 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. 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.

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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 some 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. 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 3.81).

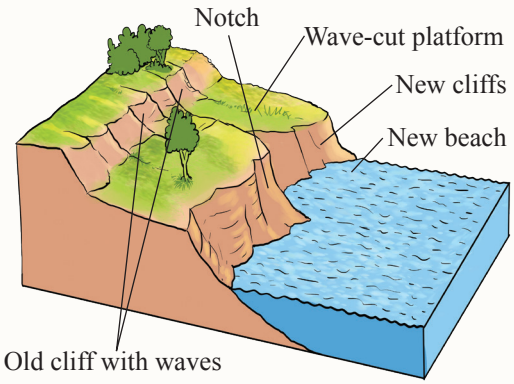


Figure 3.81: *Emerged highland coastline*

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. Mostly characterized by 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

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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 *ria*s 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 3.82). 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 3.82: *Ria coastline*

Dalmatian cost: 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 3.83).



Figure 3.83*: Dalmatian coast*

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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 3.84).



Figure 3.84: *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 3.85).

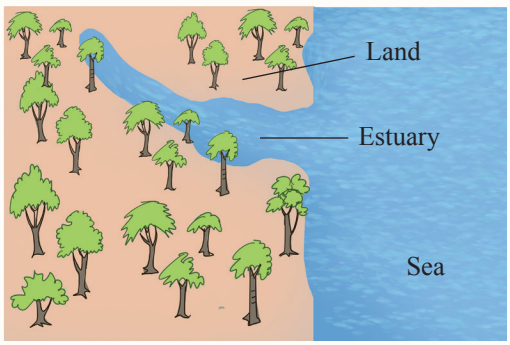


Figure 3.85: *Estuarine coast*

Stable coast: Stable or neutral coasts are coasts showing no signs of changes in sea-level or in the land but influence coastal land slowly. In these coasts the incidental erosion process is a reversible process 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. Coral reef is a limestone rock made up of skeletons of very small marine organisms called coral polyps. 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 most other coasts since they are largely organic in origin. They originate from coral polyps, which tend to live in colonies. 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.

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Conditions necessary for the growth of coral polyps

Sea temperature which ranges between 20ºC and 30ºC is a necessary condition for growth of coral polyps. Sunlight that penetrates to a depth of at least 50 m is another requirement as beyond this depth, sunlight is too weak for photosynthesis to take place. 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. It requires plentiful supply of plant food (plankton) and enough oxygen.

Distribution of coral reefs

The above conditions have encouraged the formation of coral reefs along the coast. Most of the coral reefs are found in the eastern sides between 20º and 30º North and South with warm and clear salt water, the tropical area with plentiful supply of sunlight. Also, 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 coasts. They do not develop on the west 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 atolls.

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 3.86). 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.

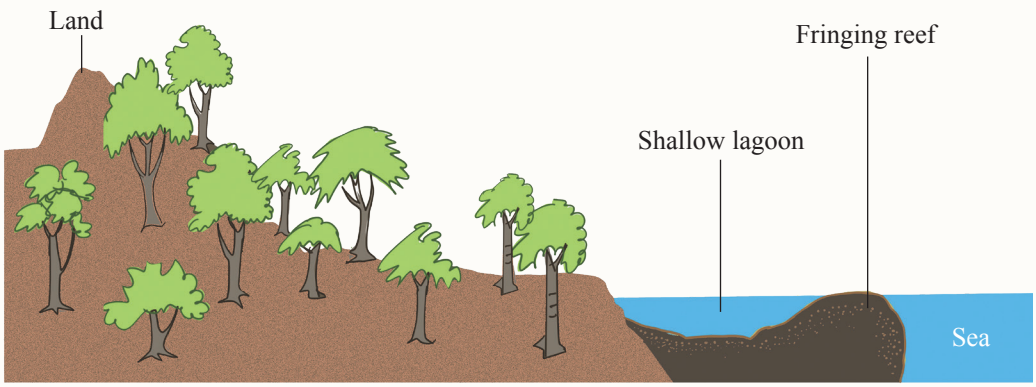


Figure 3.86: *A fringing reef*

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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 3.87). 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.

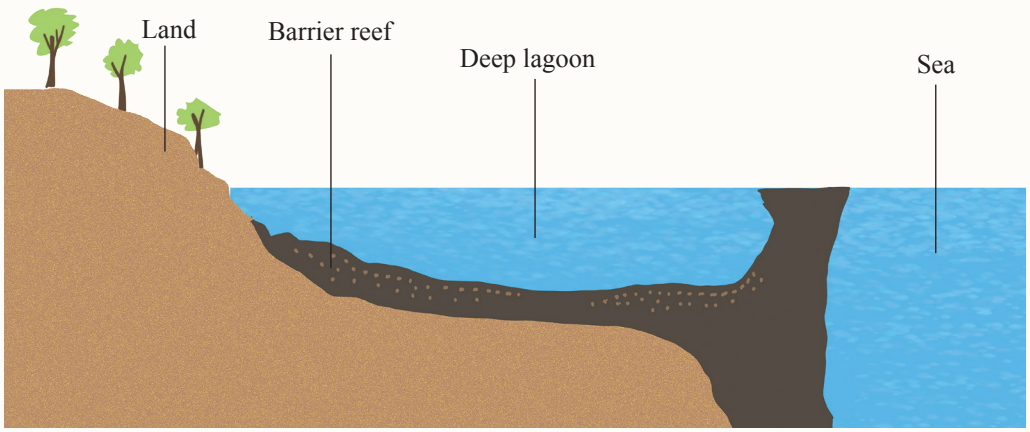


Figure 3.87: *Barrier reef*

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 in a few places to allow the free flow of water (Figure 3.88). 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.

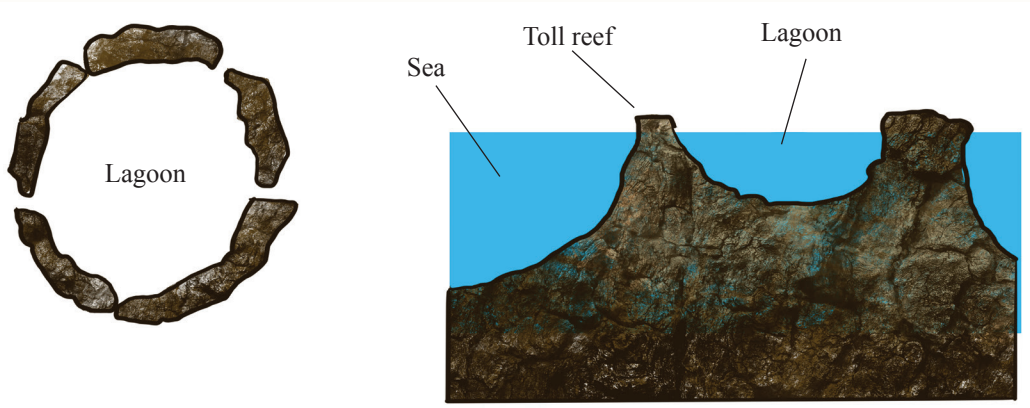


Figure 3.88: *Atoll reef*

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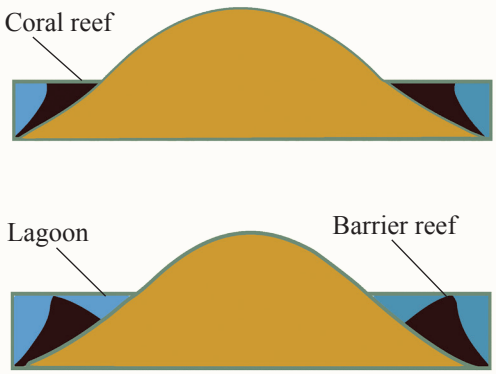
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Formation of coral reefs

The origin of the coral reefs especially barrier reefs and atoll 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 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, the coral continues to grow upwards to keep pace with the subsidence. It then forms a barrier reef. Eventually, when the land is completely submerged, the atoll is formed (Figure 3.89). Thus, according to Darwin, it is the subsidence of the land mass that caused the deepening and widening of lagoon, hence the foundation of a barrier reef and an atoll.



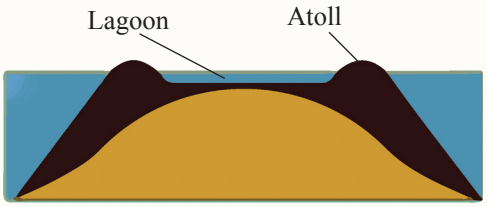


Figure 3.89: *Illustration of Darwin's theory on the origin of fringing reef, barrier reef and atoll*

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 3.90).

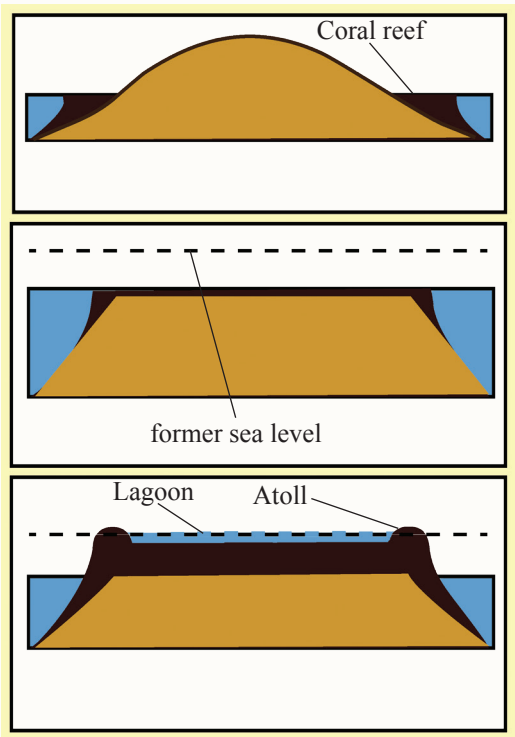


Figure 3.90: *Illustration of Daly's theory on the origin of fringing reef, barrier reef and atoll*

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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.

The Famous coral reef areas of the world

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

Firstly, the Great Barrier Reef: This is the largest coral reef system commonly found the Queensland and parts of the coast of Australia. *Secondly*, the Belize Barrier Reef: This is the second largest coral reef of the world that covers along the western Atlantic coast such as Bermuda, the Bahamas, Florida and Caribbean islands. *Thirdly*, the Andros Bahamas Barrier Reef: This is the third largest coral reef of the world that covers the east coast of Andros Island, and the Bahamas in Burma. *Fourtly*, the New Caledonia Barrier Reef: is another largest dominant coral reef of the world that covers almost the length of 1500 km. *Lastly*, the Indo Pacific coral reefs: These coral reefs cover vast area from the coast of east Africa to the Persian Gulf through the Indian and Pacific Oceans.

Importance of coral reefs

Coral reefs are important in many ways. They are used as raw materials in the manufacturing of cement; they provide stones which are used in building houses, bridges and other structures; and are also useful in protecting the coast against strong waves which can cause coastal land degradation and destruction of property. Furthermore, coral reefs attract tourists and study tours, which lead to the earning of both domestic and foreign currency. They also, provide good breeding places for fish and encourage the development of the fishing industry; and are a source of income. For example, stones selling to contractors. Finally, they act as honey pots that attract tourists to visit oceans and seas.

Problems associated with coral reefs in the world

Although coral reefs are useful in many ways as earlier explained they still have bottlenecks. Coral reefs are a great barrier to navigation. This is due to the fact that ships or canoes cannot pass through them; and also, deposition of coral reefs acts as a barrier to the formation of attractive beaches as they block fine sediments to be deposited along the coast line. Furthermore, coral masses discourage swimming in the sea or oceans. This is due to the fact that diving in the sea whose coast is made up of coral masses is dangerous. On the other hand, the caves under the coral reefs can host dangerous organisms

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like sharks and whales that can attack fishermen.

Problems facing the development and growth of coral reefs

Due to the benefits provided by the coral reefs and their geomorphic importance, it is vital to explore the problems facing their development and growth. The main problems are: strong winds lead to the formation of strong and destructive waves resulting from strong waves, and so hinder the development of coral reefs; oil spills, acid rain, poor fishing methods (using chemicals) in the ocean lead to destruction of coral rock and death of coral polyps; and breaking coral rock for the sake of manufacturing cement and getting stones for construction 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, like extracting coral for domestic or constructional purposes. 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

The coastal features are valuable in numerous ways. The significance of coastal features are: firstly, deep, well-sheltered harbours have been developed from submerged coastlines examples include Kilindini in Mombasa, Kenya, and Lagos in Nigeria. Both of these 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 feature protects the coast against strong waves which can cause coastal land degradation and destruction of property.

Problems facing coastal areas

Coastal areas are subjected to countless problems, the main problems are: 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 poor fishing methods (dynamites fishing). Land degradation caused by wave erosion, which attacks the coastal lands as well as erosion by rejuvenated river discourage formation of coral reefs. Floods caused by the occurrence of storms, tsunamis and the change in sea level due to melting of

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ice or land subsidence may properties and livelihood activities. Unpleasant smell from the sea due to water pollution makes some coastal areas unfriendly to users, as it is in 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 water. Also, deforestation may be caused by excessive cutting of trees as well as soil degradation when people establish settlements or cultivation.

Coast management

The experienced coastal degradation due to pollution and erosion can be overcome by numerous measures such as: Construction of groynes (low walls) can help minimize beaches, roads passing near the coast, and stabilizing cliff from being degraded by severe wave erosion. Planting of vegetation especially mangrove trees and grass which provide a uniform stabilizing cover that protects the surface along the coast; prohibiting people from establishing settlements and cultivating in the coastal areas, while establishing settlements and farms far from the coast; formulating coastal management policies and educating the people in the coastal areas on the importance and ways of conserving coastal areas; discouraging waste disposal in the oceans, encouraging treatment of waste before being disposed into the oceans or seas; recycling of waste should be encouraged so as to reduce the rate of dumping in the ocean (especially solid waste). Lastly, the government should open up opportunities for different economic activities rather than depending much on the fishing industry and marine tourism so as to reduce pressure on the coastal areas.

Exercise 3.9

1. Use Darwin's theory to describe the development of atolls.
2. Examine the necessary conditions for coral growth.
3. Explain the importance of corals to human life.
4. With the aid of a world map, show the geographical distribution of areas with high and low salinity.
5. Account for the variation in the distribution of salinity in ocean waters.
6. With examples, explain the importance of oceans to mankind.

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Revision exercise 3

1. (a) Write examples of mass wasting and down wash. Your examples should be drawn from different scale (global, regional and local).
   (b) What are the socio-economic impacts of mass wasting.
2. What are the major factors affecting the morphology of sand dune?
3. What are the main types of sand dunes?
4. Inspite of the low humidity and low rainfall in desert area, water is nevertheless the dominant agent of erosion and deposition. Discuss
5. Explain chemical or solution erosion as one of the process of river erosion.
6. Explain factors which determine the rate of river deposition.
7. Describe the mechanism for the occurrence of river piracy.
8. There are many erosive and depositional features in the glaciated highland, some of which are important to man. Justify the statement.
9. Illustrate four main processes involved in river erosion.
10. "The coastal zone is undergoing constant changes" Justify with vivid evidences.
11. Examine the impact of waves on coastal geomorphology.
12. "Coastal landforms can induce economic prosperity along coastal area". Justify the statement.
13. Show how the rise and fall in the sea-level and the land surface lead to the formation of coasts.
14. The origin of coral reefs is debatable. Discuss.

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Chapter Four

Water masses

Introduction

Water bodies are vital resources on the planet Earth, as they support life. In this chapter you will learn about groundwater, inland drainage, wetlands and swamps, seas and oceans, and coral coast, and their management. The competencies developed from this chapter will enable you to sustainably use water as a resource for various economic activities. Also, the competencies gained from this chapter, will enable you to plan for economic development of drainage basins in Tanzania. Moreover, you will be able to use water for healthy life, and properly engage in managing it.

The concept of water and water masses

Water is a transparent colourless fluid which forms the earth's streams, lakes, seas, oceans and rain. It is the major constituent of the fluid part of living things. Chemically, a water molecule contains two hydrogen atoms and one oxygen atom (H_2O) that are held together by covalent bonds. Water is a liquid at standard ambient temperature and pressure, but it often exists on Earth with its solid state (ice or snow) and gaseous state (steam or water vapour). When water is in liquid or solid state it appears either within the ground or on the earth's surface forming a *water mass*.

A water mass is an identifiable body of water with a common formation history which has physical properties distinct from the surrounding water. Such properties include density, temperature, salinity, chemical-isotopic ratios and other physical quantities. Also, water masses are distinguished by their location and vertical position, resulting into surface, intermediate and deep water masses.

Water covers about 71 per cent of the earth's surface. The seas and oceans make about 97 per cent of the water on the surface of the Earth, while the fresh water found in glaciers, lakes, rivers, streams, wetlands, ponds, groundwater and polar ice caps forms about 3 per cent (Figure 4.1).

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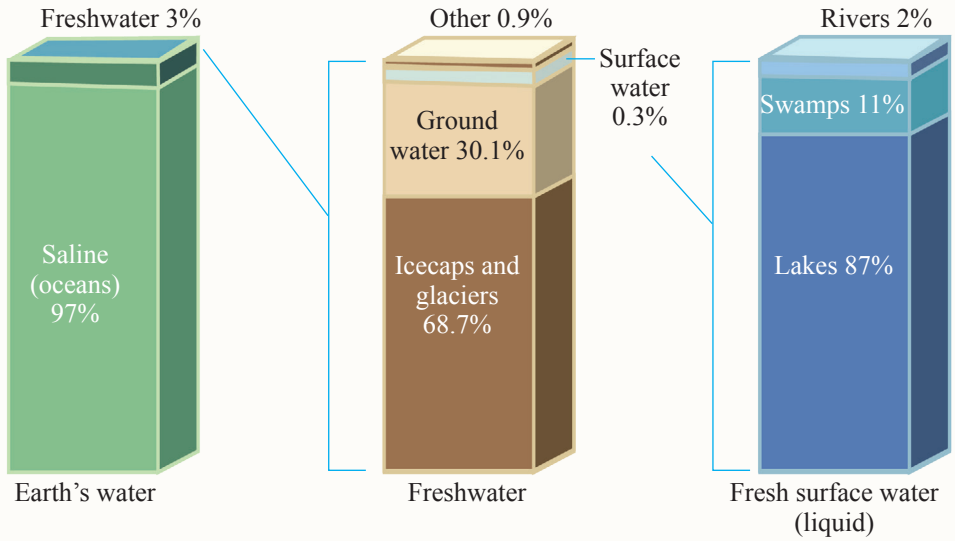


Figure 4.1: *Proportions of water resources*

Groundwater

Groundwater also known as phreatic water or subterranean water is the water below the ground surface in the cracks and spaces in the soil and rocks. Also it may 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 resource, 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 limestone containing bicarbonates during circulation becomes alkaline. Some of the most typical characteristics of groundwater include weak turbidity, constant temperature, chemical

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composition, pure microbiogical, 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 slower than it would move 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 their 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, usually has high mineral content. Thirdly, o*ceanic water* which is the type of groundwater seeped horizontally through rocks from the ocean or sea waters into the ground and 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 snow melting 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 diffusely across the landscape such as natural springs, rivers, and lakes. Recharge and discharge rate of groundwater depends on the permeability of the rock and the hydraulic gradient.

Groundwater is dependent on other features constituting a water mass, these include rock permeability, rock porosity, water table, zone of saturation, and non-saturated zone.

Rock permeability 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

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freely. Permeability is achieved by the rock which is either porous or pervious. *Impermeable rock* are rocks which do not allow water to pass through them because there are no cracks and the pores are too small. Examples of these rocks include shales, unfractured igneous and metamorphic rocks (Figure 4.2). 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 is the 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 4.2): *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.

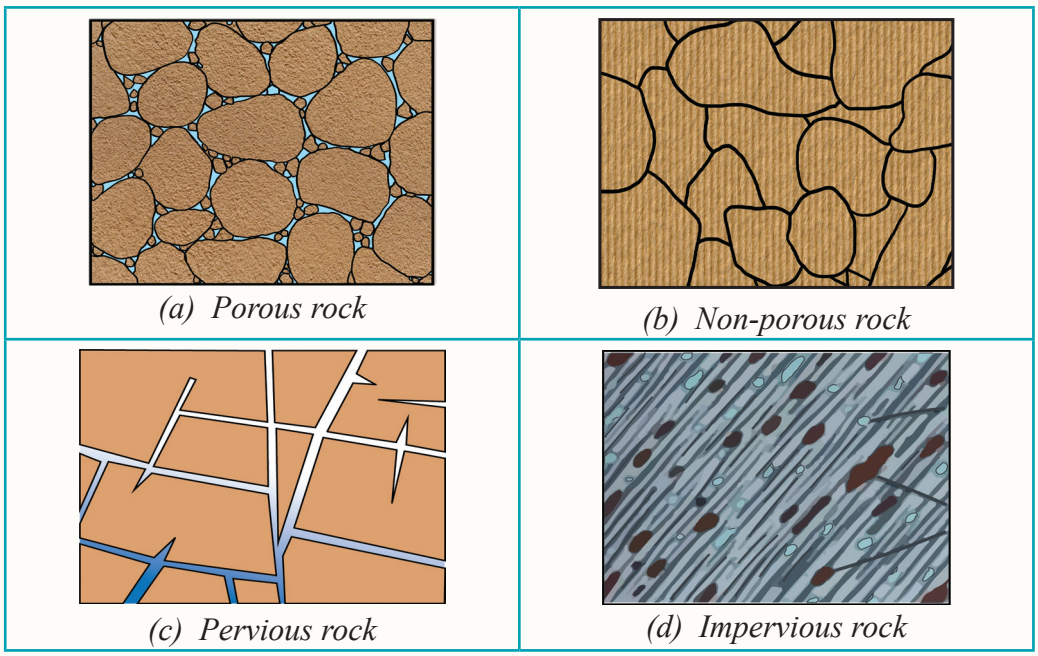


Figure 4.2: *Rock porous*

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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 reach a point where it cannot go down any further due to presence of impermeable rock.

As rainfall varies with the seasons of the year, the level of the water table also rises and falls. 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 to the surface reached during the rainy season. It can be *intermittent water table* which is the zone where spring occurs in wet season only. Also, 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* or *perched aquifer* 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 4.3).

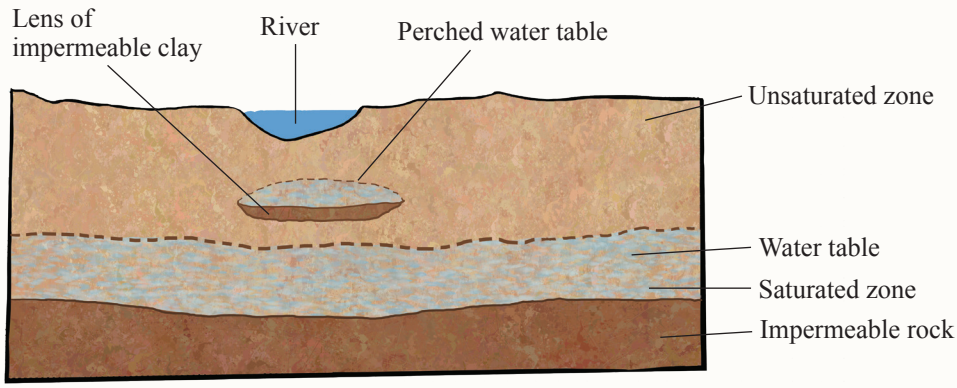


Figure 4.3: *Water table*

Zones 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

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(Figure 4.4). 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 by water but acts as an intermediate zone for water to percolate on its way to the underlying zones. On 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.

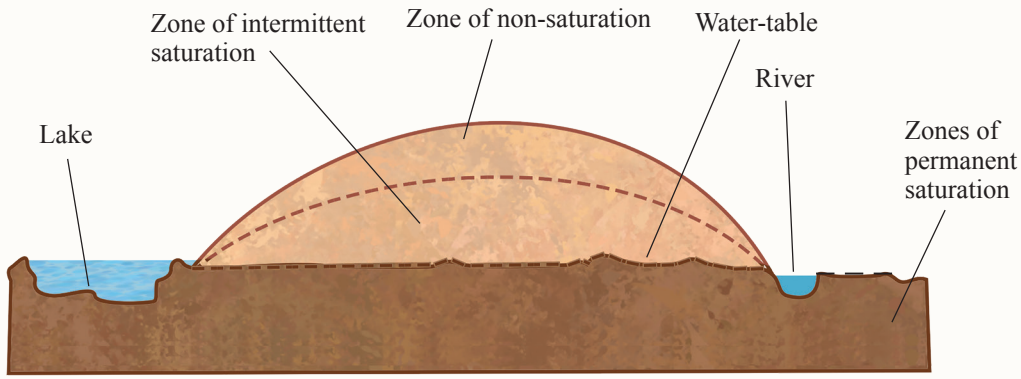


Figure 4.4: *Zones of saturation*

Aquifer

It 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 4.5). 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 impermiable rocks. The reacharge of confined aquifer occurs at a place where it exposes to the ground surface.

Unconfined aquifer: Is an aquifer which is overlain by a permiable rock. Unconfined aquifers are reacharged by the infiltration of precipitation from the ground surface.

An aquitard: Is a zone within the Earth that restricts the flow of groundwater from one aquifer to another. Aquitards are composed of layers of either clay (aquiclude) and non-porous

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rock (aquifuge). An *aquiclude* is a layer which is impermiable to the flow of water. It contains a large amount of water in it but does not permit water throught it. An *aquifuge* is an impermiable layer which is neither porous nor permiable. It cannot store water in it and at the sametime cannot permit water through it.

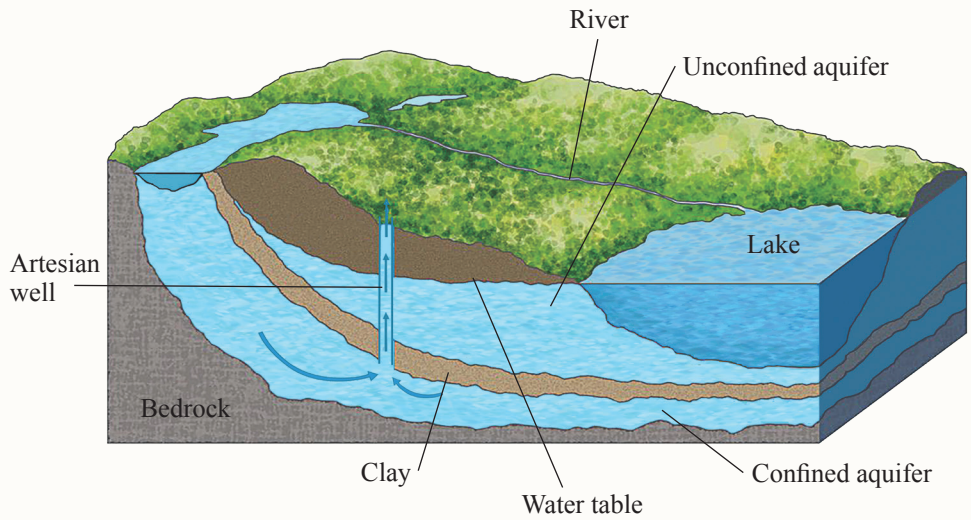


Figure 4.5: *Aquifer*

Activity 4.1

In a group of five students, develop a 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. The model can be either movable or stationary.

Groundwater occurrence

Groundwater can emerge on the earth's surface as springs, wells, artesian basins, artesian wells or wetlands:

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, that is known as temporary spring. Springs can occur singly or in a series forming a

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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 either a stream, a swamp or a pond (Figure 4.6).

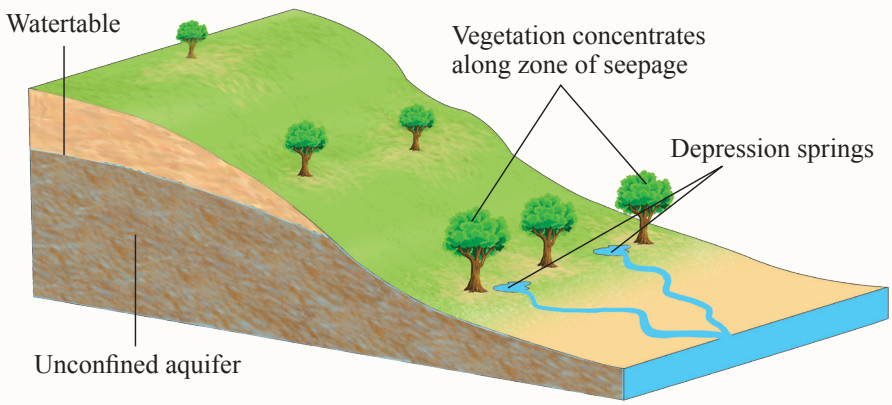


Figure 4.6: *Position of a spring*

Occurance 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 4.7 below shows two lines of springs: one is permanent and the other is intermittent.

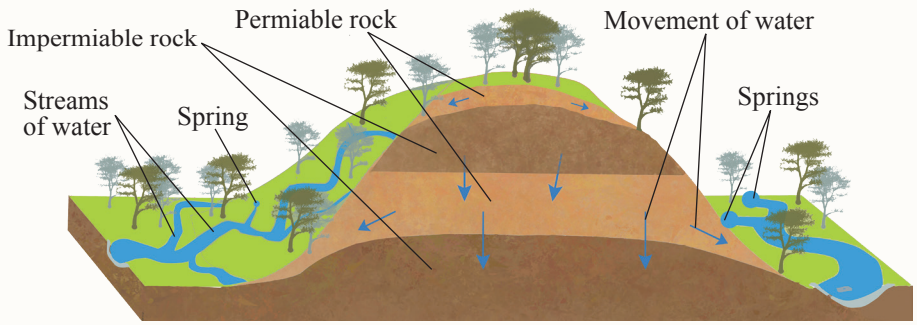


Figure 4.7*: Springs overlying permeable rock*

When well-jointed rocks form hilly landscape: When well-jointed rocks form hilly landscape, water enters the rocks through the joints, causing springs to occur where the water-table meets the surface (Figure 4.8).

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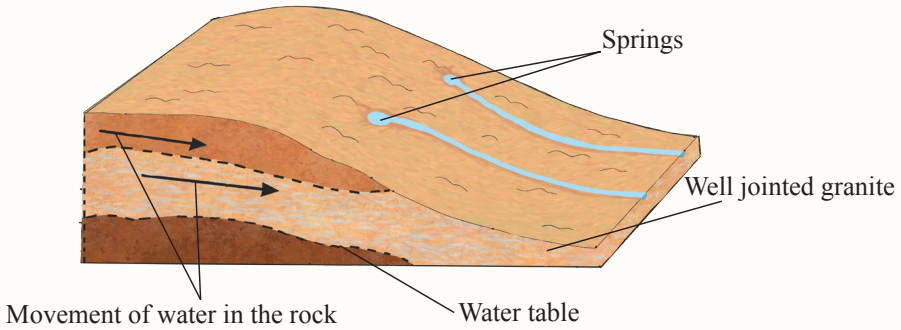


Figure 4.8: *Spring often developed on the slopes of well-jointed hilly regions*

When a dyke acts as a dam: If streams cut across a layer of permeable rock, then the water in the upslope side of the dyke is impounded, causing the water-table to meet the surface on the gentle slope of the dyke. Some springs are formed due to the damming effect of a dyke, and is termed as dyke spring (Figure 4.9).

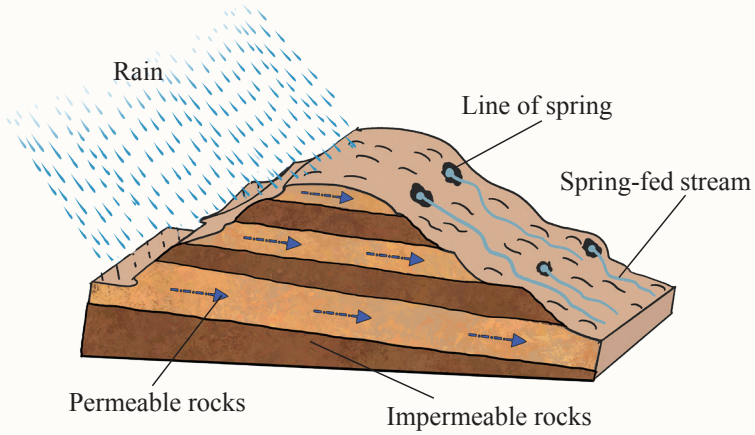


Figure 4.9: *Dyke spring*

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 4.10). Such a spring is known as limestone spring

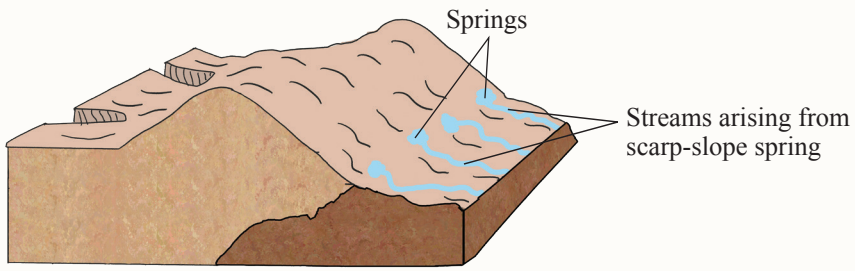


Figure 4.10: *Limestone springs*

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When rain falls on the exposed end of a 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 4.11). Several lines of springs may develop along the junctions of permeable and impermeable rocks where these form alternate layers in a hilly region.

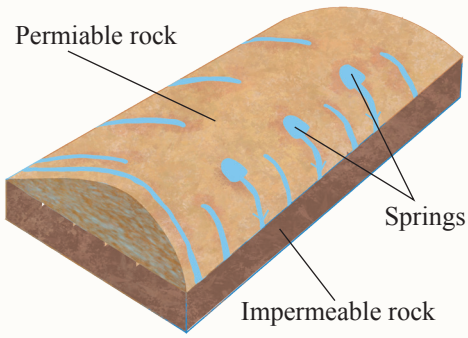


Figure 4.11: *Springs on the slope side of alternate permeable and impermeable rocks*

When a spring develops along a fault: The spring can also occur along a fault where a permeable rock layer has been brought against an impermeable rock layer (Figure 4.12). Such a spring is known as a fault spring.

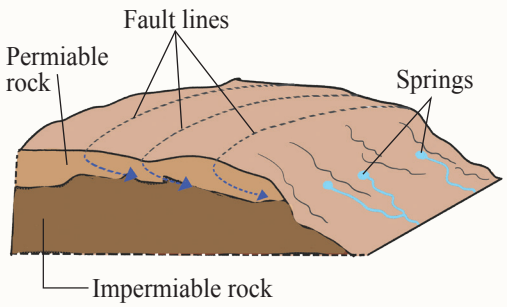


Figure 4.12: *Formation of springs along a fault*

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 4.13). Such spring is known as a depression spring.

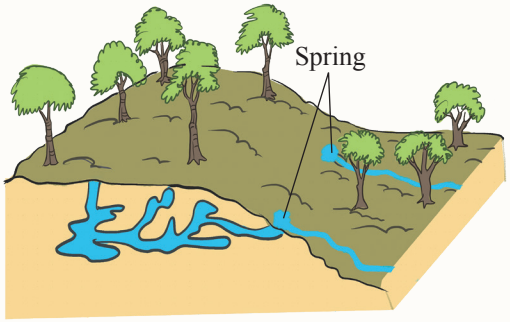


Figure 4.13: *Spring formed due to depression*

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. A well is categorized into two that is as a deep/permanent or shallow well. 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 4.14).

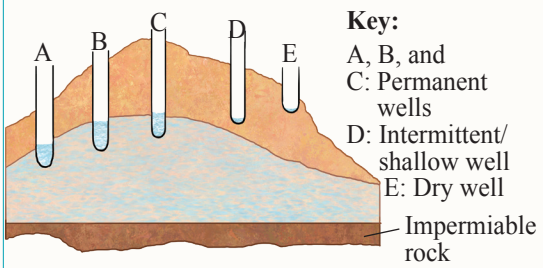


Figure 4.14: *Wells*

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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 becomes exposed on the surface (Figure 4.15). 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 the well is sunk into the artesian basin, the hydrostatic pressure in the ground forces water to come out like a fountain (Figure 4.15). 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.

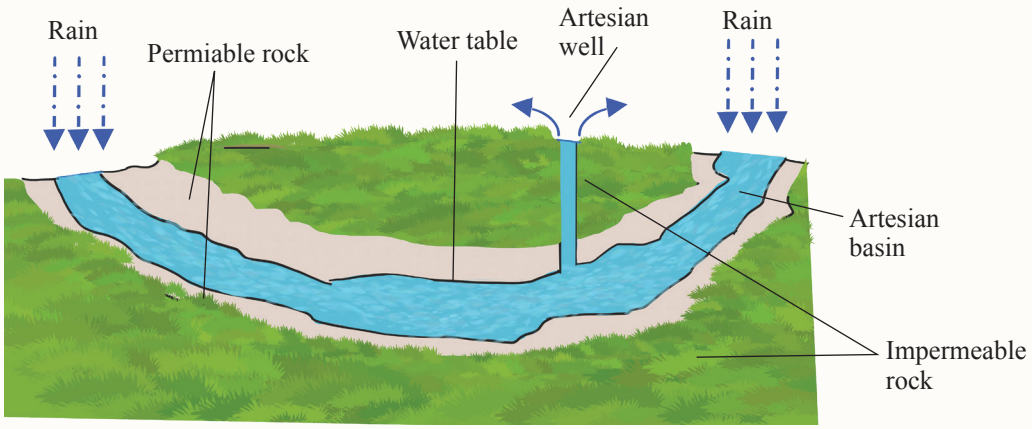


Figure 4.15: *Artesian basin and artesian well*

Conditions for the location of artesian well and artesian basin

The location of the artesian well demand three main conditions that are; 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 4.16).

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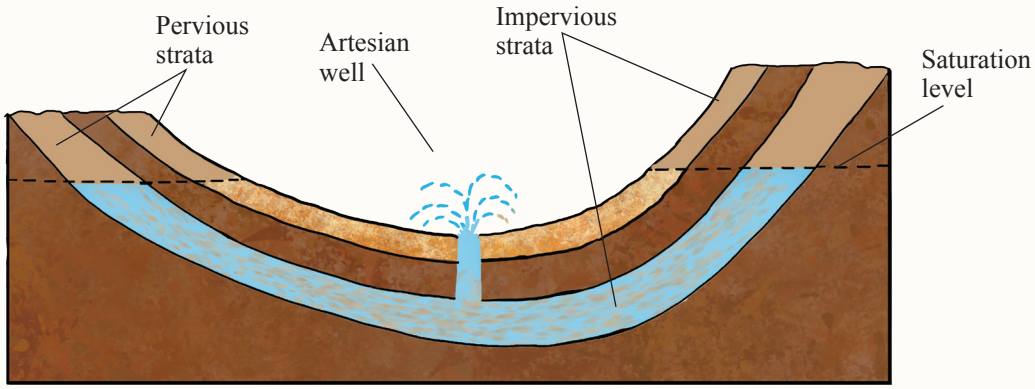


Figure 4.16: *Formation of an artesian well*

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, in turn lower the water table. On 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 (Figure 4.17). 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.

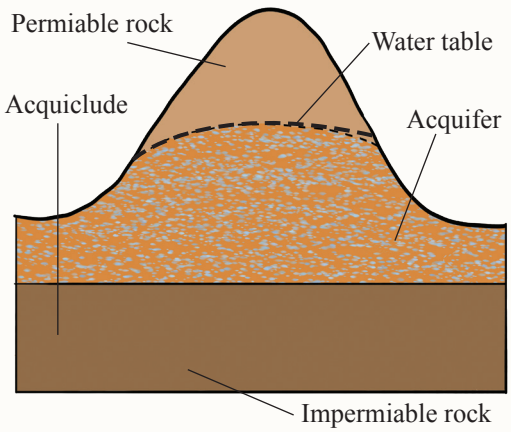


Figure 4.17: *Zone of aquifer*

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 faster, 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.

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Vegetation cover

Usually water tends to sink down in areas of dense vegetation cover but in bare rocks (surface) water runs freely down the slope such that very 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 4.2

Using the knowledge gained on the emergence of groundwater onto the surface, improvise a model of artesian basin showing an artesian well. Demonstrate the model to the class. Respond to questions asked (if any) by fellow students.

Hydrological cycle

Hydrological 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. The driving force of the hydrologic cycle is the Sun, which provides the energy needed for evaporation. The hydrologic cycle consist of physical processes that create a continuous water movement on the Earth that has neither a beginning nor an end, it is an incessant process. The water cycle processes in the Earth system (atmosphere, hydrosphere, lithosphere, and biosphere) involves evaporation, transpiration, condensation, precipitation, infiltration, runoff, and groundwater flow. 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 vapor by sublimation. Again, it should not be taken for granted that in deserts like Sahara often lack precipitation, rather it rains but it evaporates before making it to the ground.

Essentially, the unendless natural process of moving water can be explained by water which evaporates from the water bodies, plant leaves (vegetation) and the land surface into the atmosphere in form of water vapour and thereafter water vapor condenses to form clouds and precipitates in the forms of rain, snow, sleet, or hail back to the earth's surface. The precipitation falls on open bodies of water, land surface and some precipitation is intercepted by vegetation. Precipitation on the land surface forms surface runoff and/or recharges groundwater. Water that infiltrates into the ground through percolation becomes part of groundwater which eventually reappear as streamflow or can be mixed with saline groundwater in coastal zones.

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Finally, water re-enters rivers, lakes and oceans in which there is ongoing evaporation process (Figure 4.18).

Processes of the hydrological cycle

The hydrological cycle can be studied by starting at any of the following processes;

Evaporation is the process whereby liquid water is converted to water vapour (vaporization) and removed from the surface. Water evaporates from a variety of surfaces such as rivers, lakes, pavements, soils and wet vegetation. It occurs when radiant energy from the sun heats water, causing the water molecules to become so active such that some of them rise into the atmosphere as vapour (Figure 4.18). *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. It occurs as a result of water being taken by plants through the roots and released into atmosphere through the leaves. Evaporation and transpiration occur simultaneously, and there is no easy way of distinguishing between the two processes. The simultaneous process of evaporation and transpiration is termed as *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. *Condensation* is the process of changing water vapour to liquid water droplets in the air creating clouds and fog. Water vapour in the air rises mostly by convection. This means that warm, humid air will rise, while cooler air will flow downward. As the warmer air rises, the water vapour will lose energy, causing its temperature to drop. Then water vapour will change its state into liquid or ice. *Precipitation* is deposition of moisture released from clouds as rain, sleet, snow, or hail falling on the earth's surface. Precipitation is formed when water vapor, which has condensed in the atmosphere, becomes too heavy to be held in the atmospheric air currents and eventually falls on the earth's surface. The warm air rises, cools and condenses to form clouds. When precipitation reaches the Earth's surface, it adds to the surface water in streams and lakes, or infiltrate the soil to become groundwater. A portion of precipitation that reaches the earth's surface seeps into the ground through the process called *infiltration*. The amount of water that infiltrates the soil varies with the degree of land slope, forms and amount of precipitation, the amount and types of vegetation, soil and rock types, and initial soil water content. The more openings in the surface (cracks, pores, joints), the more infiltration occurs. 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 a lot of precipitation, soils become saturated, thus rainwater can no longer enter it. Runoff will eventually drain into

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creeks, streams, and rivers, lakes and oceans. Along the way, a portion of runoff evaporates, percolates into the ground, or is used for agricultural, residential, or industrial purposes. Generally, once water reaches the ground one of the three processes may occur; some of the water may evaporate back into the atmosphere, runs on the surface (runoff) or infiltrate and percolate through the soil into the rock to form groundwater or phreatic water. Groundwater either seeps to make its way to the oceans, lakes, rivers and streams, or is released back into the atmosphere through transpiration and evaporation. The balance of water that remains on the earth's surface is runoff, which enters into lakes, oceans, rivers and streams and is carried back to the oceans, where there is ongoing processes of the cycle as well.

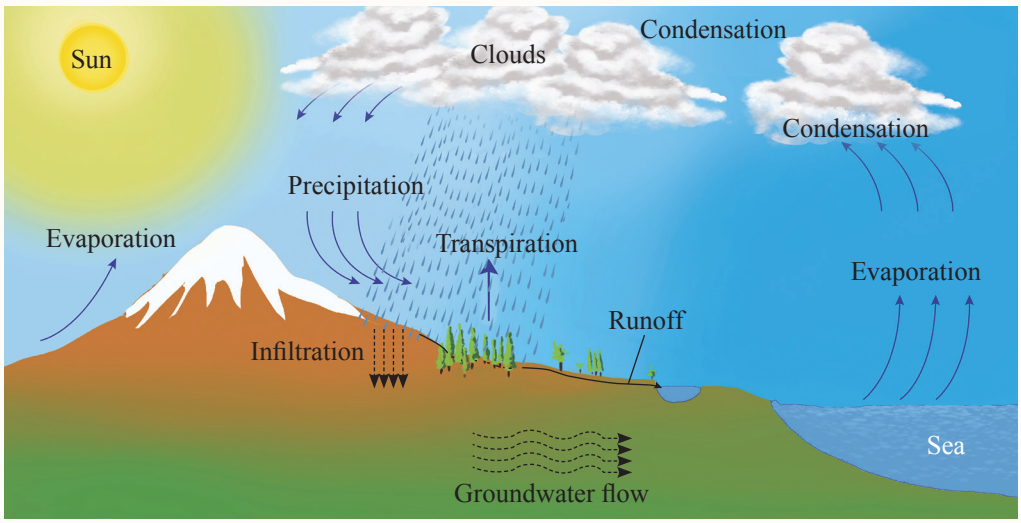


Figure 4.18: *The hydrologic cycle*

Moreover, once water enters the ground or rock it keeps percolating until it reaches the water table and the zone of saturation. The above circulation of water in the Earth system confirms the two ways in which water can enter in the ground or rocks which are groundwater in karst region and groundwater pollution.

Groundwater in a karst region

A karst region is an area characterised by developed zones of enhanced porosity within carbonate rocks that create a highly heterogeneous aquifer system with rapid rates of ground-water movement and recharge. Karst regions are pervious but not porous, meaning that water can pass along bedding planes and downward through joints but not through the rock itself. Karst area is formed by the dissolving rocks that are characterized by sinkholes, sinking streams, closed depressions, subterranean drainage and caves which are underlined by limestone or dolomite. Its topography is chiefly formed by the dissolving of rock. Kast

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areas have a wide range of closed surface depressions, well-developed underground drainage systems and strong interaction between circulation of surface water and groundwater.

Aquifers and groundwater system in a karst region

A karst aquifer is a body of soluble rock that conducts water principally through enhanced porosity formed by dissolution of the rock. Aquifers are commonly structured as a branching network of tributary channels, which connect together to drain a groundwater basin and discharge to a perennial spring. The drainage patterns of karst channels (which flow underground) resemble the branching pattern formed by streams flowing above the ground across insoluble rocks.

In karst aquifers, the channels and caves drain the pore space between the limestone rock and the fractures formed by joints, bedding planes and faults. The water tables in karst areas can be highly irregular in elevation. However, because water-carrying channels can develop at various elevations, water may also be encountered in perched aquifers. Karst aquifers are divided into three types which are Kast aquifers with large conduits, narrow joints and highly developed with interconnected large karsts and narrow karst fissures.

Karst springs

A karst spring occurs when the groundwater table intersects with the earth's surface or the groundwater rises to the surface through rock faults, fractures or depression. In most cases water surfacing from the karst springs is groundwater to a large scale. Karst springs occur where the groundwater discharges from channels or caves. Karst springs or "cave springs" can have large openings which discharge very large volumes of water. The sinkholes and sinking streams that drain to a large karst spring can be many miles away from the spring. Frequently, groundwater rises to the surface from a completely water filled stream. A karst spring receives drainage from all the sinkholes and sinking streams within its groundwater basin, equivalent to a watershed on the surface. The channels carrying water from each point where water sinks join together underground to form successively larger openings with ever-increasing flow, which eventually discharges at a spring. Karst springs can be perennial (permanent) or intermittent (temporary, ephemeral or seasonal). From a perennial spring, stream flows above land throughout the year, while the intermittent ones' flows at irregular intervals depending on seasonal variations in rainfall. Sometimes the intermittent spring can dry several times or most of the year. Seasonal springs flow only during a certain (wet or rainy) season while ephemeral springs are active only for a short time as a results of intensive precipitation. Intermittent springs are very often in karst area.

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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, 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 latter 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

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are shallow lagoons or reservoirs commonly used to temporarily store or treat hazardous liquid waste. These sites are protected with 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.

Land 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 tanks may occur when they are overfilled. Therefore, the tank content 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 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 material, when leaks eventually appear in pipeline systems, lead to a risk of groundwater contamination. In this regard, a high risk of biological and chemical pollution is associated with sewer pipelines.

Mining activities have a big impact on 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 the unsaturated zone down to the saturated zone. Moreover, groundwater can also be contaminated after spill or leak of the chemicals used to separate a target mineral substance from the ore, for example, cyanide or sulfuric acid.

Application of de-icing chemicals during de-icing of roadways, airports, and aircraft surfaces is a common maintenance activity in countries with severe winters. This is usually accomplished with chemicals such as inorganic salts like Sodium Chloride (NaCl), Magnesium Chloride ($MgCl_2$), Calcium Chloride ($CaCl_2$), or Potassium Chloride (KCl), and alcohols and glycols (propylene glycol and ethylene glycol). The brines formed as the salt dissolves and after application of the de-icing formulation can be introduced into the

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subsurface with precipitation events and alter groundwater quality.

The importance of groundwater in life

Ground water is beneficial in varying ways, mainly: spring influences sites for settlement in many regions of the world. For example, spring-line settlement in London basin, Durban and spring line village along the Atlas Mountain in North Africa. Springs are also a source of domestic water, for example Shiri spring located in Hai district is the main source of domestic water to the town of Moshi in Kilimanjaro. Also, water from wells is used for irrigation in the dry areas for example agriculture is practiced around the oases on Sahara Desert, in which commonly grown crops include dates and banana. Besides this, ground water forms a major source of water for domestic and industrial use. It acts as a source of rivers for example in Kenya Highlands and those of Southern Tanzania. Furthermore, in volcanic region, it may form hot spring and geysers which sometimes are used for generating geothermal power. A good example is the Great Rift valley of Kenya. Moreover, the artesian wells raise water from deep levels in the ground where pumping could be used. In Kansas, USA, such water is used in cattle ranching. Lastly, underground streams are useful in keeping some lakes and oceans fresh due to the groundwater seeps to the oceans, lakes, rivers and streams making water suitable for industrial and home use. Lake Naivasha, for example, has an underground seep to the Indian Ocean.

Exercise 4.1

1. Write short notes on the following terms:
   (a) Groundwater
   (b) Porous and pervious rock
   (c) Aquifer
2. Briefly explain the types of groundwater.
3. Explain the ways through which water gets into the ground.
4. Describe the hydrological cycle in relation to groundwater.
5. With examples, explain how groundwater can be contaminated and suggest measures to avoid contamination.
6. To what extent groundwater is valuable to the community?
7. Give an account for the likely health risks to be encountered by the users of groundwater from the unmonitored wells and springs.

Inland drainage

Inland drainage refers to a drainage in which rivers do not reach an ocean or sea instead empty their water in lakes or an inland sea. It is a drainage system or pattern which 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

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drainages systems which is accordant and discordant drainage systems. Accordant drainage system in the one whose pattern of flow corresponds to the structure and relief on the landscape over which it flows. Whereas, discordant drainage system describe the drainage pattern that cuts across the structural gain of an area. Besides this, a drainage basin or catchment is any area of land where precipitation collects and drains off into a common outlet such as river, bay or other bodies of water. In the drainage basin or catchment all surface water from a river and all its tributaries intersect at a single point of lower elevation. Its boundary is marked by highland which makes any precipitation drain into adjacent basins. This boundary is called a *watershed*.

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, 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 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 drainage system which follow the regional slope and is well adjusted to the geological structure. Sequent streams are further divided into consequent streams, obsequent streams subsequent streams, and resequent streams.

(i) Consequent streams: Consequent streams which are also called dip streams are the first streams to be originated in a particular region. These streams have their courses in accordance with the initial slope of land surface (Figure 4.19). In other words, consequent streams follow the 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

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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 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.

(ii) Subsequent streams: These streams originate after the master consequent stream following the axis of the anticlines or ridges and the strikes of beds (Figure 4.19). are called subsequent streams. The subsequent streams originate on the flanks of the anticlines and join the master consequent at almost 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.

(iii) Obsequent streams: These streams flow in opposite direction to the master consequent (Figure 4.19). 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.

(iv) Resequent streams: The tributary streams flowing in the direction of the master consequents are called resequents. These are originated at much later date in comparison to the master resequents. Since they are of recent origin, and hence they are called resequent. The resequent streams are originated during the initiation of the second cycle erosion in a folded structure. The gradual demotion of folded as the invention of rolled in the anticlinal ridges and synclinal valley are converted into anticlinal valleys and synclinal

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ridges, respectively. Thus, 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 4.19).

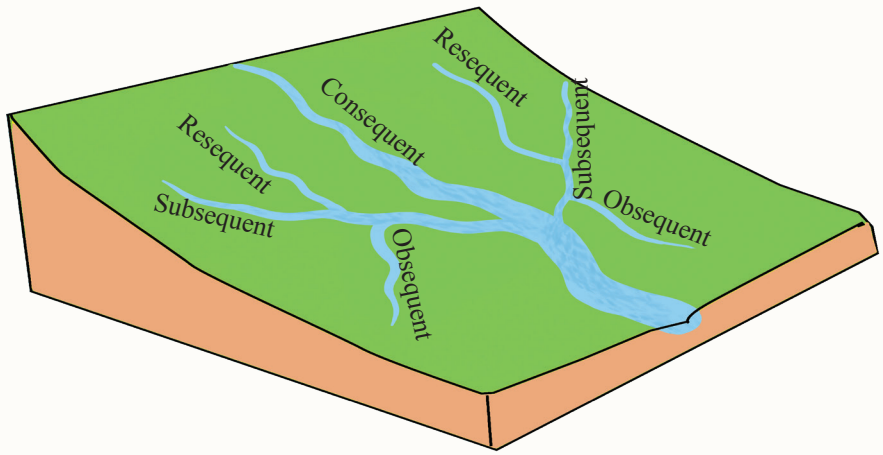


Figure 4.19*: Types of drainage systems*

Insequent drainage system

Insequent streams also known as discordant drainage system do not follow the regional slope and are not adjusted to geological structure as they drain across the geological structures. Insequent streams are further divided into antecedent streams and superimposed streams.

(i) Antecedent drainage system: This is a type of drainage in which a river maintains its course by eroding vertically the rising land at the rate which is fast enough to keep pace with the land uplift. Good examples are River Ruaha, 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 4.20).

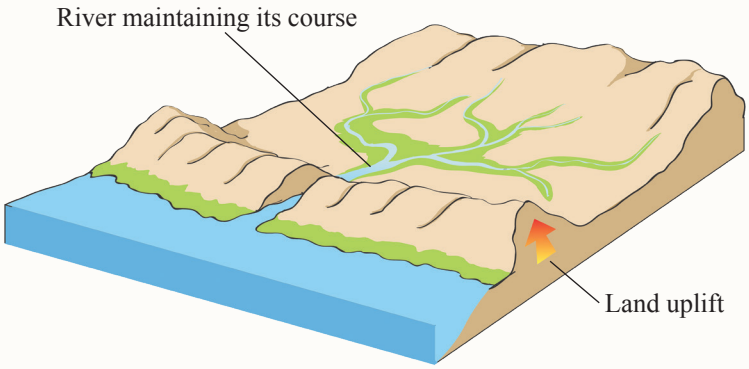


Figure 4.20: *Antecedent drainage system*

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(ii) Superimposed drainage: Is the opposite of antecedent drainage whereby a river has maintained its course into a newly exposed rock layer without following the structure of the new rock (Figure 4.21). Such rivers are younger than the rocks they cut across, for example Zambezi River.

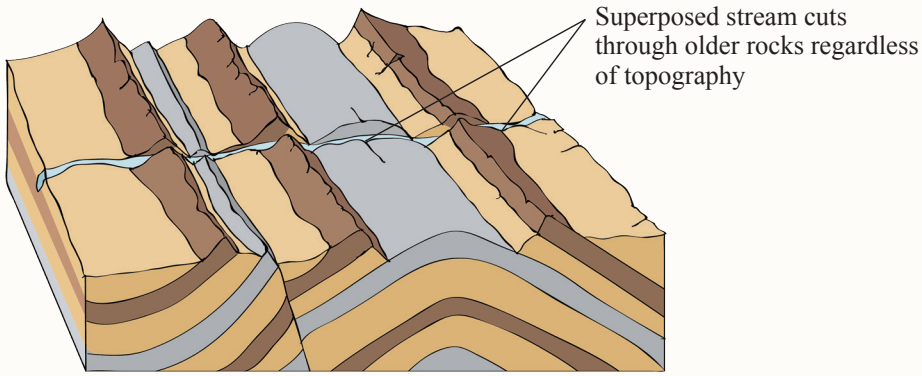


Figure 4.21: *Superimposed drainage system*

Furthermore, insequent drainage system can be *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 having a different structure while the land is being uplifted, for example the Colourado River in USA.

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 can be classified whether is related or not related to rock structure. Streams naturally flow along those lines where they find erosion easy, 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 rock hardness, 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.

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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 4.22). 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.

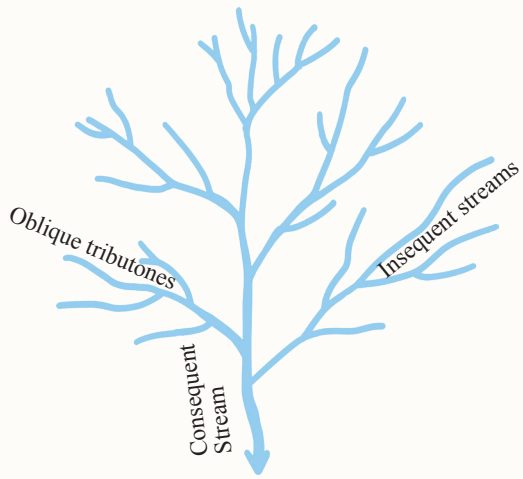


Figure 4.22: *Dendritic Pattern*

Trellis pattern

It is a drainage pattern which forms between ridge lines in 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 rock hardness and 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 4.23).

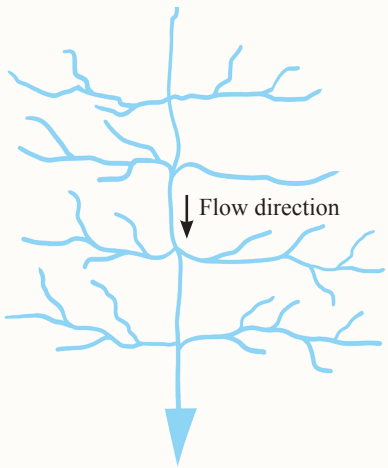


Figure 4.23: *Trellis pattern*

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 summit of mountain peak and is controlled by slope of the land (Figure 4.24).

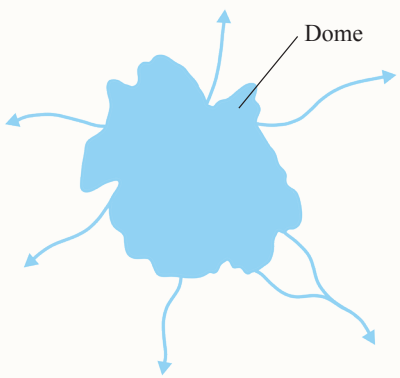


Figure 4.24: *Radial pattern*

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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 4.25). 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.

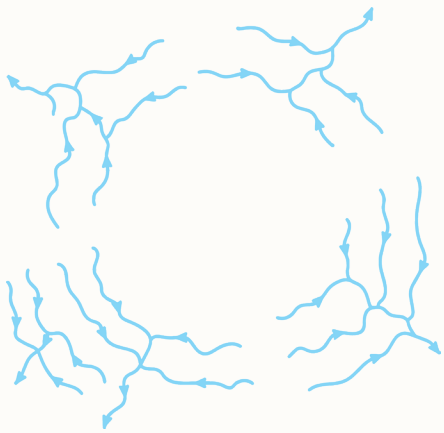


Figure 4.25: *Annular pattern*

Rectangular pattern

A 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 4.26). Generally, a rectangular pattern is developed in the regions where the rock joints form a rectangular pattern.

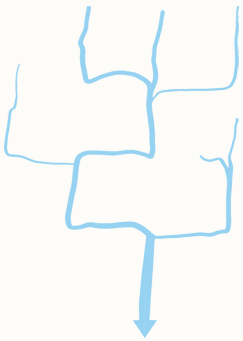


Figure 4.26: *Rectangular pattern*

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 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 4.27). 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.

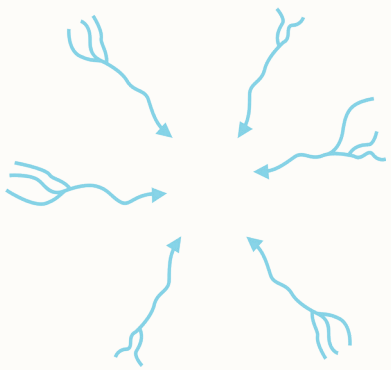


Figure 4.27: *Centripetal pattern*

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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 rejoin and split again (Figure 4.28). Braided channel are separated by sand bars or island of alluvium.

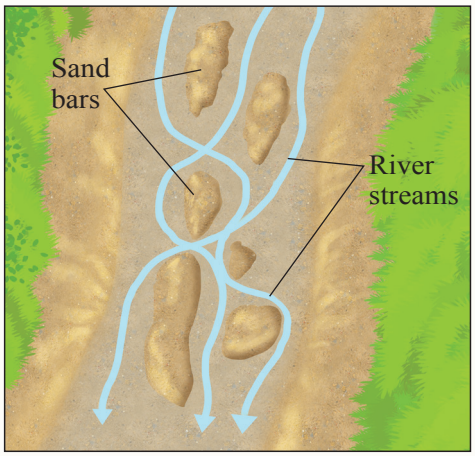


Figure 4.28: *Braided pattern*

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 4.29. Therefore, it is the reconnection of two streams that previously branched out.

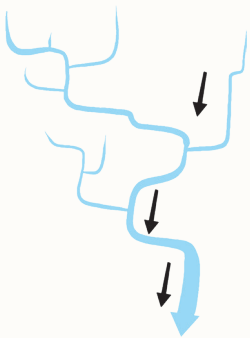


Figure 4.29: *An anastomotic pattern*

Exercise 4.2

1. Using examples from Africa, describe the common drainage patterns.
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 pattern?

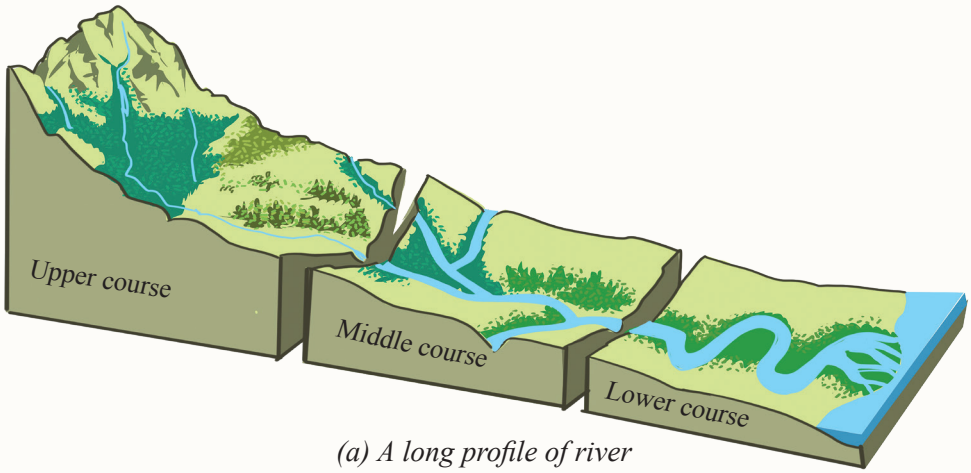
River

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 long profile of a river is a representation of a river from it source (upper course) through middle cause to its mouth (lower course) and shows how the river changes over its course. All rivers are joined by small rivers or streams called tributaries. 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 (Figure 4.30).

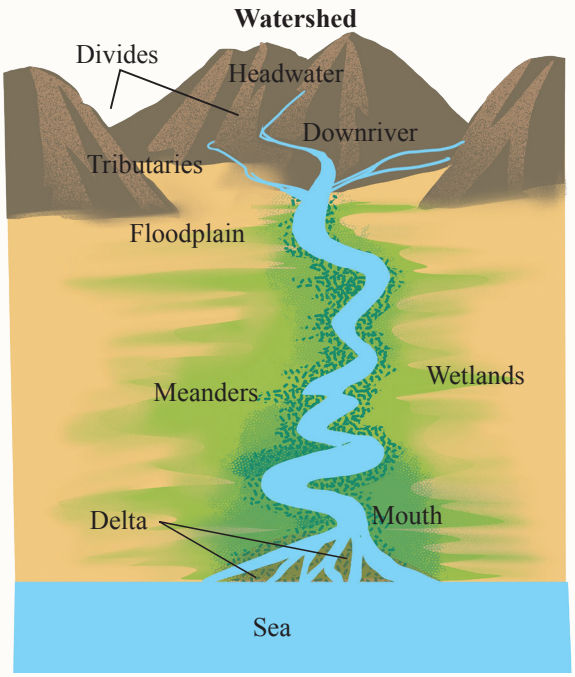
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The upper course (headwater), streams swiftly flow down steep mountain slopes and cut deep, v-shaped valleys. Waterfalls and rapids occur in this zone. *The middle course (lower-elevation),* streams merge to flow down gentle slopes. Valleys broaden as coalescing rivers start to meander. *The lower course (lowest elevations),* a river meanders across a broad, nearly flat valley and floodplain.At a river's mouth, it may divide into separate channels as it flows across a delta extending out to sea. The coastal plain and delta are made of river sediments.



(a) A long profile of river



(b) River system

Figure 4.30: *Cross-section of the river system*

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Types of rivers

Perennial Rivers: These are permanent rivers which flow throughout the year. Most of these rivers are situated in the equatorial regions, commonly found in Amazon and Congo rivers (Figure 4.31). 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.



Figure 4.31: *Part of Congo River*

Intermittent rivers: These are types of rivers which 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 St. Lawrence in USA, Orange Vaal in South Africa and Rufiji river in Tanzania (Figure 4.32) are examples of intermittent rivers.

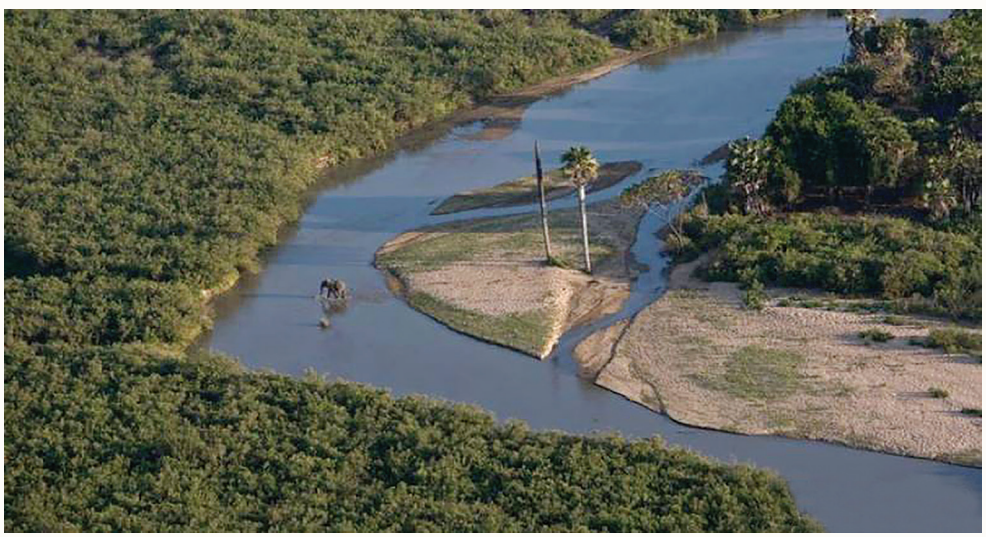


Figure 4.32: *Part of Rufiji River in Tanzania*

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Ephemeral 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 4.33), Luni and Son in India.



Figure 4.33: *Ephemeral River Kuiseb 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. Example of rivers under simple regime include River Ruvuma, Malagarasi and Ruvu in Tanzania, Tana and Galana in Kenya. Most of the rivers found in Africa experience simple regime.

Double river regime: This occurs when a river experiences two maximum water levels and two minimum water levels. 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

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volume of water in the river through out the year. This type of regime belongs to big and longest rivers whose length cut across several climatic regions. A good example is river Nile, Amazon and Mississippi.

River basins

River basin is defined as an area of land drained by a river and its tributaries. It is the unit of water resources management. River basins are primarily identified by hydrological networks which are determined by nature of morphology of particular area. The basin may consist several small basins which are known as watershed. The area that demarcates one basin from the other is known as watershed or divide. Besides, river basins being recognise by hydrological networks, there are boards which have been intrusted in the management of the river basins.

River basins in China

China is the richest country in rivers and lakes. It hosts over 1 500 rivers of varying sizes and river basin as well. The prominent rivers basins found in China are Hai River Basin, Huai River Basin, Liao River Basin, Pearl River Basin, Songhua River Basin, Yellow River Basin and Yangtze River Basin (Figure 4.34).

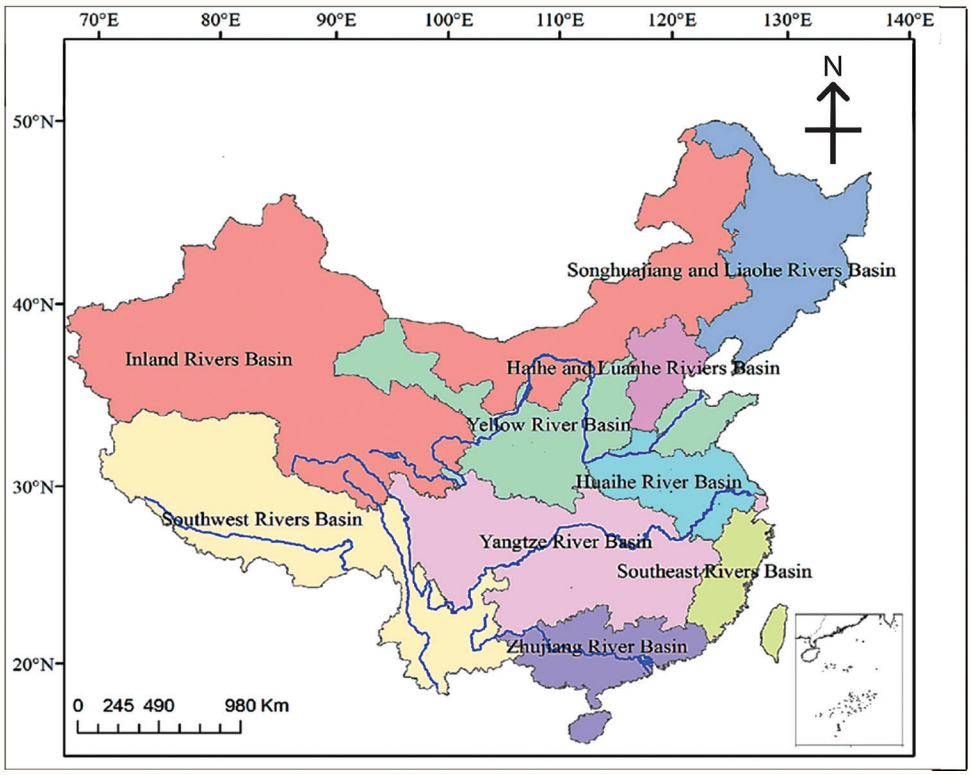


Figure 4.34: *River basins in China*

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Yangtze River Basin

The Yangtze (Changjing) River is China's longest river, and the world's third longest river with about 6300 km (Figure 4.35). The river is fed by the snow and its waterway starts in the Kunlun Mountains of the Tibetan Plateau in Qinghai Province and flows South East and later empties into the East Chinese Sea about 20 km North of Shanghai. The Yangtze River is fed by about 700 tributaries and it is the largest river system in China with a basin covering an area close to 19% of China's total land. The river provides fresh water resources to about 400 million people, which is about 30% of the Chinese total population. The total water availability per year in the basin amounts to 996 billion m^3 on a long term mean basis, which is about 36.5% of China's total waters. The Yangtze Basin area is rich in lakes, covering an area of more than 15 200 km^2 with most of them being situated in the middle and lower reaches. The area includes the two largest fresh water lakes in China which are the Poyang and Dongting lakes.

The Yangtze basin covers about 19 provinces, autonomous regions, and municipalities. The river functions as the most important transportation network through the heart of some of the most densely populated and economically important areas in China, known as the Yangtze River Economic Belt (YREB). The Yangtze is also the major inland waterway with navigation channels of about 57 000 km (of which 2837 km is mainstream), which accounts for about 52.5% of the nation's total inland navigation channels. The shipping capacity of the Yangtze River is equivalent to about four (4) to six (6) railways each of the same length. The Yangtze River Basin (YRB) is a major resource for irrigation, agriculture and hydro-electric power (H.E.P) with a technical potential exploitation of about 256 270 MW and an estimated annual power output of more than 100 TWh, equivalent to 48% and 49% of the total power generated by the nation respectively. The river currently holds about 17 hydroelectric dams, including the largest three gorge dams. Agriculture along the basin produces almost a half of the country's total crop-harvest and contributes about a third of the national grain and GDP. The Yangtze River basin is recognized internationally as an important ecosystem which is rich in biodiversity and is listed with its six wetlands in the Ramsar Convention on wetlands of international importance.

The Yangtze River basin is under custody of the Changjiang Water Resources Commission (CWRC), which is one of the seven river basin management commissions under the Ministry of Water Resources of China. Together with the prefectural and local branches of the Ministry of Environmental Protection (MEP), they are responsible for the water quality and quantity of the river basin. Also, other ministries under the state council have the responsibility related to management of water system. Regional

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authorities, including provinces, cities and public and private organizations (like conservation groups and construction firms) are considered as stakeholders on the river basin management. Figure 4.35 show Yangtze River basin.

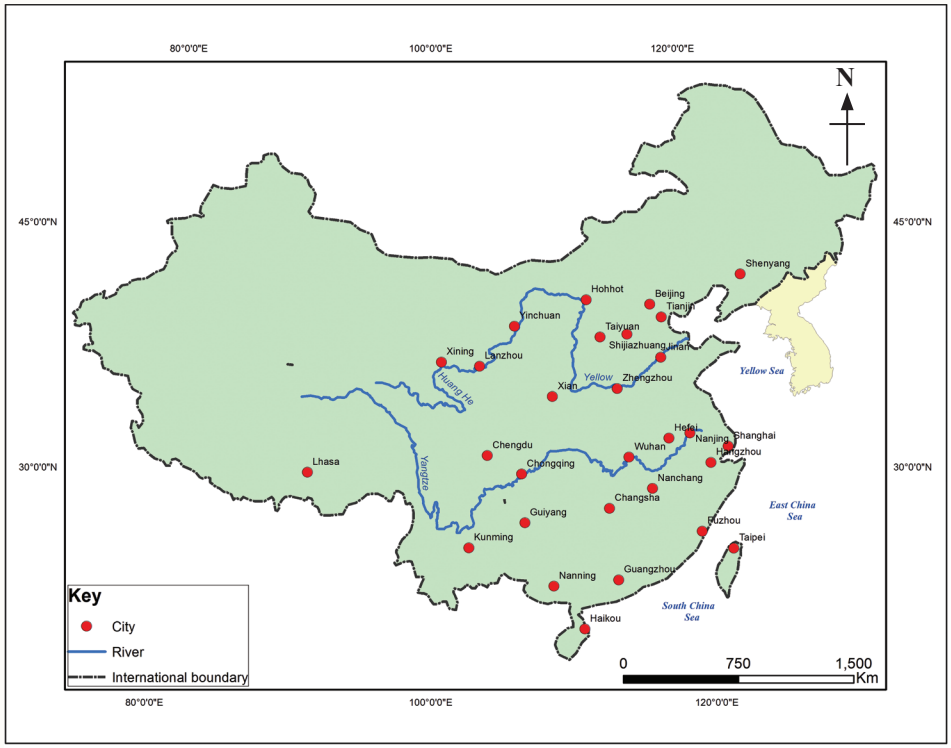


Fig. 4.35: *Yangtze River*

Exercise 4.3

1. What is a river regime?
2. With examples, describe the categories of river regimes.
3. Explain the factors influencing river regime.

Drainage basins in Tanzania

Tanzania is a home to the highest water tower in Africa Mt. Kilimanjaro as well as the deepest fresh water lake in Africa Lake Tanganyika. Tanzania has a total of nine (9) drainage basins (Figure 4.36), out of those seven (7) are transboundary basins and the remaining two (2) are not transboundary basins. A transboundary basin is the one which crosses at least one political border within a state or an international boundary. Transboundary basins include Lake Victoria, Lake Tanganyika, Lake Nyasa, Pangani, Ruvuma and Southern Coast, internal drainage basin and Lake Rukwa basin. It is only Rufiji and Wami-Ruvu Basins which are not transboundary basin. Tanzania has 14 transboundary fresh water bodies which includes rivers

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Songwe, Kagera, Mara, Malagarasi, Momba, Mwiruzi, Umba, and Ruvuma, and transboundary Lakes such as Nyasa, Victoria, Chala, Jipe, Tanganyika (the deepest lake in Africa) and Natron.

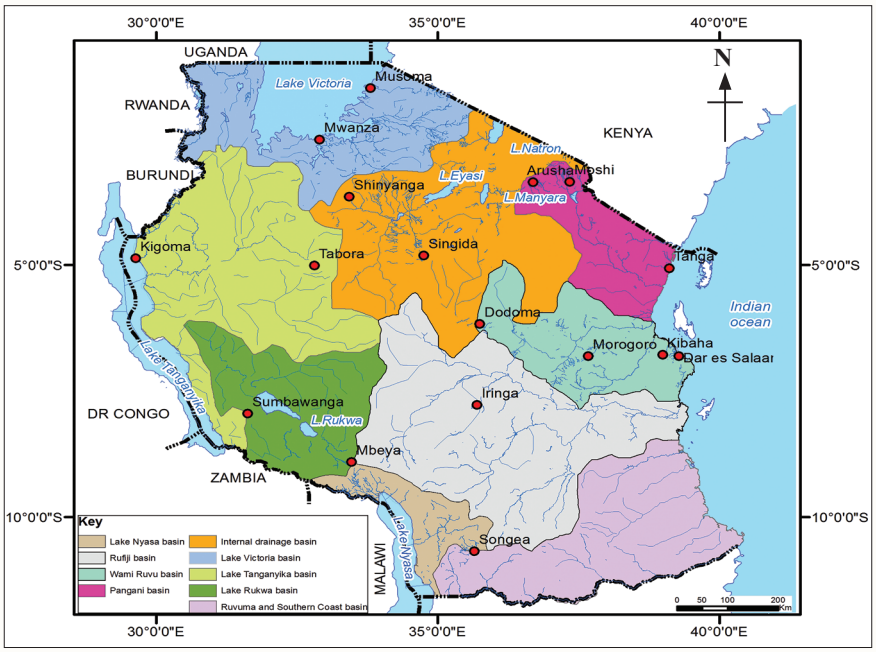


Figure 4.36*: River basins of Tanzania*

The rivers that are found in the basins in the country are important in feeding various lakes in Tanzania. This include great lakes in East Africa which are Victoria, Tanganyika and Nyasa. Besides the trans-boundary rivers, Tanzania has many large and small inland rivers which flow towards lakes or the Indian Ocean. These include the Ruaha, Kilombero, Wami, Ruvu, and Ruhuhu rivers. Lakes alone cover about 7% of Tanzania's land surface. Some of these lakes are Lake Victoria, Lake Tanganyika, Lake Nyasa (boarder Lakes), Lake Rukwa, Lake Eyasi, Lake Manyara, Lake Singidani, and Lake Natron (inland lakes).

Tanzania is divided into nine (9) water management units corresponding to the nine major drainage basins. In each basin, there is a basin water officer who is responsible for regulating and planning the use of water resources, based on the Water Resources Management Act No. 11 of 2009. The Act provides for institutional and legal framework for sustainable management and development of water resources. The major focus of the Act is to outline the principles of water resource management, to provide for the prevention and control of water pollution, and to provide for the participation of stakeholders and the general public in implementation of the national water policy.

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The water resources management section of the water sector development programme requires the Water Basin Offices to conduct their activities in line with the principles of Integrated Water Resource Management (IWRM) approach. The Water Resources Division under the Ministry of Water and Irrigation (MWI) is responsible for the quantitative and qualitative assessment and monitoring of water resources. Also, it deals with dams' safety monitoring. In this regard, the division collects and manages hydrological and water use data, develops the hydro-geologic maps, issues water use permits and inspects the existing water abstraction systems. The division is also responsible for water resources planning and research, regulation, enforcement and environmental issues associated with water resources.

Exercise 4.4

1. Differentiate watershed from a river basin.
2. Describe the transboundary drainage basins of Tanzania.
3. Discuss the challenges of managing transboundary water resources.

Drainage basins and water use conflicts

Water use conflict is a term describing a dispute or disagreement between countries, states or groups of people over ownership, access to, and use of water resources. Opposing interests of water users is one among potential indicators for conflicts occurance.

Cases of water conflicts in Tanzania

The Pangani river basin

The Pangani River Basin is about 43,650 km^2, with about 5% of its area in Kenya, and the remainder distributed across the Arusha, Manyara, Kilimanjaro and Tanga regions in Tanzania. The Pangani River system drains the southern and eastern sides of Africa's highest peak, Mt. Kilimanjaro (5,985 m) as well as Mt. Meru (4,566 m). It then passes through the arid Masai Steppe, draining the Pare and Usambara Mountains before reaching the coastal town of Pangani, makingits estuary with the Indian Ocean.

The Pangani Basin is one of Tanzania's most productive areas, with nationally important agricultural outputs and hydropower production. The basin has forest and biodiversity resources that are important globally. The basin hosts millions of people, who rely directly or indirectly on irrigated agriculture for their livelihoods. Water within the basin serves human needs such as drinking, cooking, washing and sanitation. The water in the basin also allows arid land to become productive through irrigation; provides a habitat for plants, fish, and wildlife; supplies urban and industrial uses; generates electricity through hydroelectric power; and supports many recreational activities.

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Water conflicts in the Pangani basin

The frequently recorded conflicts in Pangani river basin have been linked to water users of different sizes and power in the basin. The basin supports both small scale and large scale agricultural activities that relie on water from the basin. In addition, water is used by the H.E.P plant. Similarly, the three urban centres of Arusha, Moshi and Tanga in the basin have been demanding much more water to cater for their expanding socio-economic needs. This eventually, necessitated the emergence of conflicts among the three users who are the city, municipality and farming communities. The dominant water use conflicts in the basin are related to water allocation, quantity and water quality in space and time. Therefore, water conflicts may be categorized into four main groups, namely water tenure conflicts, conflict of allocation, peasants against pastoralists conflicts, and peasants against peasants conflicts.

Conflict of water right: Water right refers to the legal right of a water user to utilize a given water source, such as a river, a groundwater source, a dam, a lake and a pond. The water user rights are secured by paying the user fees. Many small-scale users in the Pangani Basin are reluctant to apply and pay for water rights, with a notion that water is a 'gift from God', as a result the communities have been undermining government efforts to manage water resources, to an extend of destroying water control gates and structures thus, leading to the water use conflict.

Conflict of water allocation: Despite the role played by the Pangani Basin Office and its Board of managing and allocating water resources in the basin and ultimately balancing stakeholders' demands, still the dissatisfaction among the users have been fueling on the modalities of using water, and consequently results into conflicts between the authority and peasants.

Pastoralists against farmers: Conflicts may occur when individual water users have divergent interests. For example, in the past decade, the Maasai pastoralists from the northern areas of Moshi and Arusha have been streaming towards the basin, mostly at Kilindi with tens of thousands of their livestock in search for water and grazing pasture. In the process of feeding large numbers of livestock, they have been unlawfully entering into farmers' fields, destroying, crops and irrigation infrastructures, and thus causing serious conflicts.

Conflict resolution

Some of the necessary steps to resolve these conflicts include the following: raising communities' awareness about water sector reforms and the likely effects of climate change on water availability; organizing stakeholders' workshops, which will bring together representatives from communities, local and central government officials, and

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technical experts to discuss the situation and propose a way forward; recognizing the efficacy; and, to some extent, reinstituting traditional systems whereby water is managed by hydrological boundaries and not administrative boundaries. These measures will make it easy to negotiate agreements between upstream and downstream users.

Cases of water use conflict in North-East Africa

The Nile River Basin

The Nile River Basin is an international water basin which covers eleven different sovereign nations, namely the Democratic Republic of Congo, Rwanda, Burundi, Tanzania, Kenya, Uganda, Eritrea, South Sudan, Sudan, Ethiopia and Egypt. The basin is named after the Nile river which is the longest river in the world covering about 6 853 km (4258 miles). The Nile is the only significant source of water in North Africa supporting about 40% of Africa's population living in the Nile River Basin. The Nile has two major tributaries namely White Nile and the Blue Nile whereby the former is longer than the latter. The White Nile starts from the the Lake Victoria basin which is located in Tanzania, Uganda, and Kenya, and it flows via Uganda, Southern Sudan. The Blue Nile originates from Ethiopia's Lake Tana and flows into Sudan from the Southeast. In addition to being a source of internal conflict within nations, water from the Nile has caused external tensions between sovereign states. While Egypt consumes 99% of the Nile's water supply, it is only a small amount of Nile's water that originates from within Egypt's sovereign borders. Higher water demands of a lower riparian have often fuelled regional conflicts. For instance, the construction of a large man made dam in Ethiopia and the use of water in Lake Victoria for irrigation have been among the causes of misunderstanding among the countries which have shared uses of basin.

However, Egypt has been for long time taking control of the Nile over the years. The intesification of the conflicts over the basin have been recorded ever since early 20th century mostly fueled by the rapid increase in population (which doubled from 25 to 50 million between 1960 and 1987) and the accompanying demand for food that led to the building of the Aswan High Dam (opened in 1971) and several new schemes to irrigate the desert near Cairo (late 1980s). The main purpose of the High Dam has been to hold back the annual flood water generated by the summer rains in the Ethiopian Highlands. Some water is released throughout the year, allowing an extra crop to be grown, and every surplus is saved as an insurance against a failure of the rains. The river regime below Aswan is now more constant, allowing trade and navigation throughout the year. The dam incorporates a hydro-electric

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power station which provides Egypt with almost a third of all its energy needs for domestic and industrial purposes. Lake Nasser, which is also located on the Nile Basin, is important for fishing and tourism.

Water use conflicts in the Nile basin

Egypt and Sudan hold absolute rights to use 100 percent of the Nile water under agreements reached in 1929 between Egypt and Britain (which was then the colonial power in Kenya, Sudan, Tanzania, and Uganda) and in 1959 between Egypt and Sudan. In such agreement, Egypt was assigned mandate to issue consent to other nations' use of the Nile's water, due to this most of other basin countries have been passive in developing projects that extensively utilize water of the Nile river. For many years, economic constraints, external pressures and internal strife have precluded upstream countries of the Nile basin from developing their water resources, allowing Egypt to take full advantage of downstream water flow. However, over the years, due to considerable population growth, economic development, political consolidation and improved opportunities to harness their water resources and increased demand for energy and arable surfaces, other basin countries have contested the validity of these treaties and demanded their revocation to make way for a more equitable system of water use along the Nile valley and its tributaries.

Out of all countries draining water to Nile river, Ethiopia is the most important, as its Ethiopian highlands provide nearly 86% of the Nile's water. Along with this role, it has recently been developing its largely untapped potential for hydro-energy and irrigation. Such water development plans in Ethiopia and other upstream countries will require only a small portion of the Nile's water, the prospects for increased water utilization in the near future raise serious concerns among the downstream countries of Egypt and Sudan. Due to this, Egypt which receives only very limited amounts of rain that makes it largely dependent on irrigation in the Nile River for sustaining its agricultural production, raises much concerned with ever emerging uses in upstreams. This has been among the reason for Egypt to discourage any upstream projects that could reduce downstream river flow. Eventhough, the construction of projects such as the hydro-power facilities on the Nile tributaries will not necessarily lower the downstream flows, yet Egypt has been worried of upstream damming projects. This has frequently been causing tensions and fear among the riparian countries in the basin. For example, the 2011 tension that was recorded has a result of Ethiopia's move on the construction of a 6 000 MW hydroelectric dam (the Grand Ethiopian Renaissance Dam) on the Blue Nile-the main tributary of the Nile basin in the absence of any

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agreement with downstream Egypt. Due to this however, there have been series of unsuccessful attempts to reach consensus among the concerned countries.

Exercise 4.5

1. Explain how water use can result into conflict.
2. Examine the possible ways which can be used in resolving water use conflicts
3. Explain the use and importance of water to peoples' livelihoods.

Activity 4.3

In a group of five students, draw a map of Tanzania, then;

(a) Indicate main transboundary rivers, river basins and lakes.

(b) Indicate the destination where the respective rivers drain their water and show the countries that share the indicated rivers.

(c) Discuss the importance of transboundary water resources to the recipient countries.

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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 in case of Kyoga loses water to the White Nile, meanwhile Lake Tana loses water to the Blue Nile. Lakes contain fresh water four times more compared to the rivers. If it could not be continuously supplied with fresh water, they can disappear through desiccation or accumulation of sediments. Basically, there are ten largest lakes in the word as shown in Table 4.1.

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Table 4.1: *The World's ten largest lakes*

No.	Name	Location	Area in km^2
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 and 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, 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 also are 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 lakes: These lakes are formed when water occupies basins formed due subsidence of the earth's crust as a result of tectonic movements (Figure 4.37). Good 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.

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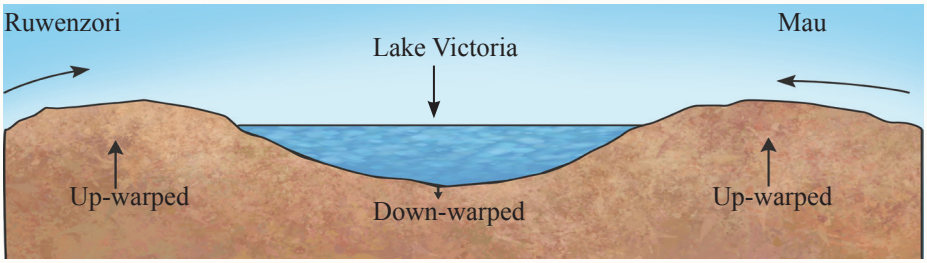


Figure 4.37: *Lakes formed through subsidence of the earth's crust*

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 4.38). 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 best 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).

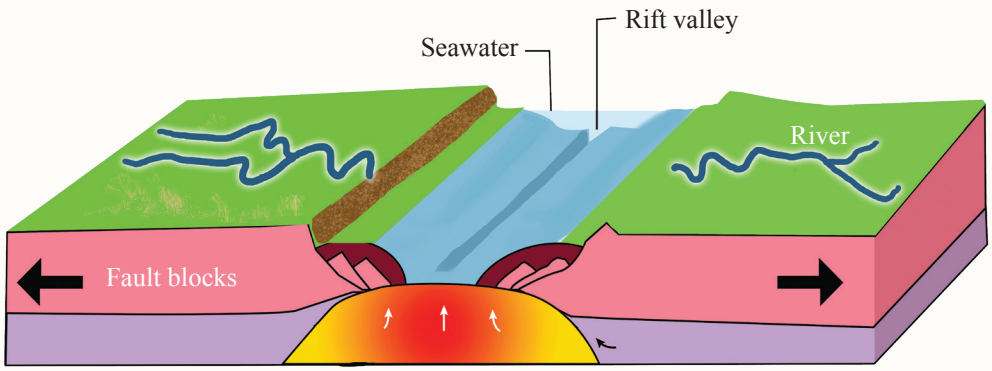


Figure 4.38: *Lakes formed through divergent of the crusted blocks*

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.

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 filled with water later on to form a caldera lake (Figure 4.39). Examples of crater lakes are Lake Oregon in USA, Lake Toba in northern Sumatra (Indonesia), Lake

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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.

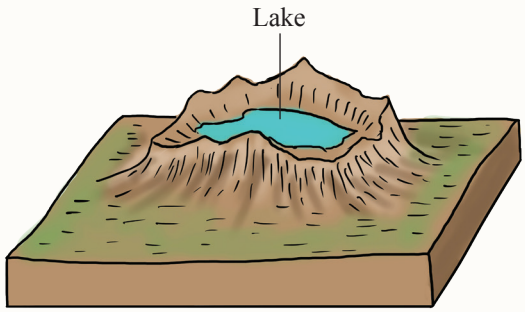


Figure 4.39: *Caldera lake*

Lava-dammed lakes: These are lakes that form when lava flows from volcano towards a river or a stream valley. After 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 4.40). 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.

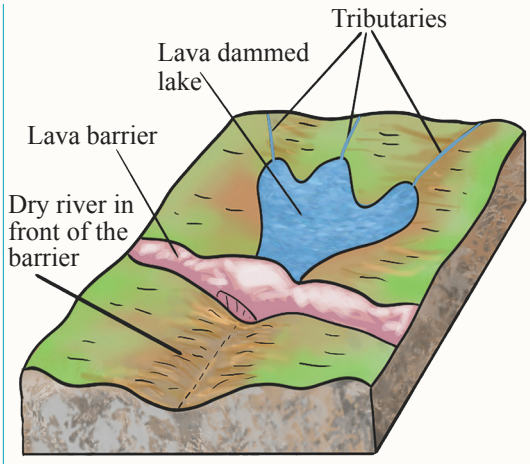


Figure 4.40: *Lava-dammed lake*

Lakes formed due to erosion

These are lakes formed due to glacier or wind erosion. Glacial lakes are formed as a result of the scouring action of ice leading to over-deepening of rock surface to form two types of lakes namely Cirque and Trough (Figure 4.41).

Cirque lake: Refers to depressions that occupy armchair-like depression called a cirque once ice and glaciers retreat. It occurs in mountains and valley sidewalls at high elevations. A cirque lake is also called a tarn. These lakes sometimes feed a mountain river. Tarns can be found on the sides of Mount Kenya, for example the Teleki Tarn.

Trough lake: This type of lake occupies an elongated depression excavated by ice at the bottom of a U-shaped valley. It is sometimes called a Ribbon lake. A good example of ribbon lake is Lake Michaelson found in the Gorges valley near Mount Kenya.

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Rock basin lake: This is formed by scouring action of an ice sheet or valley glacier. These lakes are common on the Baltic and Canadian Shields.

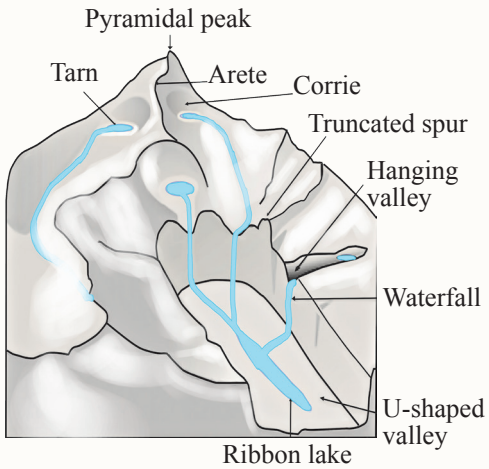


Figure 4.41: *Lakes formed due to glacier erosion*

Wind erosion lakes

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 are lakes formed due to deposition by rivers, ice and sea or oceans. Sometimes these lakes 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 lake (Figure 4.42). Several ox-bow lakes are found along the River Galma in Nigeria. Ox-bow lakes may disappear when vegetation and sediments fill them.

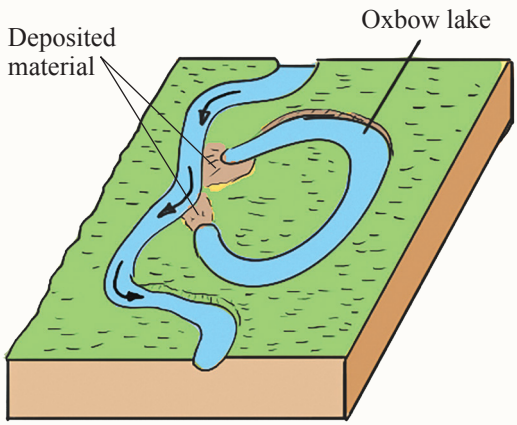


Figure 4.42: *An Ox-bow lake*

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 4.43). Delta lakes are found in the Nile Delta in Egypt and Rhône Delta, where Etang de Vaccares Delta lake is found.

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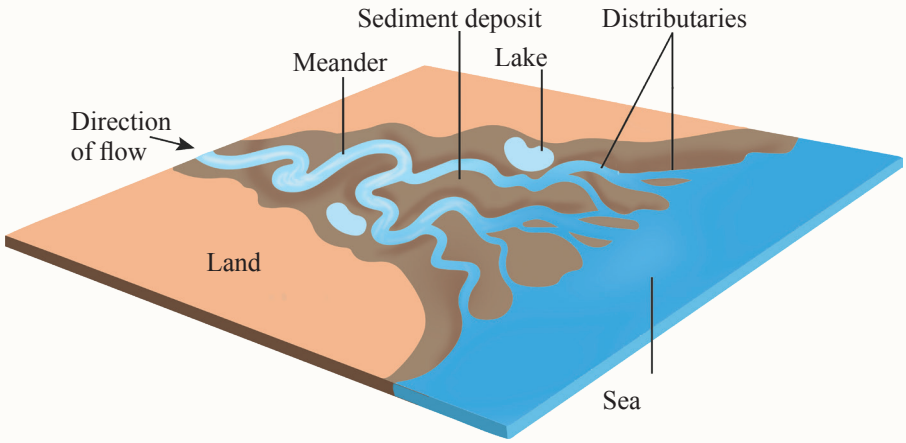


Figure 4.43: *A delta lake*

Flood plain lakes: These lakes are formed in the flood plain 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 formed due to glacial deposition

Moraine-dammed lake: This type of lake is formed when a terminal moraine is deposited across a valley, building up a barrier behind which river water collects (Figure 4.44). Examples of lakes formed through this process include Lake Garda in Italy and Lake Mahoma in the Ruwenzori Mountain ranges.

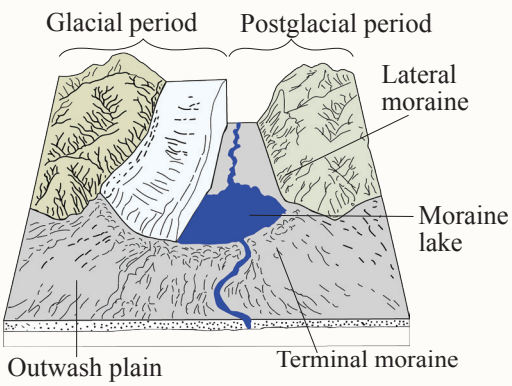


Figure 4.44: *Moraine-dammed lake*

Boulder clay lakes: These lakes form when boulder clay materials are deposited on the landscape in which the drainage is highly irregular, hence forming many small lakes. Lakes of this type are common in the Canadian Shield and in Scandinavia.

Lakes formed due to marine deposition

Haffs lake: Coastal lagoons are lakes that are formed when a sand bar extends along a coast or when a barrier beach extends across the mouth of a river. Such lakes are very common along the West African coast. Good examples are Keta lagoon in Ghana and Lagos lagoon in Nigeria. Also many small lagoons are found along the Mozambican coast.

Solution lakes: These lakes are formed in the Karst Region where rainwater or groundwater dissolves limestone rocks. Solution of limestone rocks form a cave and when the roof of the cave collapses, a solution lake is formed.

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Examples of solution lakes are Lake Scutari in Yugoslavia and Lake Ojikoto in Namibia.

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 by 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.

The economic importance of lakes

Both natural and man-made lakes are useful in a varied way. The main importance of lakes is:

Firstly, lakes are useful for fishing purposes. Fishing is a widespread traditional activity in the lakes throughout the world. It involves extraction of fish and other aquatic animals for commercial and domestic purposes. There is a need to conduct more research on water bodies in order to understand optimal exploitation of resources supplied by lakes. *Secondly*, lakes are useful habitats for aquatic organisms. Lakes provide a conducive environment for aquatic organisms' habitation. Fish and other aquatic creatures find their home in lakes. *Thirdly*, lakes are used for navigation because water transport take place in lakes. Ferry transport services on lakes Victoria, Tanganyika and Nyasa are of vital importance today. Similarly, in North America, the Great Lakes provide easy access into and through the heart of the continent. *Fourthly*, lakes are useful for irrigation purposes such that areas surrounding some lakes foster agricultural activities through irrigation. For example, the plains surrounding Lake Chad are suitable for irrigation which supports about 22 000 hectares. Furthermore, wheat, rice and cotton are grown in these plains. Likewise, the low-lying areas are suitable for plantations. For example, areas close to Lake Kariba in Zimbabwe supports bananas' irrigation farming. *Fifthly*, lakes supply water for domestic and industrial use. Water from lakes may be harnessed for domestic and industrial use. Throughout Africa, farmers build their own small dams to provide water for their cattle, small scale irrigation and domestic use on one hand. On the other hand, lakes such as Victoria, Tanganyika and Nyasa provide water for

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the cities and towns in the interlacustrine regions. The Gaborone dam in Botswana, supplies water for the capital city.

Sixthly, lakes are used for hydro-electric power (H.E.P) production. All the large man-made lakes in Africa have been constructed primarily as reservoirs for H.E.P generating stations. In Tanzania, for example, the Kidatu, Mtera, Kihansi, and *Nyumba ya Mungu* dams are used for H.E.P production. *Seventhly*, lakes are important for weather and climate moderation. The cool on shore breeze which develops in the afternoon alongsides the large lakes is an attraction in tropical areas. The large size of Lake Victoria results in higher rainfall totals on the western and northern shores, which have thus become centres of intensive agriculture and population settlement. *Eighthly*, lakes are sources of minerals. In this case valuable minerals are extracted from lakes. For example, Lake Magadi in Kenya, Lake Natron in Tanzania and Lake Katwe in Uganda are inland drainage lakes that are naturally sarline. Due to this, soda-ash is produced commercially from Lake Magadi, and salt from Lake Katwe. Potash, Phosphate and Lime are extracted from Lake Manyara and are used as raw materials for the Minjingu Fertilizer Industry. *Lastly*, lakes are useful recreational destinations. Lakes are potential for development of recreational activities. Lake Nakuru in Kenya, for example, is a game park because of the abundance of birds which attract many tourists. Lake Nyasa provides an ideal recreation resort with facilities for sailing, swimming, snorkelling, diving and wind surfing. Similarly, Lake Natron attracts migratory flamingos which attract tourists.

Problems facing lakes

Lakes encounter numerous threats that impair their usefulness. The main problems are:

Firstly, pollution whereby the disposal/discharge of unwanted materials into lakes through industrial and domestic wastes disposal, oil spillage and poisonous fishing leading to lake pollution, thus endangers aquatic organisms. *Secondly*, excessive water exploitation due to population growth, whereby water is used more excessively than it can be renewed, results into lowering of water levels in some lakes. *Thirdly*, human encroachment through establishment of human activities such as farming, animal keeping, mining, and constructions near lakes and reclamation threatens the existence of lakes. *Fourthly*, deforestation, particularly at catchment and river sources limits inlet discharge, causing a fall in the water levels of lakes. *Fifthly*, water weed and hyacinth invasion have an effect on limiting navigation and fishing activities in lakes, and threatens the existence of small lakes. *Lastly*, is the evaporation and siltation processes such that excessive evaporation and addition of silt on the lake floor cause a decrease in water level and hence threaten the existence of some lakes.

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Exercise 4.6

1. Describe types of lakes based on their mode of formation.
2. With examples, explain the social economic significance of lakes.
3. Explain challenges facing lakes in Africa.

Wetland and swamps

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 which at low tides does not exceed six metres. 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 4.45). 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 4.45: *Wetland*

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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 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

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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 4.46). 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.

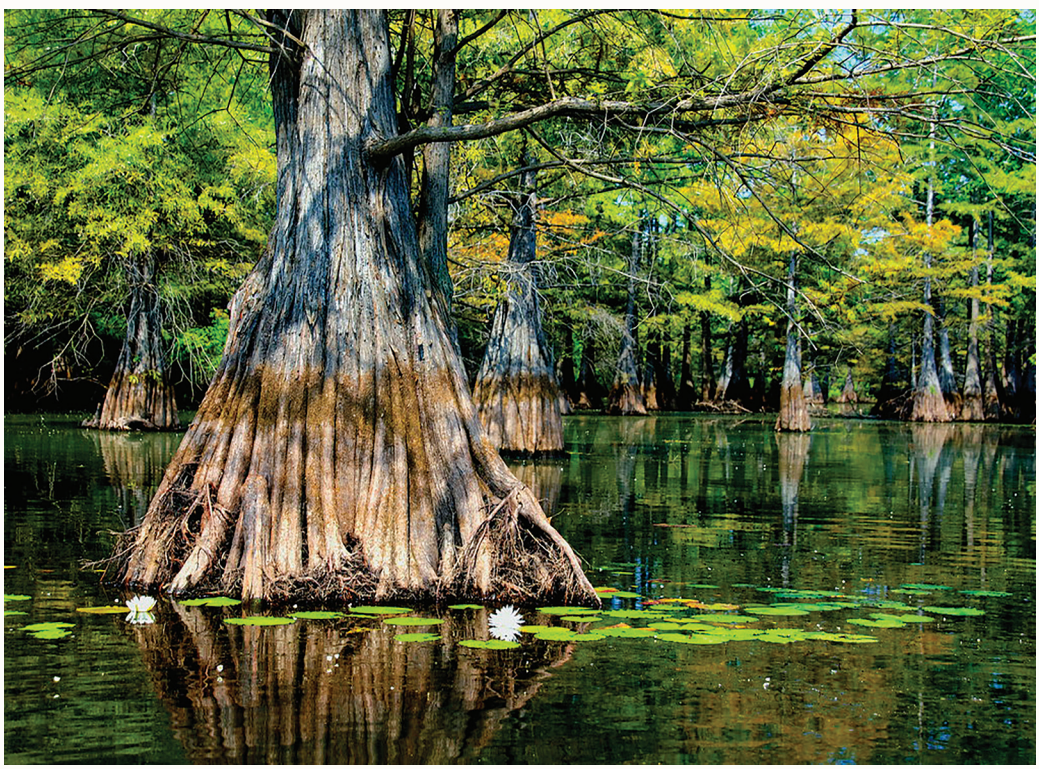


Figure 4.46: *Marshes*

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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 4.47).



Figure 4.47: *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 acid areas, frequently

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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 4.48).

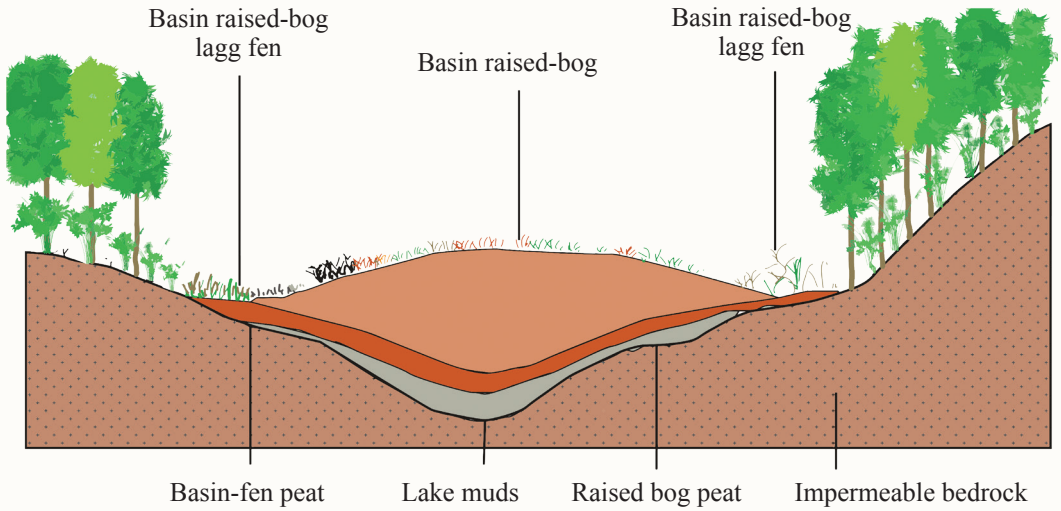


Figure 4.48 *Fens and bogs*

Importance of wetlands

Wetlands are the link between land and water and are one of the most productive ecosystems in the World. There are various important functions of wetlands, these includes;

Provision of habitat for a wide variety of wildlife and plants: More than one third of the world's threatened and endangered species live only in wetlands and nearly a half use wetland in their lives. Estuarine marine fish and shellfish, coastal birds and many other mammals depend on coastal wetlands to survive. Most commercial and game fish use coastal wetlands as their nurseries for food, shelter and protection of their young ones. Also, wetlands are vital for breeding and migratory bird populations.

Purification and storage of water: As surface runoff passes through a healthy natural wetland, it acts as a filter retaining excessive nutrients and breaking down some pollutants before it reaches open water. Therefore, wetlands maintain high surface water quality. In addition, most wetlands act as a sponge, absorbing water when it is available in excess and releasing it into the groundwater supply slowly. They have positive impact on the hydrology as they ensure adequate stream flow throughout the year.

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Floods control: In riparian systems of wetlands and rivers, the sponge-like action of wetland plants prevents floods. Preserving and restoring damaged wetlands can lead to flood control, which would require very expensive dredging operations and levee construction.

Protection of shoreline erosion: Wetlands act as wind and tidal forces breaker, which could otherwise cause shoreline erosion. Coastal areas are subjected to tremendous erosion when exposed to storm surges. Wetlands hold soil with their roots, absorb the energy of waves and break up the flow of stream or river currents. Also, wetlands at the margins of lakes, rivers, bays and ocean protect shorelines and stream banks against erosion. Erosion control is very important today as many countries spend considerable resources to protect sensitive areas along rivers and coasts.

Provision of places for recreational activities: Wetlands have recreational, historical, scientific and cultural values. For instance, in the USA more than half of the adult population hunt, fish, bird-watch or take photographs of wildlife in wetlands. Also school field trips often involve the study of wetlands. Painters and writers often find inspiration to create their art in wetlands.

Natural products: Some of the fishing industries, like shell fishing industries harvest wetland-dependent species. Several plants found on wetlands are valuable such as blue barriers, timber and wild rice.

Agricultural activities: Wetlands have abundant supply of fresh water, and fertile soils. They serve as good areas for agricultural activities where crops like paddy, potatoes, and vegetables are grown. Water from wetlands can be used for irrigation purposes.

Water supply for domestic uses: Water from wetlands is used for domestic purposes in Africa. Most African countries outside of the rainforest zone receive little rain for most of the year. Hence water from temporary wetlands is used in households to serve domestic needs.

Control of climate change: Wetlands have mitigation effect through their ability to sink carbon. Wetlands store approximately 44.6 million tons of carbon per year globally which could otherwise be available in the atmosphere and contribute to the greenhouse effect.

Wetland loss and degradation

The life supporting importance of wetlands was largely undermined in the past. As a result, they were drained, dredged, dammed, and channelled. In some cases, they were eliminated and converted into dry-land for cropland, pasture, mining the underlying resource, and distorted their life support. Moreover, in some areas, they were filled with sand for road beds, flooded them for open water lakes, or use them as dumping

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sites for water and sewage. Generally, wetlands are degraded through the following human activities:

Draining: Over many years, wetland areas have become one among the populated areas with human beings carry out various socio-economic and developmental activities. As a result, wetlands are drained for the sake of constructing roads, railways, industries, housing, and cities. Most often crop farming and for controlling mosquitoes.

Diverting: Wetland waters are also diverted via man made canals to other areas for agricultural use. They are also being directed to cities, for various uses including making the cities green.

Converting: Some wetlands are converted to aquaculture for controlled growing of fish, shellfish, molluscs (oysters, mussels, clams), crustaceous (lobsters, shrimp, crabs) and seaweed.

Destruction of habitat and plant species: Trees and shrubs in mangrove swamps are cut down, and whole ecosystems is disturbed. In some areas, mangrove forests have been completely cleared and totally destroyed for urban development.

Pollution: Apart from the destruction of wetlands through different economic activities. Some of the human activities have been associated with contaminating the wetlands with pesticides and chemicals. With time, such contamination threaten the existence of wildlife and bird populations due to the increase pollution mostly caused by anthropogenic activities.

The Effects of wetlands destruction

The destruction of wetlands has resulted in serious impacts including the following. *First*, decline of water sources and wetlands functions. Critical water changes occur when wetlands are altered causing decline of water table, disappearance of wetland vegetation, and water becomes inadequate to purify the wastes. *Second*, changes of ecosystems and weather. In some areas, wetlands have significantly changed. As the wetlands are being converted to cater for various human needs, thus leading to drastic change or disappearance of natural wetland ecosystems. *Third*, decline and loss of native and migratory species. Some of the living organisms, such as nesting birds, amphibian insects, reptiles and other organisms which inhabit wetlands have been lost or seriously affected due to shrinking of wetlands. Migrating birds in great numbers are forced to fly further and for long time looking for other wetlands since their food sources have been degraded. For example, flamingos have been known to fly up to 375 miles (600 km) each night in search for conducive wetlands. Some species, such as crawling insects, plants, flowers and young wildlife

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are perishing due to degradation of wetlands which no longer provide life support.

Fourth, the ecosystems and species in the wetlands have become at risk, in various ways. As natural wetlands are destroyed or degraded by human actions, species and ecosystems in these areas are highly affected. Most species which cannot adapt to new harsh environment become vulnerable and are likely to became extinct. Through human activities in the natural wetlands, the natural capacity for protection of these wetlands against erosion and degradation becomes minimal, making the area inhabitable. Many species have gone extinct and others have migrated due to loss of wetlands which formally habitated them. It should be noted that many species in wetland ecosystem are uniquely adapted in those physically isolated areas from other aquatic areas. Therefore, destroying such wetlands could lead to loss of the entire ecosystem.

Wetland management

The wetlands can properly be managed in various ways. However, the following are the main management measures: formulation of policies, enactment of laws and regulations which are specific to wetland management; provision of education on the value and importance of wetlands to both human life and the ecosystem. There should also be provision of wetland management and conservation skills at all levels to enhance accountability; encouragement of construction of artificial wetlands in order to preserve the available natural ones so that they may not perish but flourish; promotion and encouragement of controlled farming in wetlands, such as controlled irrigation system to maintain water levels in wetlands. This should go hand in hand with avoidance of bushfire and shifting cultivation, as well as overstocking and overgrazing in wetlands; prevention of encroachment and poaching in wetlands, and control of settlement expansion towards wetlands. Furthermore, discouraging overfishing and avoiding illegal fishing that uses dynamite explosions and poison; avoiding over-draining of water from wetlands for both domestic and industrial use.

Exercise 4.7

1. Explain the importance of wetlands.
2. Using a case of Tanzania, analyse the threat faced by wetlands and suggest remedial measures.

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

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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 surface 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 through variations of such elements 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 4.2. 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 (Figure 4.49).

Table 4.2: *Ocean location, area, volume and average depth*

Ocean Location	Area (Km^2)	Volume (km^3)	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 4.49: *Map of the major world oceans*

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Physical features of the ocean floor

The floor of the ocean has complex structures caused by horizontal and vertical tectonic motion, 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 from time, when flat, coastal areas became inundated due to increase in the height of the sea level from previous time. The width of the shelf varies from tens to hundreds kilometers and its depth can vary from 80 to 500 m. The continental slope adjoins the shelf framing the continental borderland. The slope varies from 1 to more than 30 m. The bottom of the slope reaches depth of 3 000 to 3 500 m 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 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 4.50).

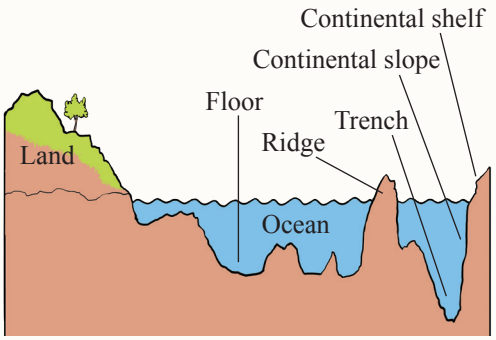


Figure 4.50: *Common Physical Features of the Ocean Floor*

Chemical composition of the ocean water and sea

Ocean and sea water contains a number of mineral substances (mineral salts) in 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 the simultaneously 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 results in the proportion of salts remaining in the oceans, but the amount of salts in a

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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 kg of water and its average is 35 kg. This means that in every 1 000 kg of water there will be 35 kg 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. It 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.

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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 flow 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 are 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. In general, polar waters sink and move towards the equator, while equatorial waters move as surface currents towards the poles. If a body of cold water meets a body of warm water, the cold water sinks below the warm water.

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 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 km because its salinity is much lower than that of the Atlantic.

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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 polarward 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 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.

Exercise 4.8

1. Differentiate between cold ocean currents and warm ocean currents.
2. Explain the importance of ocean movements to life in the ocean.
3. Explain how chemical composition of the ocean water affects the movement of water in ocean and sea.
4. Describe various features of the ocean floor.

Water use

Water use describe the total amount of water withdrawn from its source to be used. Water can be used for direct and indirect purposes. Direct purpose of water use includes bathing, drinking, and cooking, while the indirect purposes of use includes use of water in processing wood to make paper and in producing steel for automobiles. The bulk of the world water use is for agriculture, industry and electricity.

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Water use management

Water use management refers to the whole process of optimum use, planning, developing, and distributing water resources, which is essential for all forms of life. Water management is the control of movement of water resources to minimize damage to life and property as to maximize its beneficial use. Water is one of the most important resources not only to human beings but also to plants and animals. Only 3% of the water available in the world is fresh, of which only 1% is freely available to human beings. There are several sources of water namely, rainfall, wells, springs, rivers, lakes, seas and oceans.

Water harvesting practices

Water harvesting is the means of capturing or trapping rain as it falls or as runoff and properly manage by avoiding activities that may distort water quality and quantity. Water can be harvested to supplement the ever-increasing water shortages in some areas and therefore, relieve community's unmet need of water for drinking and irrigation by increasing groundwater, reducing storm-water discharge, and reducing water along the coastal areas which could have caused side effects to flora and fauna. Broadly speaking there are four techniques of harvesting water, namely; capturing rainwater from rooftops, capturing runoff from local catchments, capturing seasonal flood waters from local streams and conserving water through watershed management.

Rainwater harvesting methods

Rainwater harvesting is the collection and storage of rainwater for reuse on site rather than allowing it to spread on the land surface. The stored water can be used for various purposes, such as gardening, domestic uses, and irrigation. There are two ways of harvesting rainwater. These include roof top rainwater harvesting, and surface runoff harvesting.

Roof-top rainwater harvesting: This is a system of tapping rainwater as it falls. Under this method, the roof becomes the catchment from which rain water is collected. Such water can either be stored in a tank or diverted to artificial recharge system. The method is less expensive and very effective. Moreover, if it is implemented properly, it can help to increase the groundwater level of the area.

Surface runoff harvesting: Through this method, rainwater in form of surface runoff can be trapped and used for recharging aquifer. This method can be most relevant in rural areas where there is acute water shortage due to inadequate water supply and poor distribution.

The importance of rainwater harvesting

Rainwater harvesting increases water availability for both domestic, industrial and agricultural use. Meanwhile, environmental degradation has increased surface runoff so that rain falling on surface flows away rapidly thus affecting the rate of groundwater recharge. It is

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clear that, water sources are insufficient to meet the demands of water supply in both urban and rural areas on one hand. On the other hand, the over exploitation of groundwater resources has led to a decrease in groundwater levels and quality. Therefore, to minimize the challanges it is important to tap rainwater by either storing it for direct use or by recharging it to groundwater aquifers.

Rainwater harvesting, if properly managed, has the following advantages: It can help meet the increasing demand for water in the urban and rural areas. It can reduce runoff and prevents flooding of roads. The polluted groundwater can supplement domestic water requirements during drought conditions. Rooftop rainwater harvesting is easy to construct, operate and maintain. It can reduce soil erosion in urban and rural areas.

Activity 4.4

1. Using local materials available in your surroundings, improvise a model of roof-top rainwater harvesting. Demonstrate the model to the class and respond to the questions asked by fellow students.
2. In a group of five students, visit three nearby water sources, with the help of the water users, then;
   (a) Identify their usage and management practices in the area.
   (b) Collect their responses and record your observations.
   (c) Present your findings in the class, and
   (d) submit the final report to the subject teacher for marking

Water conservation

Water conservation refers to the act of protecting water from destructive influences. It is the task of not only protecting but also maintaining water as a precious resource. Water must be conserved and protected from all sources of pollution and degradation that may compromise its quality and quantity for unlimited uses.

Water pollution

Water pollution is the release of chemical, physical or biological substances into bodies of water that makes water unsafe for diverse use. Water pollution occur when the composition of water is altered to make it less suitable for purposes it would otherwise be suitable in its natural state. There are several types of water pollution such as groundwater pollution, chemical pollution, nutrients pollution, oxygen depletion pollution, microbiological pollution, suspended matter pollution, and surface water pollution. Hence, polluted water contains numerous impurities that are not only poisonous to the aquatic organisms but also unsafe for human use. The sources of water pollution include domestic, industrial and effluent wastes, as well as massive construction.

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Types of water pollution

Water Pollution can be classified using several criteria in this case water pollution is classified based on types of water pollutants and the source of water pollutants.

Types of water pollution based on type of water pollutants

In this criteria water pollutants can be classified into three categories namely chemical, radioactive and biological. *Chemical pollutants:* This is the contamination of water with various chemical pollutants. The most common water pollutants include crude oil and various petroleum products with a range of chemicals such as gasoline, diesel, and motor lubricants. These compounds are lighter than water, due to this they will remain on the top of water. However, some of these, even in trace amount may be harmful and unfortunately, may remain un unnoticed into water. Another is fertilizers (example, nitrate and phosphate) which are beneficial to algae, micro-organisms and plant growth. However, their higher amounts in water are harmful to human and aquatic life.

Also, chlorinated solvents which include carbon tetra chloride and freons is another chemical pollutant of water. Since these chemicals are denser than water have a tendency of sinking into water and are persistent and toxic in nature. Another water pollutants are petroleum solvents (include benzene, toluene, xylenes). These are harmful chemicals to human being and the environment when discharged and find their way into water bodies. Moreover, antibiotics and other pharmaceutical products once accumulate into water they contaminate it to an extent of making water no longer useful not only to human being but also to micro-organism and other life forms. Other forms of chemical pollutants include metal and their compounds. Organo-metal compounds forms following the reaction between metals and organic compounds that exist into water. The resultant pollutants into water bodies are harmful to human and aquatic life.

Radioactive pollutants: This pollutant is also known as radioactive contamination. It is another source of water pollution whereby the improper dispose of these pollutants seriously harm life and the environment. *Biological pollutants:* This includes various types of micro-organisms such as bacterial, worms and viruses of which their presence in large quantities in water bodies account for water pollution, hence unsuitable for human consumption.

Types of water pollution based on sources of water pollutants

The classification of water pollutants based on sources of pollution results from an accidental disposal of chemical substances from various sources. These sources can include pharmaceutical, industrial, construction sites, household, agro-chemicals disposal and accidental oil spills. These contaminants pollute

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water in different ways and degrees as describe below.

Domestic wastes: Despite increasing demand of water for domestic uses still different sources of water are polluted by various human activities. As a result, rivers become loaded by domestic wastes such as sewage, washing water, dead bodies, food wastes, plastic containers, old tyres, old metals and glass bottles. These wastes are of concern and dangerous to life as most of them cannot easily decompose. Moreover, wastes like mercury and lead are carcinogenic. Untreated wastes of this nature are hazardous to human beings and other life forms, and some of them act as sources of water borne diseases such as dysentery, cholera and typhoid. Sometimes chemicals from pesticides and fertilizers are drained to sources of water.

Industrial Wastes: Industrial wastes may include petroleum, detergents, heavy metals, and radioactive materials which often find their way into rivers and other sources of water. Rivers in turn pour their water into oceans, seas and lakes thereby adding or intensifying pollution of those large water bodies. Based on this chain, oceans are being overloaded with unbearable wastes. Some of the wastes received by the oceans particularly, mercury and lead can accidentally be taken by aquatic organisms such as fish. These chemical often accumulate in their bodies without causing them harm. However, human consumption of those contaminated food stuff can increase the chances of getting diseases such as cancer.

Massive construction: The increasing constructions near water catchments and sources, such as construction of bridges; encroachments of settlements and establishment of industries near water bodies significantly contribute to pollution of those water bodies. The pollutants include remaining metals, cement, pieces of wood, paint, and pieces of ceiling boards. Upstream development such as road construction and agricultural activities often increase soil erosion, resulting in increased sedimentation. This leads to flooding in mid-stream areas and reduction of water flows downstream. Overuse of limited water resources is influenced by humans interference the natural water cycle.

Overexploitation of water resources: The increased demand and uses of water vary from one place to another depending on the level of social, economic and technological advancement which often lead to a mismatch between availability and supply of water. The major consumers of water are rich industrialized countries while the minor consumers are the least developed countries. The amount of water that Africa uses for agricultural purposes is equivalent to about 0.1% of the water that industrialized countries use for the same purpose. This amount is also equivalent to 3% of the amount of water that is used in North America.

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Misuse of water: Overuse of water in one area deprive uses in other areas. This is likely to compromise agricultural production and its effects can be extended to food security, loss of income, and loss of sources of wages. Misuse of water occurs where clean water is taken or used and returned to the water system in an unusable state. Sometimes, the water is not returned to the system at all due to unsupportive infrastructure.

Agricultural chemicals: The agricultural chemicals used in irrigated farming often contaminate surface water and groundwater. Potassium and nitrogen from fertilizer applications on both rain fed and irrigated land, may be washed into groundwater or surface water where they can lead to algal blooms and eutrophication of surface water. Irrigation can also concentrate naturally occurring salt minerals through application of fertilizer which in turn flows back to groundwater or surface streams and rivers. Irrigation in arid regions can also lead to leaching of naturally-occurring toxic elements, such as selenium from soils into surface and groundwater. Over-irrigation can lead to water logging, which reduces yields substantially. Industry and urban centres also return contaminated water to both surface and groundwater resources.

Revision exercise 4

Answer the following questions;

1. Write short notes on the following;
   (a) Groundwater,
   (b) Inland drainage,
   (c) Wetlands and swamps, and
   (d) Oceans and seas.
2. Describe the role of rock porosity in the movement and occurance of groundwater.
3. The hydrological cycle has neither a beginning nor an end. Explain.
4. What are the advantages and disadvantages of water logged areas?
5. Assess the impact of water pollution to socio-economic development of the communities in East Africa.
6. Climate is the single and most important factor affecting the volume of water in the river. Discuss.

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7. What is the importance of a river to human life?
8. Describe types of drainage system based on geological structure.
9. Sketch a world map and show the ten biggest rivers of the world.
10. Using a long profile of a river, show how the river changes its course.
11. What is the geomorphic importance of East Africa lake basins?
12. Describe the role of watersheds and water tables in a river basin.
13. Explain factors affecting sea and ocean salinity.
14. Discus the chemical composition of ten big lakes in the world. Suggest dominant economic activities that can take place in each of the lakes.
15. Explain the formation of Lake Tanganyika and its role to the people of East and Central Africa.
16. Describe classification of lakes according to their modes of formation.
17. Describe classification of wetlands based on their location and soil types.
18. What features distinguish rivers from other forms of water masses?
19. Describe measures used to control water pollution.
20. Discuss the driving forces for water harvesting.
21. Examine problems experienced in water harvesting and suggest ways of overcoming the problems.
22. Show how the interaction between the ocean and the atmosphere plays a fundamental role in controling the ocean water circulation.

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Chapter Five

Soils

Introduction

Soils are living systems that provide the most fundamental functions needed for life. In this chapter, you will learn about concept of soils, components of soil, soil properties, soil profile, soil formation, soil classification, soil fertility, and soil conservation and management practices. The competencies developed from this chapter will enable you to use soil resources for various economic activities like agriculture, building and construction, and tourism. Also, you will be able to participate in soil conservation and management practices for self and national development.

Concept of soil

Soil is defined as the naturally occurring, unconsolidated upper layer of the Earth made of the mixture of minerals, organic matter, gases, liquids and organisms that together support life on earth. It consists of unconsolidated materials of the soil which form a thin surface layer of the earth above bedrock refered to as regolith. Soil is an outcome of interrelationships and interactions between physical, chemical and biological processes with varying natural environment. Soil is a natural body known as *pedosphere* which performs different functions, such as acting as a medium for plant growth and a means of water storage, supply and purification. The scientific study of all aspects of soil such as origin, formation, characteristics and ultilization is called *pedology*. Soil is one of the important natural resources that supports life and ecosystem of an area. Soil provides nutrients, water, oxygen and heat to natural land area. It is important to understand the ability and capacity of soil for proper management of land.

Components of soil

Soil consists of four major components, which are mineral or inorganic matter, organic matter, water, and air. These components exist mostly in a fine state of subdivision and are intimately mixed to the extent that a complete

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separation is difficult. Soil contains about 50% pore space (air 25% and water 25%), 45% mineral matter, and 5% organic matter (Figure 5.1). The proportion of air and water in the soil is subject to great fluctuations due to natural conditions such as soil texture and structure, rate of evaporation and precipitation of an area. It is the proportion of air and water in the soil that determine the soil suitability for plant growth.

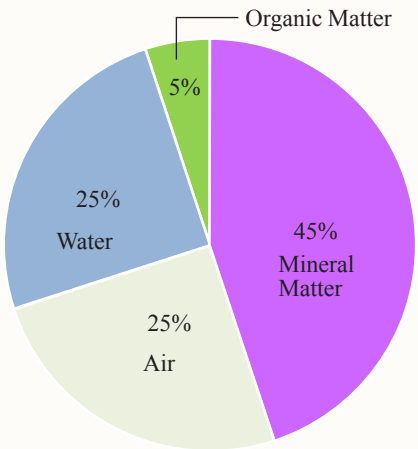


Figure 5.1: *Soil components*

Mineral matter

The largest component of soil is the mineral matter, also known as inorganic matter, which makes up approximately 45% of the total volume of soil. Soil minerals are derived from two principal mineral types: primary minerals and secondary minerals. Primary minerals are those which have not been chemically altered since their crystallization from molten lava, commonly found in sand and silt. They are similar to the parent rock materials from which they are formed. They are often round or irregular in shape. Secondary minerals result from the weathering of the primary minerals, which release important ions and forms more stable minerals, such as silicate clay. Clays have a large surface area, which is important for soil chemistry and water holding capacity. Additionally, positive and negative charges found around soil minerals influence the suitability to retain important nutrients. Mineral matter of the soil is significant in adding fertility to the soil, which determines the types of crops suitable to be grown in the given soil. Additionally, mineral matter helps to determine the types of parent rock. In general, inorganic matter determines soil properties, rate of soil formation and textural categories of soils.

Organic matter

Soil organic matter entails the dead decomposed plant and animal remains or humas as well as living soil microorganisms such as bacteria, fungi and earthworms. Organic matter constitutes 5% of the total volume of soil. The decomposed organic matter is renewed in the soil through addition of dead plants and animal remains and the waste products from living organisms to form humus. There are two sources of humus in the soil: primary source is from plant remains and secondary source is from animal remains. Some of the humus from those sources are more resistant to further decomposition and are called stable soil organic matter,

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and actually it is what is called humus. Those which are rapidly decomposed and get completely lost are called labile organic matter. Soil organisms such as earth worms, insects, fungi and microscopic bacteria play the role of breaking down dead plants and animals, mixing them with the mineral soils near the surface. As a result, the upper most horizon of the soil is generally rich in organic matter. This horizon is darker than the lower mineral horizons. The amount of organic matter in the soil represents a balance between the addition of plant residues and the destructive decomposition by soil micro-organisms. Generally, the organic matter content in the top soil is about 3-5% by weight and influences most of the physical and chemical properties. Despite its small content, organic matter has great influence on both physical and chemical properties of soil. Amount of organic matter varies with space due to differences in drainage, relief, vegetation and climate.

Soil water

Water is one of the basic components of soil which mainly comes from the atmosphere through precipitation and underground water. Water makes up to 25% of the total volume of soil. Water is important for transporting nutrients to growing plants, soil organisms and for facilitating both biological and chemical decomposition. Amount of soil water (soil moisture) normally varies from soil to soil due to the number of factors including soil structure, texture, nature of underlaying rocks, relief and climate. Soil water availability (available water capacity) is the capacity of a particular soil to hold water for plant use. The amount of soil moisture that is held after excess water has drained away and after the rate of downward movement has decreased (usually 2-3 days after rain or irrigation) in pervious soil of uniform texture and structure is known as *field capacity*. This exists in soil as hygroscopic water which is the type of soil water mostly present in the soil, unless the soil becomes completely dry. Water that is attracted to and forms film around the hygroscopic water with lower cohesive strength is known as *capillary water*. Another type of soil water is gravitational water which is found only when the soil is wet but unavailable as excess water drains away. The smaller the particles in soil, the higher the water holding capacity. The capacity of soil to hold water is largely dependent on soil texture. Thus, clay soil which has very small particles has higher water holding capacity compared to sand which has large sized particles. The point where water is held microscopically with too much energy for a plant to extract is called the *wilting coefficient* or *permanent wilting* point. When water is bound so tightly to soil particles, it becomes difficult for most of the plants to access it. This limits the amount of water available for plant use. If the soil water content decreases to the permanent wilting point or any lower point, most plants can no longer retrieve soil water for transpiration, thus

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wilt. Moderate or medium pore spaces allow the flow of required moisture (water) in the soil, which in a long run support living organisms present in the soil to effectively perform bioactivities and ensure supply of humus and plant growth.

Soil air

Gas or air is the basic component of the soil. Air occupies the same proportion of pore spaces as that of water (25%) in the total volume of the soil. Air fills the pore spaces left unoccupied by soil moisture. Compared to the atmospheric air, the air in the soil contains more carbon dioxide released by plant and soil biota, and more water vapour but less oxygen. Despite its trace proportional in the soil, still Oxygen is essential for root and microbe respiration which helps to support plant growth. Carbon dioxide and nitrogen are also important for underground plant functions, such as nitrogen fixing bacteria. If soils remain waterlogged a situation by which gas is displaced by excess water, it can prevent root gas exchange and may often lead to death of plants. This is a common concern in floods and water-logged areas. Amount of soil air is mainly determined by climate of the area, season, relief, soil structure and texture.

Soil properties

Soil properties include physical and chemical characteristics of the soil. Physical properties include texture, structure, profile, colour, temperature, porosity and density. Chemical properties include soil pH, anion and cation exchange.

Physical properties of the soil

These are properties related to physical characteristic and processes in the soil namely; soil texture, soil structure, soil colour, soil temperature, soil porosity and soil density.

Soil texture

Soil texture refers to the degree of coarseness or fineness of soil particles. These soil particles range from coarse, medium to fine that form sand, silt and clay soil respectively. The classes are distinguished in the field by textural feel which can be further clarified by separating the relative proportions of sand, silt and clay by using grading sieves, based on the particle size distribution. The classes can be used to determine crop suitability and approximate the soil's responses to various environmental and management conditions, such as drought and calcium (lime) requirements. In soil science, individual particles of soil are given names according to their specific diameters. Table 5.1 presents soil texture classification as per the United States Department of Agriculture-USDA against the World Reference Base for soil Resources-WRB (Formed by International Union of Soil Science - IUSS).

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Table 5.1: *Soil classification by texture (USDA versus WRB)*

Name of Soil	USDA Diameter Limits (mm)	WRB Diameter Limits (mm)
Clay	Less than 0.002	Less than 0.002
Silt	0.002 - 0.05	0.002 - 0.063
Very fine sand	0.05 - 0.10	0.063 - 0.125
Fine sand	0.10 - 0.25	0.125 - 0.20
Medium sand	0.25 - 0.50	0.20 - 0.63
Coarse sand	0.50 - 1.00	0.63 - 1.25
Very coarse	1.00 - 2.00	1.25 - 2.00

Soil texture analysis

Soil texture is determined by the proportions of sand, silt and clay particles. In the field, it is possible to decide whether a soil sample is mainly sand, silt, or clay by feeling it. Sand soil feels gritty and lacks cohesion, silt is smoother, soap like feel and is having a considerable cohesion. Clay is sticky, plastic and is high cohesive in nature. The more precise method for determining the proportion of particles in a given soil is through laboratory measurements such as sieving and sedimentation methods. Sieving method involves the use of sieve that consist different meshes that allows some of the texture to pass and filter some of it (Figure 5.2). Clay textures accumulate at the bottom, while stones remain at the top. Course, sand and silt are filtered separately between top and bottom to their size of the texture while stones (gravels) are filtered at the top.

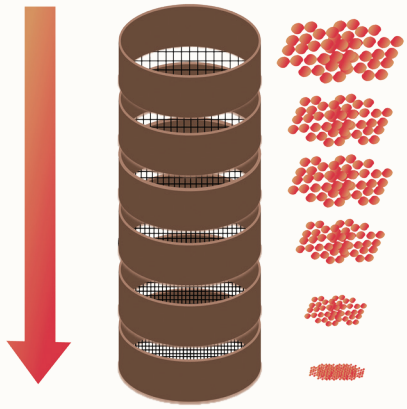


Figure 5.2: *Sieving method*

Sedimentation is generally a process that allows particles in suspension in water to settle out of the suspension under the effect of gravity. The method may involve placing the soil sample into a beaker of water, then, the beaker is shaken thoroughly and left to settle. The course texture settles at the bottom quickly and clay suspends at the top as seen in Figure 5. 3.

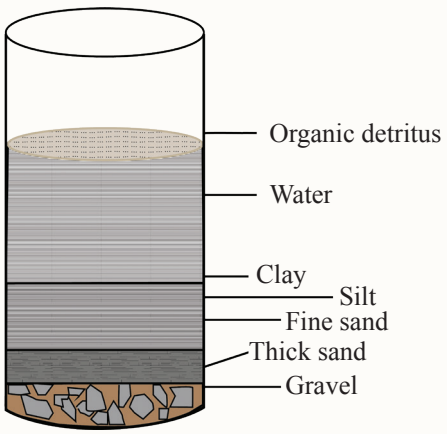


Figure 5.3: *Sedimentation method*

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The results obtained are either plotted as a pie chart or as a triangular graph. Since the proportion of sand, silt and clay vary considerably, it is traditional to have 12 texture categories as shown in the soil texture triangle (Figure 5.4). The soil texture triangle is used to convert particle size distribution into recognized texture class based on the relative amounts or proportions of sand, silts and clay in various types of soil as a percentage.

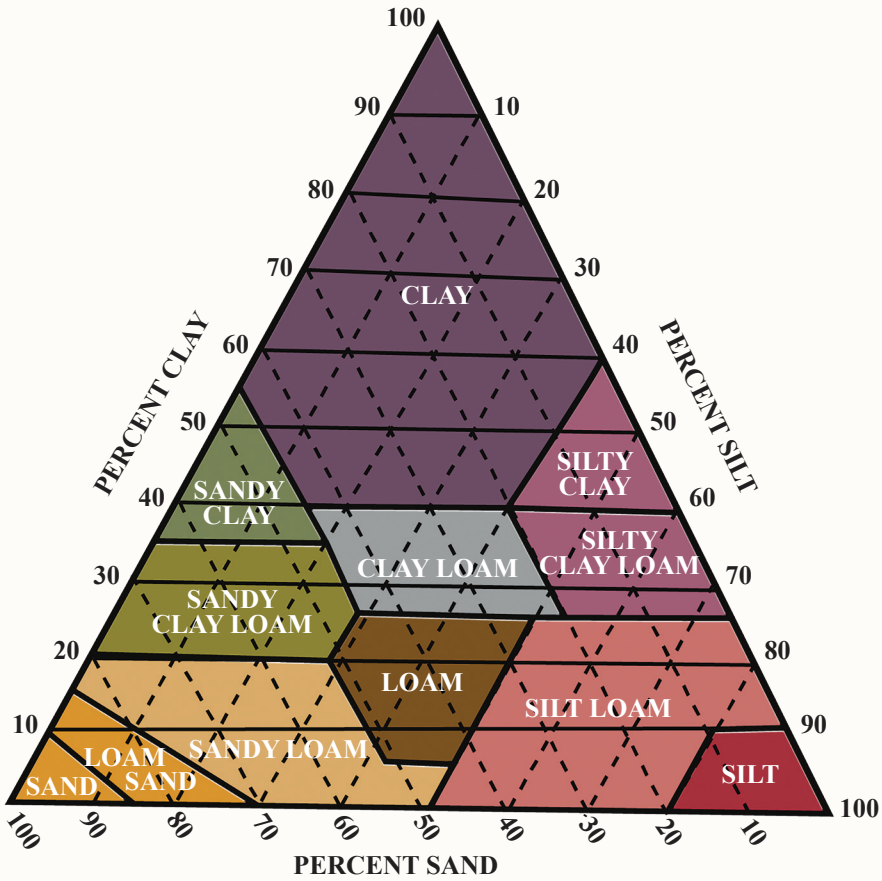


Figure 5.4: *Soil texture triangle*

Textural classification of soil

Sandy soils

These are coarse grained soil particles with a gritty feel and lack of cohesion. Sandy soils are light soils consisting mainly of sand particles with diameters between 0.05mm and 2mm. Sandy soils contain about 70% or more of sand, it allows water to drain rapidly and retains little proportion of moisture. Moreover, it is well aerated and suitable for the growth of ground nut, peas and horticulture. However, it is more vulnerable to leaching, drought and erosion.

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Silt soil

Silt is a granular material with small size between sand and clay, whose mineral origin is quartz and feldspar. Silt may occur as soil or as sediment mixed in suspension with water in a body of water such as river. It may also exist as soil deposited at the bottom of a water body. Silt is typically non-sticky. Silt particles range from 0.002mm to 0.05mm in diameter. It is associated with cementation which subjects them to sheet erosion during heavy rains.

Clay soil

This is a fine-grained soil with sticky feel. It is elastic when wet being very cohesive and may be rolled into various shapes. Clay soil consists of fine particles of less than 0.002 mm. It holds little air but much water, and becomes impermeable after absorbing water. It is rich in plants nutrients and it is often fertile. As its name suggests, clay soil contains more than 35% clay. The soil supports perennial crops and is suitable for growing paddy and other cereal crops. These soils are characterized by tillage difficulties due to their sticking tendency in wet seasons and hardness in dry seasons.

Loam soil

Loam soil is composed of sand (40%), silt (40%) and clay (20%). The soil prevents water logging capacity but it allows moisture holding capacity and retaining of nutrients. Top quality soil has a loose and open structure that makes it fast draining but also retains enough water so that plants are not vulnerable to drought stress. Loam soils are easier to till than clay soils. It is potential soil for agriculture as it is composed of enough proportion of clay component to hold and retain nutrients; sufficient sand to prevent water logging and to improve drainage; as well as enough silt to bind sand and clay together.

The importance of soil texture

Soil texture influences plants growth in varying ways. It influences soil permeability, structure and retention capacity. Texture controls the availability and retentions of nutrients for plant growth within the soil. For example, clay soils tend to hold more water and are less well drained and aerated than sandy soils. Nutrients are absorbed into clay particles thus, become less leached by infiltration than in sandy soil. Also, it influences plant growth and roots penetration. For example, plant roots can penetrate coarse soils more easily than finer soils and lighter sandy soils are easier to plough for arable farming than heavier clay. Moreover, soil texture influences soil resistance against erosion. For example, light soils are more prone to soil erosion than heavy soils. Also, it determines the type of crop to be grown, since different types of crops have different water requirements for their growth.

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Exercise 5.1

1. Explain the importance of soil texture to plant life.
2. Compare clay, silt, and sandy soils in terms of their characteristics.
3. Why some of the soils are most suitable for growing plants compared to others?
4. Which soil type would be most suitable for building a pond or reservoir? Explain why?
5. Why sandy soils are considered less fertile than loamy soils?
6. Explain the sources and agronomical significance of soil organic matter.
7. With the aid of a diagram, describe the soil texture triangle.
8. Describe the two methods of determining soil texture.

Activity 5.1

In a group of five students, walk around the school premises or neighbourhood, then do the following;

(a) Dig different pit holes at different points and fill them with water,

(b) Leave those holes with water for several hours, for water to infiltrate. Based on your observation, identify the type of those soils basing on the rate of infiltration, and

(c) If water does not infiltrate, then leave it for a day. Investigate the type of soil.

(d) Discuss the findings with your fellow students and write a summary in your exercise book.

(e) Present the findings before the class and address all the emerging questions.

Soil structure

Soil structure refers to the arrangement of individual soil particles into larger particles called aggregates. Aggregate is a group of soil particles held together by electrostatic forces. These aggregates form different shapes known as ***peds***. Soil structure is easily determined by taking a sample of soil that has not been disturbed and observe it closely to determine its shape. A number of factors influence the stability of soil structure. The primary factor is soil organic matter whose breakdown products create a cementing effect holding mineral particles together. Other factors include soil colloids, tillage, and freezing and thawing cycles. Soil structure can be categorized as single grained structure and massive structure. Single grained structure is when the soil is broken into individual particles that do not stick together. It always accompanied by a loose consistence, commonly found in

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sandy soils. Massive structure is the type of structure, where individual particles of soils are cemented to one another into different shapes of different sizes, such as prismatic, platy, blocky, crumb, columnar and granular shape.

Crumb structure

In this structure, the aggregates are almost round with axis of the same size (1-5mm). The particles are similar to breadcrumbs and are porous in nature (Figure 5.5). This type of soil is found in the A horizon and in loam soil. The soils in this structure are very productive, well aerated, drained, and have good roots penetration, hence influence considerable plant growth.

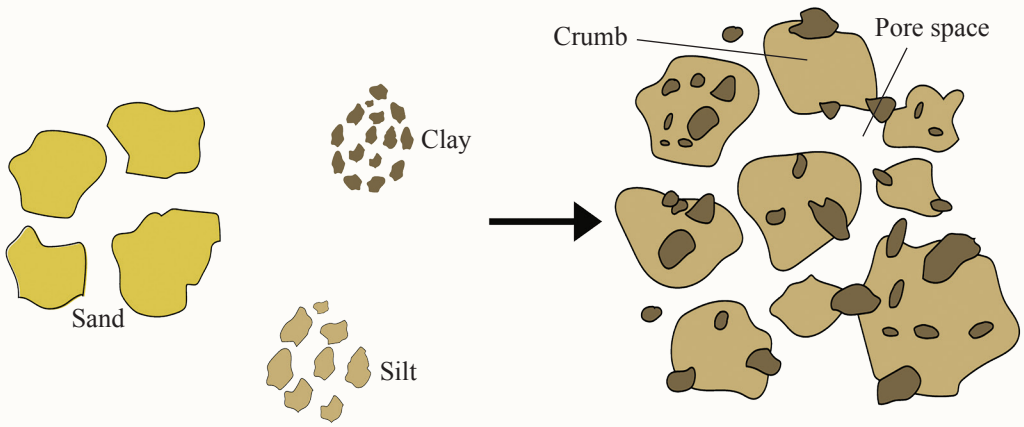


Figure 5.5*: Crumby soil structure*

Granular structure

This structure contains small individual particles which are usually non porous. Its size ranges from 1 to 5 mm. It is found in A-horizon, and compacted in clay soil. Soil mineral particles are both separated and bridged by organic matter, broken down products and soil biota which exudates organic compounds making the soil easy for cultivation. This soil is fairly productive and has a problem of drainage and aeration. This structure allows for good porosity and easy movement of air and water (Figure 5.6).

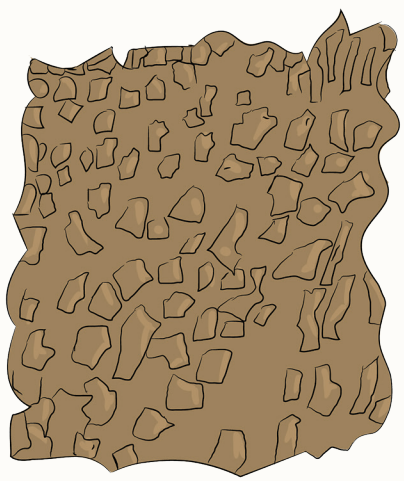


Figure 5.6*: Granular soil structure*

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Platy structure

In a plate-like structure, individual particles of soils are arranged on top of one another horizontally like plates and bound in compacted soil (Figure 5.7). Its size is between 1mm and 10mm and it is found in B-horizon. It is usually found in compacted soil of clay and silt and they are stretched more horizontally than vertically. Moreover, it allows moderate water penetration, aeration and drainage. It is less productive and restricts roots penetration.

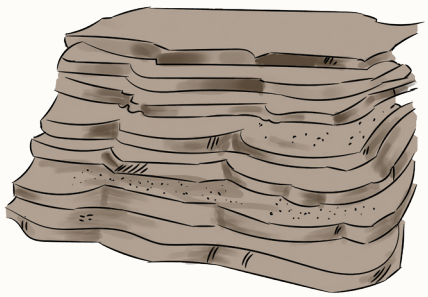


Figure 5.7: *Plate-like soil structure*

Blocky structure

This is a soil structure which has a shape like angular blocks and having more or less edge. Its particles are irregular in shape, with horizontal and vertical axes of about equal length. The particles may be rounded or angular but closely fitting (Figure 5.8). They are commonly found in B-horizon where clay-loam soils have accumulated. The soil is productive, well drained and aerated. Its size is between 10 mm and 75mm its formation is associated with wetting, drying and thawing processes.

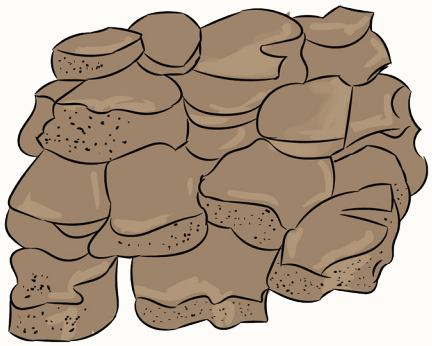


Figure 5.8: *Blocky soil structure*

Prismatic structure

It is a massive type of soil structure containing particles arranged in vertical columns of soil. Its sizes range from 20 mm to 100 mm long. It is very common in the lower part of subsoil B or in the transitional horizon C often in areas with limestone and clay soils. Its vertical axis is larger than horizontal axis (Figure 5.9). Usually it is quite productive, formed by wetting and drying it has adequate water movement and root development.

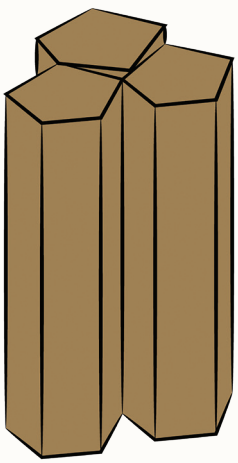


Figure 5.9: *Prismatic soil structure*

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Columnar structure

This is a soil structure in which the soil particles are arranged with vertical axis much larger than horizontal rounded caps and sides of column (Figure 5.10). Its size is between 20mm and 100mm. It is commonly found in horizon B and C, form in alkaline and desert soils, associated with accumulation of sodium. It is very dense and difficult for plant root to penetrate. It is quite productive if water is available

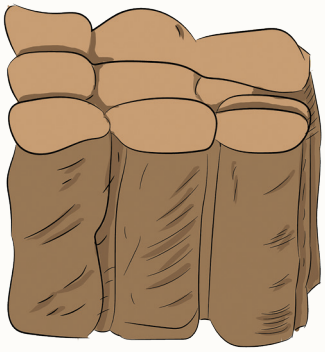


Figure 5.10*: Columnar soil structure*

The importance of soil structure

Soil structure influences almost all plants growth factors, such as water supply, aeration, availability of nutrients, microbial activities, seed germination, and root penetration. Moreover, it modifies the influence of texture with regard to moisture and air relationship. For example, a platy structure normally hinders free drainage and root penetration because it has very fine particles (Table 5.2). A crumb structure is well aerated, drained and good for plant growth. It is an indicator of soil fertility. It is also, suitable for various activities including settlement and construction. Good soil structure facilitates the activities of microorganisms, and determines temperature and moisture of the soil.

Table 5.2: *Classes of soil structure*

Size classes	Shape of structure		
	Granular and Platy (mm)	Prismatic and Columnar (mm)	Blocky (mm)
Very fine	<1	<10	<5
Fine	1-2	10-20	5-10
Medium	2-5	20-50	10-20
Coarse	5-10	50-100	20-50
Very coarse	≥10	100-500	≥50
Extremely coarse		≥500	

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Exercise 5.2

1. With the aid of diagrams, describe the soil structure.
2. Explain the significance of soil structure to plant growth.
3. Explain how soil texture relates to soil structure.
4. With examples, explain factors affecting soil structure.

Soil colour

Soil colour gives an indication of unique characteristics and various processes going on in the soil. Also, it can suggest soil fertility and the type of existing minerals in the soils. For example, the red colour in the soil is suggests the abundance of iron oxide under oxidized conditions (well-drainage) in the soil. Dark colour is generally associated with the accumulation of highly decayed organic matter, yellow colour is suggests the hydrated iron oxides and hydroxide, and black modules suggests the presence of manganese oxides. Mottling and glorying are associated with poor drainage and/or high-water table. Abundant pale-yellow mottles coupled with very low pH indicate possible acid sulphate soils. Colours of the soil matrix and mottles are indicative of water and drainage conditions in the soil, hence suitability of the soil for agriculture. Low oxygen soils usually appear grey or greenish due to the presence of reduced ferrous iron oxide. The presence of other minerals can also influence soil colour, for example, manganese oxide makes the soil black coloured; gluconate makes the soil green; and calcite can make soil in arid regions appear white. Though, soil colour does not have direct impact to farming, yet dark coloured soil is believed to be rich in organic matter, hence fertile.

Soil colour is described by the parameters called hue, value and chroma. Hue represents the dominant wave length or colour of the light (these are red, yellow, and blue). Value refers to the lightness or darkness of the colour. Chroma deals with relative purity (paleness) or strength of the colour. The colour of the soil in terms of the above parameters could be quickly determined by comparison of the sample with a standard set of colour chips mounted in a note-book called Munsell Soil Colour Charts (MSCC) (Figure 5.11). In these charts, the right-hand top corner represents the hue, the vertical axis represents the value, and the horizontal axis represent the chroma.

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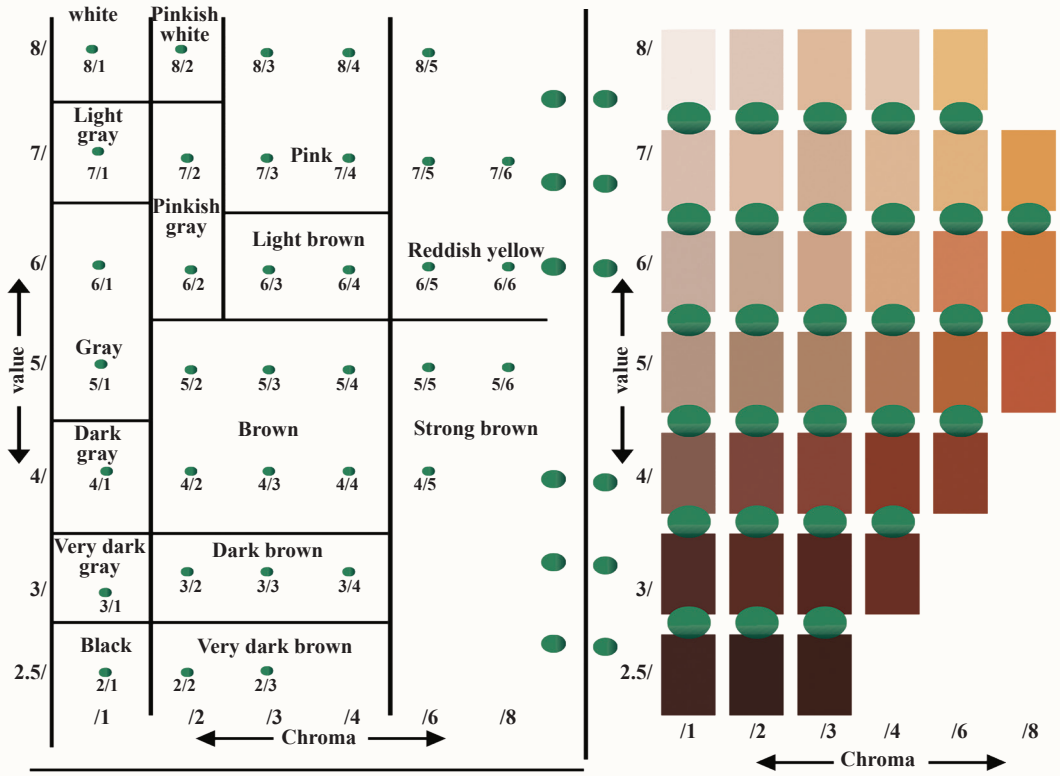


Figure 5.11: *Munsell soil colour charts*

Importance of soil colour

The soil colour can give information on its uses. For example, the darker the soil, the higher the relative productivity often contributed by its richness in organic matter content. Generally, dark colour indicates the relative amount of organic matter present in the soil. In contrast, light colour is an indication of non-fertile soils. In young soils, the light colour is an indicator of parent rock materials while in mature soils it is an indication of climate in which the soil had developed. Warm climates generally results to the formation of red coloured soil. Light colour results from leaching of iron minerals. Mottling or patches (spotty colours) is the result of intermittent reduction and oxidation reaction, thus solution and removal of some soil components. Mottled colours indicate temporary excess of water and lack of aeration.

Exercise 5.3

1. Soils vary in colour based on their mineral content and environment. Explain.
2. What are the main factors that influence the soil colour.
3. Soil organic matter are not the only colouring pigments in the soil. Discuss.

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Soil temperature

Soil temperature is the warmth or coldness of the soil as a result of incoming solar radiation being absorbed, diffused, reflected or scattered by the earth's surface. There are several factors which affect soil temperature such as climate, slope of the land and vegetation. Soil temperature vary from one place to another due to variation in the climatic condition. In polar latitude for example, the soil is cold because of the small amount of insolation received. In tropical areas soils are warm due to high intensity of insolation reaching the surface. A warm moist soil will have greater biota activity, giving a more rapid break down of organic matter on one hand, and on the other favour the chemical weathering of the parent rock materials. The warm moist soil will not only contribute to the availability of soil nutrients but also will boost rapid seeds germination as compared to cold and dry soil. The ideal soil temperature that support the growth of most of the plants is between 18 ºC and 24 ºC (65 ºF-75 ºF). Soil temperature depends on soil texture. Sandy soils warm up quicker than clay or fine-grained soils. Fine-grained soils carry a large amount of water; therefore, warm slowly. Soil moisture is the most vital controlling factor in soil temperature. Soil structure affects soil temperature by controlling the pore spaces. Soils with well drained structures (granular or crumb) warm up rapidly because of limited water-logging. Besides this, it should be noted that the soil is composed partly of mineral matter and partly organic matter. The specific heat of mineral substances is less than that of organic materials. Specific heat of iron is 0.11, whereas of humus is 0.44. Hence, mineral soils get heated more readily than organic soils. Also, soil temperature depends on soil colour. Dark-coloured soils usually warm up more easily than light-coloured soils. This is because they possess a greater capacity for absorbing the sun's heat.

Also, soil temperature depends on soil moisture; temperature of water is higher than temperature of soil. Moist soils get heated more slowly and have higher specific heat capacity than dry soils. Consequently, they have lower temperature than dry soil. The evaporation of water rather helps to lower the temperature of a moist soil. Other factors that determine soil temperature include slope of the land (topography) and vegetation cover. Soil temperature decreases with increase in elevation. In terms of aspect, north-facing slopes may differ from adjoining south-facing slope because they receive different amount of incoming solar radiation. Soils that are covered with vegetation absorb less heat than those of bare soil. Vegetation acts as an interceptor and retards the warming of the soil surface. On the other hand, plant cover prevents the soil from getting cool as it retards the loss of heat. Hence, soils carrying a dense plant cover are cooler in summer and warmer in winter than unprotected soils. Bare soils cool off rapidly than those covered with vegetation. Temperature determines the

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rate of decomposition of organic matter and consequently soil fertility. Also it influences seed germination, chemical reactions and life of microorganisms.

Soil porosity

Soil porosity refers to the amount of pore spaces present in the soil. It is abbreviated as 'P' referring to the ratio of the volume of voids (Vv) to the total volume of soils (Vt). Pores or pore spaces form when plant roots, insects and earth worms move through the soil. A more porous soil allows much water and air circulations in large quantity than those with low porosity. The porosity of soil depends on several factors including, packing density, the breadth of the size distribution, cementing of the structure and the shape of particles. For example, clay and sandy soils have high porosity because they have angular grains of sandy which are loosely packed, while the clay soils have very small grain and numerous pore spaces (Figure 5.12). As porosity increases, water retention decreases and drainage increases, accordingly. The formula below illustrates how soil porosity is calculated.

$$\text{Porosity (P)} = \frac{\text{volume of voids (Vv)}}{\text{total volume of soil (Vt)}}$$

Soil porosity is usually expressed as a percentage or decimal fraction. It is a measure of soil capacity to hold water and air.

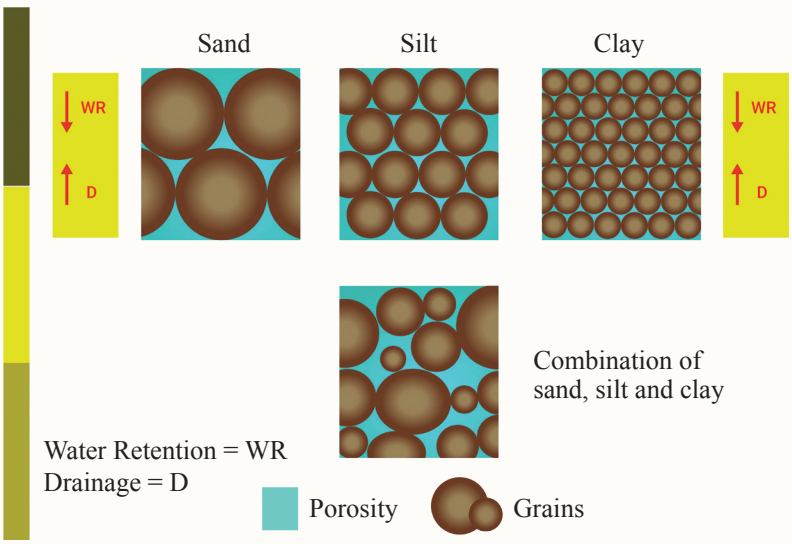


Figure 5.12: *Soil porosity of various soil grains*

Soil porosity determines the permeability of soil. Soil permeability is the measure of how easily water flows through soil. Soil permeability is defined as the property of a porous soil to transmit water or to allow seepage of water and air through its interconnecting voids. A soil having continuous voids is called permeable. Gravels are highly permeable while stiff clay is the least permeable, and hence

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such a clay may be termed impermeable in practical purposes. It depends on the size of the pore spaces and how well are connected to one another.

Exercises 5.4

1. Briefly explain factors affecting soil temperature.
2. Differentiate between soil porosity and soil permeability.
3. Why do plants need pore spaces?
4. Explain geographical significance of soil porosity.

Soil density

The relation between mass and volume of a dry soil is referred to as soil density. The volume is determined with the use of diameter and height value of the soil sample. Soil density is expressed in two accepted concepts which are particle density (absolute specific gravity) and bulk density (apparent specific gravity). Particle density or bulky density is commonly expressed in g/cm^3 or g/cc but it can also be expressed as g/m^3 or mg/cm^3. The particle density is the weight per unit volume of solid portion of soil (accompanied by water and air). Generally, the particle density of normal soils is 2.65-2.75 grams per cubic centimetre (2.65-2.75 g/cm^3). The particle density is higher if large amounts of heavy minerals such as magnetite, limonite, and haematite are present in the soil. But when soil is rich in organic matter, the particle density decreases. The particle density of organic soil range from 1.2-1.7 gm/cm^3. Also, the particle density is termed as true density. Table 5.3 shows the particle density of different soil textural class. Particle density is expressed by the following formula;

$$P.D = \frac{MS}{VS}$$

Where;

P.D = Particle density

MS = Mass of solid portion of soil

VS = Volume of solid portion of soil

Table 5.3: *Particle density of different soil textural classes*

Textural class	Particle density (g/cm^3)
Coarse sand	2.655
Fine sand	2.659
Silt	2.798
Clay	2.837

Bulky density is the weight per unit volume of dry soil, inclusive of pore spaces. The bulk density of mineral soil ranges from 1.0-1.8 g/cm^3 while the bulk density of organic soil is about 0.5 g/cm^3. The bulk density of the soil is always smaller than its particles density and normally decreases as the minerals become finer in texture. The bulk density decreases with increase in total space in the soil and it is a good estimate of the porosity of the soil (Table 5.4). Bulk density is of more importance than particle density in understanding

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the physical property of the soil. Bulky Density is expressed by the following formula;

$$B.D = \frac{MS}{Vt}$$

Where;

MS = Mass of dry soil (g or mg)

Vt = Total Volume of soil (cm^3 or m^3)

Table 5.4: *Bulk density of different Soil textural class*

Textural class	Bulk density (g/cm^3)	Pore space
Sand Soil	1.6	40
Loam	1.4	47
Silt Soil	1.3	50
Clay	1.1	58

Chemical properties of the soil

These are properties relating to the chemical processes taking place in the soil. The chemical reactions taking place between solid and liquid phase in soil control soil chemical properties. The chemical properties affect the relationship between soil and plants. They can make nutrients available for plants and soil organisms. The bulk of a chemical and mineralogical composition of the soil is derived from rocks resulting from various chemical processes. The important chemical processes in the soil include soil colloids, anion exchange, cation exchange capacity, and soil pH. Thus, soil chemical and mineralogical composition is related to that of the rock's origin.

Soil colloids

Soils possess charged tiny particles called colloids. A colloid is a substance which, when apparently dissolved, cannot pass through a membrane since it is smaller than 0.1 micrometer in diameter. A colloidal system consists of dispersed medium that is the phase forming particles and the dispersion medium that is the medium with which particles are distributed. The colloid particles in the soil are the determinants of chemical activities in the particular soil. There are two types of colloids, which are organic and inorganic or mineral colloids. *Organic colloids* are humus particles which make an appreciable portion of soil colloids. *Inorganic colloids* are clay minerals or separates of less than one micron or hydrous oxides of iron and aluminium. Colloidal particles, being very small in size, have large surface areas for chemical reaction and water retention. They possess charges which are either net positive or negative, and thus they have capacity to hold and exchange ions on their surface. Both organic and inorganic colloids are generated as a result of decomposition of organic and inorganic matter.

Ion exchange

Ion exchange is a reversible process through which ions interchange between solid and liquid phases. Ion exchange may take place between solid particles lying adjacent to liquid. Therefore, ion exchange is defined as a simple reversible process by which ions are

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exchanged between a solid and a liquid phase. When the cations (positively charged) are involved, the process is called cation exchange, but when the anion (negatively charged) are involved, the process is called anion exchange, though the latter is less common.

Cation exchange

This refers to the interchange between cations in solution and another cation on the surface of any negatively charged material such as clay colloid or organic colloid. Negatively charged soil colloids have the tendency of adsorbing positively charged ions released in the soil solution from weathering of the parent rock materials, the charge of each depends on the valency of individual element. The commonly exchanged cations in the soil include Mg^{2+}, K^{+}, NH_4^{+}, Ca^{2+}, Mn^{2+}, Fe^{2+}, Zn^{2+} and Cu^{2+}. Cations are absorbed by plant roots and move along the concentration gradient. The excess uptake of cations by plant roots releases hydrogen ions into the soil solution, in order to maintain electric neutrality between the roots and soil solution. The release of hydrogen ions into the soil solution increases acidic condition of the soil solution, which in turn promotes weathering of parent rock materials to replace the up taken cations by plants.

The energy of absorption of the specific cation is normally related to valence and degree of hydration. Therefore, monovalent cations with a large hydrated radius like sodium Na^{+} is weakly absorbed making it more freely available ion in the soil solution which accounts for its vulnerability to leaching. On the other hand, divalent cations with small hydrated radius like calcium Ca^{2+} in particular are strongly absorbed, and this defines their resistance to leaching and therefore forming a calcified soil in semi-arid climate. Generally, absorption sequence decreases rightwards thus, $Ca^{2+}>Mg^{2+}>K^{+}>Na^{+}$. Hence, the combination of colloids and attached cations is called the colloidal complex, and it is a delicate mechanism. If it holds the nutrients strongly, they will not be leached away, yet if the bond is too strong they cannot be absorbed by plants. Thus, a fertile soil is likely to be one in which the cation-colloid attraction is in a state of balance (Figure 5.13).

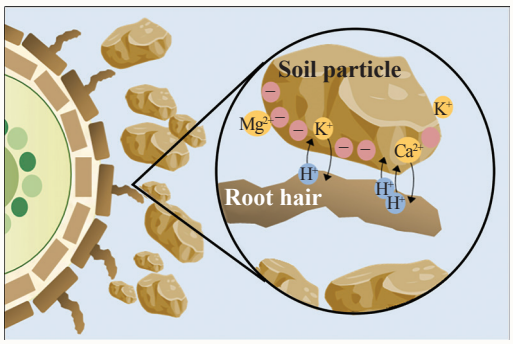


Figure 5. 13*: Cation exchange*

Advantages of cation exchange

Cation exchange helps plants to absorb both macro and micro nutrients from the soil for their growth and general life processes. It results into the formation of acidic environments in soil solution due to replacement of metallic cations Mg^{2+}, K^{+}, NH_4^{+}, Ca^{2+}, Mn^{2+}, Fe^{2+}, Zn^{2+}

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and Cu^{2+} by acidic cations particularly of hydrogen ions H^+ which tends to promote weathering of the parent rock materials. An acidic condition resulting from cation exchange on the other hand creates a suitable medium of growth for acid loving plants. Cation exchange depends on the number of factors such as amount of organic matter which provides organic colloids with large quantity of negative charges. Also, it depends on the types of clay minerals present in the soil. For instance, soils with large quantity of smectite clay have high cation exchange capacity than those with kaolinite clay minerals. In addition, it depends on the soil reaction pH, as capacity of absorbing cations increase with the increase of basicity and vice versa.

Cation exchange capacity

Since colloidal particles are charged, the negatively charged colloids are able to hold various positively charged ions known as cations, such as Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^+), Hydrogen (H^+), and Aluminium (Al^{3+}). The total amount of cations held in the soil are given by an expression known as cation exchange capacity. The cation exchange capacity (CEC) is a measure of the ability of a soil to retain cations for plant use. Soils with a low CEC, such as sands, are less capable of keeping essential plant nutrients than those with a high CEC, like clays and humus; consequently, they are less fertile. Also, soils with high organic matter have high cation exchange capacity.

Anion exchange

This is an exchange of anions between soil solution and soil colloids or between soil colloids and plant roots. During the exchange process, anions absorbed by a positively charged colloids and the hydroxyl groups from plant roots tend to replace each other causing anion to move along the concentration gradients to the roots, and the hydroxyl groups OH- migrate to the soil solution. The commonly involved anions include Cl^-, NO^-_3, SO_4^{2-}, PO_4^{2-}. The excessive uptaking of the anions release hydroxyl groups OH- that maintain electric neutrality. Like the cation exchange, the process enables plants to obtain nutrients. It creates alkaline medium in the soil solution due to the released basic anions. The release of hydroxyl groups into the soil solution creates the alkalinity condition which may favour some plants that grow in acidic condition and determines the type of fertilizers to be added. Anion exchange is the soil reaction dependant, amount of organic matter and type of clay minerals present in the soil. Anion exchange capacity is the sum of all negative charges of all absorbed anions i.e. Cl^-, NO^-_3 , $SO^2_4{}^-$ $PO^2_4{}^-$ each of them contributes a negative charge equivalent to its valence. Like in cation exchange absorption of anions depends on the valence and degree of hydration. PO_4^{2-},> SO_4^{2-}>Cl^- >NO^-_3 (Figure 5.14).

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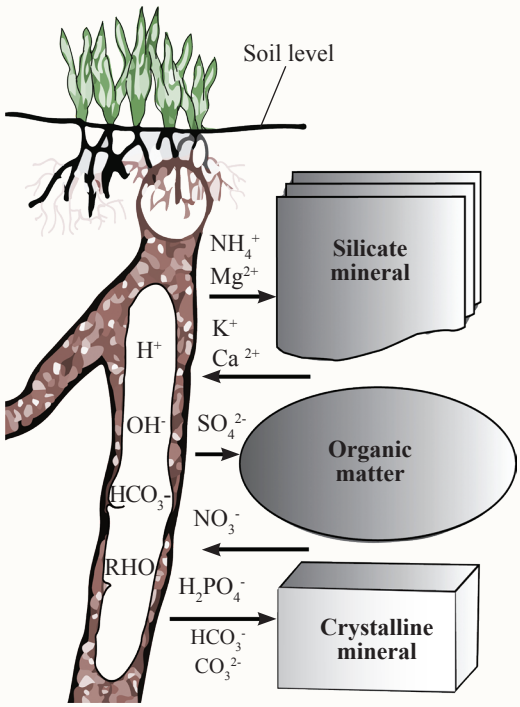


Figure 5.14: *Anion exchange in soil*

Soil pH

Soil pH is a chemical soil property which expresses the degree of acidity and alkalinity in the soil. Also, soil pH can be defined as the logarithm of the reciprocal or the negative logarithm of the hydrogen (H^+) ion activity or concentration in the soil.

It is a measure of acidity or alkalinity of the soil. It is a measure of hydrogen ion concentration in an aqueous solution and it is measured by a pH scale that ranges in values from 1 to 14 (acidic to basic). However, practically the ideal soil pH ranges from 4.5 to 6.8 and 7.0 to 9.5 as pH values beyond those extremes are toxic to life forms. A soil pH of 7 is termed as neutral, above 7 pH are alkaline and below 7 pH are acidic (Figure 5.15). Soil pH depends on a number of factors including climate. Heavy rainfall removes basic cations especially Calcium (Ca^{2+}), Magnesium (Mg^{2+}), and Sodium (Na^+), through leaching. Heavy rainfall replaces them by acidic cations especially of Hydrogen ions (H^+) and Aluminium ions (Al^{3+}) resulting into formation of acidic soils. In regions with little amount of rainfall, particularly semi-deserts, alkaline soils are likely to be formed due to salinization and calcification leading to the formation of saline soils especially at the topsoil. Also, parent rock materials determine soil pH, whereby acidic soils result from the acidic parent rock materials particularly granite rocks as opposed to limestone rocks which forms alkaline soils. Other factors include the decomposition of organic matter, acidic rain, the use of industrial fertilizers such as ammonia and ammonium as well as urea. Also, respiration of soil organisms may alter soil and the exchange of ions.

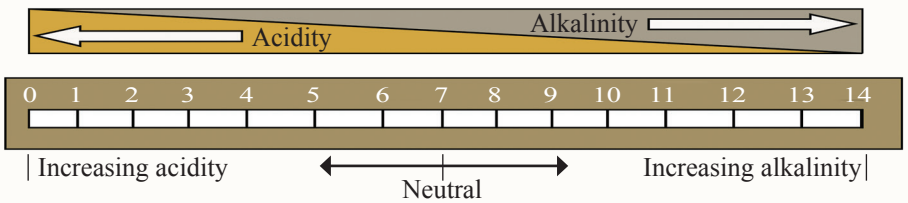


Figure 5.15: *Soil pH scale*

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Soil pH is measured in a suitable soil water suspension with a pH meter. Since soil pH influences the amount of exchangeable cations, the soil reaction can be deduced from the amount of cation exchange capacity present in the soil. When the percentage base saturation is above 50%, the soil is said to be alkaline while below 50% the soil is acidic.

Levels of soil pH required to grow specific crops in the soil varies among crop variety. The ideal soil pH for most of the plants ranges from 6-7.5, though can tolerate to pH ranging from 5.5-8.5. The tolerance of plants and animals to extreme soil pH varies with varying plant and animal species (Table 5.5). Some of the crops grow well in relatively high acidic soil while others grow well in alkaline soil. Basically, the most favourable soil for crop productivity is neutral soil.

Table 5.5: *Crop species and their various soil pH tolerance*

pH	Description	Crop type which can grow
Below 4.8	Extremely Acid	No normal crop grown
4.8 to 5.2	Strongly Acid	Oat, potatoes, Kale, rye, field lupin
5.3 to 5.7	Moderately Acid	Those above, plus wheat, beans, swede, turnips, maize, cabbage
5.8 to 6.4	Slightly Acid	All normal crops
6.5 to 6.9	Very Slightly Acid	All normal crops
Above 6.9	No Acidity	All normal crops

It is possible to manipulate soil acidity to suit particular crops. Some of the ways to modify soil acidity include: adding plenty of decomposed organic matter (compost) during planting of crops. The added organic matter in the soil during crop sowing increases the soil acidity gradually to a suitable concentration for plant growth. Meanwhile, adding aluminium sulphate and sulphur will change soil instantly as aluminium increases soil acidity as soon as it dissolves in the soil, while adding lime in the soil raises the soil pH level of a particular soil.

Importance of soil pH

It helps to determine the suitability of a given soil as a medium for plant growth and microbial activities. The suitable ranges for most crops are slightly acidic to slightly alkaline. Acidic condition is desireable in preventing diseases to some plants such as, cotton mosaic. Soil pH affects the availability of nutrients such as nitrogen, calcium, phosphorus, potassium and magnesium. These nutrients are mostly available at pH 6.5 – 7.5. Acidic conditions increase availability of Iron, Copper and Zinc, but they tend to decrease the availability of molybdenum,

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which is available at pH ranging from 0-6. Organic matter decomposition is slowed down under extreme acidic or alkaline conditions due to slow microbial activities. Soil pH being an indicator of the degree of acidity or alkalinity, give an estimate of the modifications needed (for acidity cation or liming) to achieve the favourable soil conditions for plant growth and microbial activities.

Exercise 5.5

1. With examples, discuss how soil pH may affect plant growth.
2. How can a farmer check the soil pH of a field?
3. With examples, explain how the soil pH in your home garden or farm can be maintained.
4. Describe the importance of soil pH.

Soil profile

Soil profile is the vertical section of a soil showing the succession of horizons or layers and the underlying parent rock materials. The different soil colour and texture help in dividing the soil profile into layers or horizons. There are four major soil horizons, which may further be divided into smaller horizons, which are shown by O or A, B, C and D letters to indicate their genetic origin. However, O-horizon is not common in all soil types, due to absence of accumulation of organic matter in some of the soils. The variations within the horizons are indicated by subscripts, like A_1 and A_2, or, B_1, B_2, and B_3. Organic-matter deposits on top of the mineral soil are often labeled as Ao, F, H (Figure 5.16). A soil profile helps to determine the best soil suitable for growing a certain type of crops and identifies the part where plant nutrients can be found. Note that the top soil is the richest part of the soil in nutrients. It helps to determine water holding capacity, nature of the parent rock materials and the type of mineral salts available to plants. There are a number of processes that are involved in the development of a soil profile such as decomposition of organic matter, weathering of the parent rocks, leaching, among others.

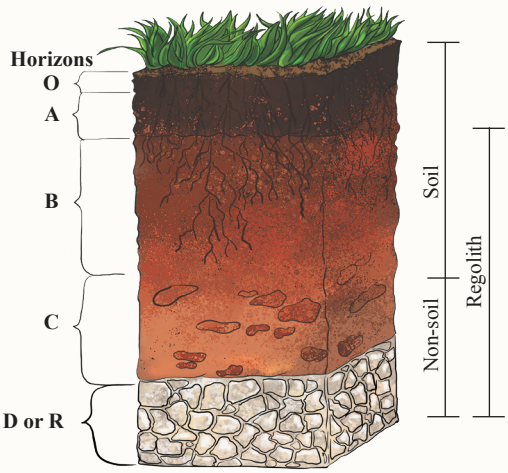


Figure 5. 16: *Cross-section of soil profile*

A - Horizon

This is the upper layer where biological activities take place, and is rich in humus. Organic matter forms Ao (surface

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horizon) at this zone. It forms organic matter both fresh popularly known as "L" and "F" and decaying, makes up most of the volume. The A-horizon results essentially from litter derived from dead plants and animals. The A-horizon is most affected by the leaching of soluble materials and by downward movement of clay particles. The washing out of materials, that is, the removal of organic and mineral matter from the A-horizon is known as *eluviation*. The A-horizon is therefore termed as the zone of eluviation. The upper part of this horizon is dark coloured due to down–washed humus from Ao. On the other hand, the lower part of the horizon has lighter colour due to removal of clay and iron.

A_1 forms the top soil, it is a mineral layer that contains enough partially decomposed organic matter to give soil dark colour. A_2 is normally light in colour than O and A_1 sublayers. This layer marks the transitional layer from O-horizon, A-horizon to B-horizon.

B – Horizon

This is the zone beneath the A-Horizon. It is known as the zone of *accumulation*, or *illuviation*, where clays and other materials that are removed from the A-horizon are re-deposited. Illuviation is the process of in-washing- the re-deposition of organic and mineral matter in the B–horizon. It is brighter in colour due to deposition of iron and aluminium. The A and B horizons together make up the true soil or **solum**. Horizon B is divided into B_1, B_2 and B_3. It is popularly known to form subsoils. The layer is a collection zone of clay, Iron and Aluminium. B_1 is usually a layer of great, heavier texture, great density and relatively great clay content than A. B_2 is a darker layer in colour. It is the layer of accumulation of colloids. B_3 is a transitional layer from B-horizon to C-horizon.

C – Horizon

This zone consists mainly of semi weathered parent rock materials (in-situ) resting on the bedrock. The layer consists of unconsolidated and semi weathered parent rock materials, mostly altered by weathering-subsoils. It lacks the content of organic matter. The horizons O, A, B and C form regolith.

D – Horizon

Beneath the C-horizon is the D or R – horizon which consists of unaltered or un weathered bedrock.

Activity 5.2

1. With the facilitation of subject teacher, form groups of five students and do the following; find a plot of land in the school premises,
   (a) Dig a hole of atleast one-meter depth to show vertical cross-section of soil.
   (b) identify soil layers from top to bottom.

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(c) Examine the physical characteristics of each layer.

(d) Take note of the key features observed

(e) In your groups discus the findings and write them in your exercise book.

(f) Present to the class, respond to questions and issues raised from your fellow students.

Exercise 5.6

1. Explain why the upper part of the A-horizon is usually dark in colour?
2. What are the differences between eluviation and illuviation processes?
3. What horizon is characterized by the accumulation of clay-sized particles? Explain why?
4. Explain why the A and B horizons are considered as the true soil.

Soil formation

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 weathering of the parent rock. Soil formation is the accumulation of a layer of loose, broken, unconsolidated parent rock materials known as regolith. The Regolith not only originates from weathering but may also be derived from the deposition of alluvium, drift, loess and volcanic materials. There are five main factors that affect the process of soil formation. These factors includes 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

Parent rock materials

The mineral material from which soil forms is called parent rock material or soil materials. Also, the parent rock known as 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, at the end is 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 theexceptions of nitrogen, hydrogen and carbon. There is greater relationship between soil formed with parent rock materials for example, soils formed from mafic rocks are usually more fertile, with

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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 resulting soils are very similar. In well leached environments, the soils formed are acid, 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 percent 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 percent 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 sites of mineralogical alteration and release of ions in soils formed as the glaciers retreated. As 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 the saturated conditions. They often have acquired and preserved thick organic matter residues, thus forming organic soils called histosols.

The way in which volcanic ash material enters 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. The good examples are in Java, Japan, Central America, and the rift valley in East Africa, specifically Rungwe and Kilimanjaro Mountains. Most of the soils formed from volcanic ash are now classified as Andisols.

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Climate

Climate is the dominant factor 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 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 5.17). Topography influences the rate of precipitation, runoff 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 slope 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 slope there is low rate of soil erosion but the high rate of deposition, due to the receipt of material moved downward 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.

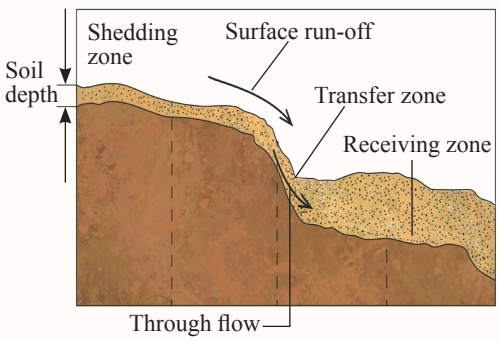


Figure. 5.17 *Topography soil formation*

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

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in particular gives life to the soil, 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 utilize easily digestible materials like simple sugars and carbohydrates found in the plant material, leaving more resistant materials such as fats and waxes behind. The material left behind is not easily decomposed; it comprises the humus found in 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 help to create 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 mm and under extreme conditions up to 1 000 years for 1 mm. 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.

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Activity 5.3

In a group of five students;

(a) Read books and internet sources about factors affecting soil formation,

(b) Discuss the findings you have collected from the sources you read,

(c) Summarize the read materials and present the findings to the class.

(d) Incorporate all the comments.

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 in 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. Losses occur 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 two categories, namely; 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. Also it determines the rates of release 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 the 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 the surface vegetation, causes chemical weathering leading to the breakdown of clays and the dissolving of soluble salts (bases). Calcium and magnesium are

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eluviated from the A-horizon, making them increasingly acidic as they are replaced by hydrogen ions. These are subsequently illuviated to the underlying B- Horizon, or are leached out of the system (Figure 5.18).

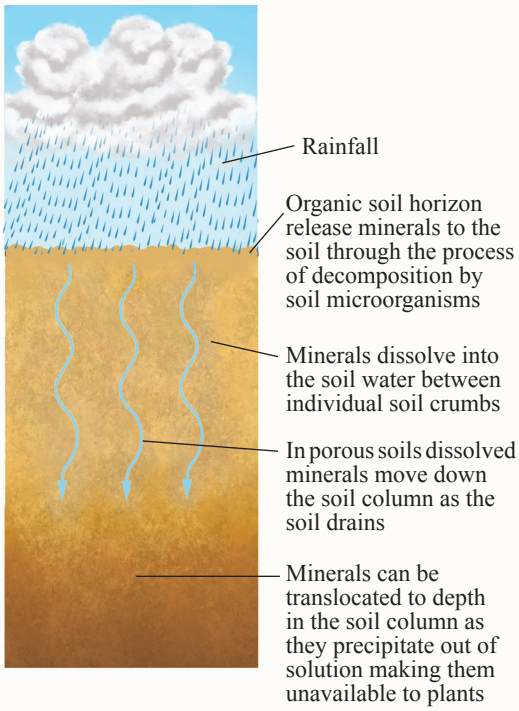


Figure 5.18: *Leaching in soils*

Eluviation

Eluviation is the downward movement of soil material that is organic and mineral matter from the A-horizon to the lower horizon in solution or in colloidal suspension. It differs from leaching in that 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 change 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 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

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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

Several processes operate within the soil to re-organize mineral 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

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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 to the surface. It is therefore found locally in dry climates, and it is a characteristic of desert soils. As moisture evaporates from the surface, salts are drawn upwards in solution by capillary action. Further evaporation results in the deposition of salt as a hard crust, thus making salinization to become 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 incomplete decomposition of organic matter giving 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.

Soil catena

This refers to the variation on the soil type in terms of maturity and soil temperature according to the variation in slope (Figure 5.19). Soil is sometimes formed in a series from the top down the slope of the relief with different characteristics because of different parent rock materials. This phenomenon is called *soil catena*. A catena is a sequence of soil types down a slope where each soil type (facet) is different from, but linked to its adjacent facets. Soil catena is a function of topography. The variation of soil type from top to the bottom of the slope is influenced by leaching, erosion and deposition. At the top, eluviation or input takes place while at the middle translocation takes place. At the bottom zone, illuviation or output takes place. Therefore, soil is thick at the top and bottom, but thin at the middle. Temperature also varies along the slope, resulting in differential rate of decomposition of organic matter. Also, along the slope soil pH is likely to differ as the top and middle soils may be subjected more to leaching than the bottom soils. Soils at the bottom of the hill is likely to be poorly drained especially when the parent rocks are impermeable.

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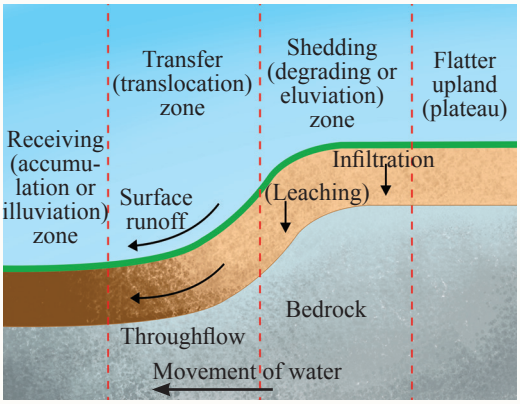


Figure 5.19: *Soil catena*

Soil as a system

A system usually is made up by a number of inter-related components that works together as a whole. The idea of soil as a system is derived from a system's theory that was propounded by a biologist called Ludwig von Bertalanffy (1968). The soil is an open system because the materials and energy resources are gained and lost at its boundaries. A soil system comprises inputs or store, processes, outputs and recycling or feedback loops. The interaction amongst soil components is a network that recycles every aspect through lose and gain loops. *Inputs or store* refers to all ingredients that are added in the soil in order to make a better soil. The inputs include such components like water from the atmosphere or though run-off that adds moisture contents which is essential for transportation of soil nutrients. There are mineral nutrients from weathered materials that are needed as food for plants. Other inputs are gasses from the atmosphere, and respiration of soil organism, organic matter and nutrients from decaying plants and animals, and solar energy and heat that is necessary for rock disintegration. The *processes* involve the mechanisms responsible for the formation of soil with simple or complex processes such as weathering, leaching, eluviation, illuviation, humification, mineralization, organic sorting, cheluviation, salinization, calcification, and podsolization. The process is responsible for the formation and development of the soil profile. The *outputs* include the end results obtained after the interaction of various processes. It exits as the results of what is stored in the process, thus, it is the resultant effect from the inputs and process. The components of output include water loss to the atmosphere through evapotranspiration resulting to the loss of moisture in the soil that can also affect soil productivity. Loss of soil nutrients through leaching process as well as through surface run-off. Also, loss of soil nutrients results from decreased amount of nutrients in the soil, for example harvesting by uprooting of crops, and loss of soil particles through soil creeping and soil erosion. *Recycling or feedback loops* is a self-enriching mode of soil entity that inform the repetitive nature of soil forming chain. It gives the summary of the three processes of inputs, process and outputs. A soil recycles by releasing the stored nutrients allowing them to return to the soil ready for future use through a process known as nutrients/ humus cycle.

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Exercise 5.7

1. With examples, describe how human activities accelerate the rate of soil formation.
2. What is the difference between weathering and soil formation?
3. Describe mechanical and chemical weathering processes and their contribution to soil formation processes.
4. With examples, explain why climate is considered as a dominant factor for soil formation.
5. Soil is an open system. Justify the statement.
6. Explain how soil properties are determined by the five soil forming factors.
7. Describe the major soil formation processes.
8. Differentiate simple from complex soil forming processes.
9. Soil catena is a function of topography. Justify.

Soil classification

Soil classification is the grouping of soils with a similar range of properties (chemical, physical and biological) into units that can be geo-referenced and mapped. Soils contain all naturally occurring chemical elements and combine simultaneously solid, liquid and gaseous states. Moreover, the number of physical, chemical and biological characteristics and their combinations are nearly endless. Hence many different approaches have been proposed to come to sensible grouping of different soils.

Criteria of Soil classification

There are many criteria applied in soil classification. These include classifying soils in terms of maturing, whereby zonal soil stand for mature soil. Azonal soil stands for immature soils such as alluvial, till, sands, gravels, salt marshes and volcanic soils. Intrazonal soil is a soil of more recent origin such as calcimorphic, hydromorphic and holomorphic soils. This classification is based on time and stage, that is, whether the soil profile has been well developed or not. Another criteria is based on climatic disparities in which two soil categories emerge, that is: soils of humid tropics for example, laterites and soils of cold regions for example, tundra soils. Another soil classification is based on soil forming factors such as parent rock materials and time of development. Soils are also classified based on soil formation processes such as gleying that produces peat, and podsolization that produces podsols. Again, morphological characteristics such as texture, structure, colour, depth, and porosity are used to classify soils. Finally, presence or absence of diagnostic horizons or features that reflect soil forming processes is used as one of the classification criteria.

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Approaches in Soil classification

The existing various soil classification systems originate from different approaches, attributed to differences in soil cover and space that lead to distinguishing different architypes. However, lack of uniformity in soil classification might be attributed to the fact that, soil science was distributed across the world in a rudimentary state and was generally developed independently in different countries. There are many approaches that are used in soil classification. These include; morphological, which classify soils on the basis of morphological properties of the soil profile; genetic approach that bases on genetic characteristics; and integrated which also is called morpho-genetic approach. Basing on these approaches among other factors, different soil classification systems have been developed for different purposes. These are USDA Soil Taxonomy which was developed in order to interpret soil survey; the FAO Legend which was developed for representing the global distribution and geography of soils; and World Reference Base (WRB) of 1980 which is the international effort to provide a reference base that could incorporate numerous soil classification systems into a system of names that would be universally recognized ever since in 1980. Among the basic principles and criteria adopted by this system is an attempt to define and use diagnostic soil characteristics related to soil-forming processes and diagnostic features of significance to soil management. As a basic principle, these classifications have excluded such as climatic parameters, soil temperature and soil moisture regimes of Soil Taxonomy as criteria for classifying soils. Development of soil classification systems in the history of soil science have passed through different steps from the ancient societies which can be generally divided into two main phases namely: *first phase* that is early soil classification and the *second phase* that is modern soil classification.

Early soil classification

The ancient civilization of human society all over the world started with a cross bond that human beings developed with soil, and through which soil differences were established. From that knowledge a traditional system of soil categorization emerged. However, the earliest formal attempt to classify soils can be found in the Chinese book "Yugong" which shows the way Chinese soil was classified into three categories and nine classes basing on soil texture, colour, and hydrological features (drainage) that were used as the basis of land value determination for tax assessment. This signified the earliest introduction of morphological classification system.

Modern soil classification 1882 - 1900

The modern soil classification system was initiated by the Russian geologist Vasily V. Dokuchaeiv who introduced

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the scientific theory of soil classification on "Russian chernozem" in 1883. Dokuchaeiv introduced zonation of the global soils temperature and precipitation distribution and vegetation gradients. He proposed that soil properties reflect a combined global effect of genetic factors of soil formation, and consequently he categorized the global soils into three main types namely; normal soils, transitional soils and abnormal soils which were later developed by his successors such as C. F. Marbut and others, as Zonal, Intrazonal and Azonal soils, respectively. Moreover, the broadening of the modern soil science in USA between 1920s and 1930s built on the Dokuchaeiv`s ideas and C.F. Marbut borrowed and modified the Russian pedological views and ultimately developed a comprehensive system of soil classification. Progressively, the Great Soil Groups was evolved into soil orders and sub-orders such as Zonal soils, Intrazonal soils and Azonal soils.

Soil classification according to age

Zonal soils

Zonal soils are mature soils. They result from the maximum effects of climate and living matter (vegetation) upon parent rock in areas where there are no extremes of weathering, relief or drainage and where the landscape and climate have been stable for a long time. Zonal soils have had time to develop distinctive profile and have clear horizons.

Classification of zonal soils

Zonal soils are classified into four classes based on the zonation of climates and vegetation. These classes are the arid and semi-arid soils, cold climate soils, tropical climates soils, and lateritic soils.

The *arid and semi-arid* soils are soils that develop in arid areas of the tropics. Because of scarcity of rainfall, the desert soils are light coloured and sandy in some areas they may be saline due to salinization process caused by high temperature, semi-arid, sub-humid and humid grassland. They are dark-coloured soils, such as chestnut soils, chernozem and prairie soils. *Cold climate soils* are tundra soils which develop in areas of very low temperature with permanently frozen sub soils, a low rate of evaporation and a short period of plant growth. Deep soils cannot develop under such conditions due to frozen subsoil which limits chemical weathering and microbial activities.

Tropical climate soils are soils of tropical climates. They include latosols, black and dark grey soils. Latosols are the soils which are formed in the tropical regions which experience high rainfall and high temperatures with definite dry season. The high rainfall causes heavy leaching to take place in these soils. The soils include laterites soils, black and dark grey soils, and soils of tropical humid regions where there are

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basaltic rocks. The soils may be sticky when wet but dry and crack during the dry season. They are very rich in humus in tropical rainforest, which gives them a black colour as observed in black cotton soil. *Lateritic soils* are soils of forested warm-temperate and tropical regions. They include reddish-brown lateritic soils, yellowish-brown lateritic soils and laterite soils.

Azonal soils

Azonal soils are young soils which occur in areas where the soil forming processes have inadequate time to operate on the components that form the soil. Azonal soils exhibit characteristics of their parent rock, material resulting from weathering or deposition, and so they have not developed complete soil profiles. Also, they are not associated with specific climatic and vegetation zones.

Classification of azonal soils

Azonal soils are classified into six classes which are mountainous soils, alluvial soils, glacial soils, windblown soil, marine soils, and volcanic soils. *Mountainous soils or scree soils* are the result from weathering, especially on mountains. They are composed of screes, which are small loose rock particles that accumulate at the foot of a mountain. *Alluvial or fluvial soils* result from deposition of clay, silt and sand left by flowing water in a river valley or delta popularly known as river borne soil. Such soils develop mostly in flood plains where the river deposits most of its load. They develop very fertile soils due to composition of various materials. *Glacial soils* (till soils) are boulder clays or other unstratified sediments deposited by glaciers in glaciated lowlands. They are formed from moraines. The composition of till soils reflects the character of the rocks over which the flakier has passed.

Windblown soils or loess soils are immature soils that result from deposition of materials by wind at the edges of a hot desert or along the coast also known as aeolian soil. They are composed of sand and clay. Good examples are sand dunes, loess and sand sheets. *Marine soils* are azonal soils which are made up of materials derived from the sea which built up along the coast in form of mud banks, sand banks, and dunes. The formation of marine soil is a function of natural processes like wave erosion and deposition. Good examples include salt marsh soils, mud-flat soils and marine clays. Volcanic or tectonic soils are soils formed from volcanic eruptional materials like lava. They are often very rich in nutrients, and they hold water well because of their volcanic ash content. These soils are called andisols and they are often very young (immature) and acidic, depending on which type of the volcano they are derived from. *Volcanic soils* around the equator can be very well weathered, and can lose some of their nutrients unless there is another eruption. These materials can be very dark in colour. When mixed with organic matter they become more fertile.

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Example of these soils are recent lava and ash soils.

Intrazonal soil

This is a type of soil whose occurrence and development reflects the dominance of one local factor such as relief, parent rock materials, or extremes in slopes, drainage and vegetation. Examples of intrazonal soils are those which occur in a forest which is locally influenced by the forest conditions. Major characteristics of intrazonal soil are: they occur under the influence of one local factor like relief or parent rock materials; and have well developed soil profiles which display the horizons clearly. They are not found in zones and can be subdivided into three major categories: calcimorphic, hydromorphic and halomorphic soils. Calcimorphic soils are also called calcareous soils. They develop on chalk and limestone areas. They are poor soils because they are porous and have no humus. These include the rendzna and terra-rosa (red soils) in the Mediterranean countries. Hydromorphic soils have high water content. Also, peat or bog soils occur in water logged areas like on coastal lands by gleying. They can be reclaimed by artificial drainage. They are common in the coast of Africa mangroves, the Atlantic Coast of USA, and the Gulf coast. Halomorphic soils are soils that have high level of soluble salts which render them saline and have developed through the process of salinization. They mostly occur in hot, dry climate.

The USDA soil taxonomy

The soil taxonomy is a set of classes that is defined approximately at the same level of generalization or abstraction and that includes all soils. The USDA soil taxonomy was first published in 1975 after several phases of modification. This classification relies on horizon diagnostic properties comprised of 12 orders (Figure 5.20), 64 sub-orders, and 300 great groups summarize the orders of the soil Taxonomy according to the USDA 7th Approximation system.

Alfisols

These have a combination of an ochric or umbric epipedon, an argillic or natric horizon. They serve as a medium to high supply of bases in the soil. Also, they have water available to mesophytic plants for more than a half of the year or more than three consecutive months during a warm season. Presence of water and bases make them intensively used. They are extensively common in low and middle latitudes. Also, these soils have high content of clay.

Andisols

These are characterised by a dominance of short–range-order minerals or Al-humus complexes that result from weathering and mineral transformation with a minimum of translocation. They have a high phosphorus retention, available water capacity, and cation-exchange capacity. They are formed

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from volcanic ejecta or volcaniclastic materials. They can form in almost any environment as long as suitable temperature and adequate moisture are available to permit weathering and the formation of short-range order minerals. The soils can have any diagnostic epipedon or surface horizon as long as the unique property of andisols is in 60% of the upper 60 cm of the soils, disregarding O–horizons that have 25% or more organic carbon. Prior to 1989, the current classified soils as andisols were included in inceptisols.

Aridisols

The unique properties common to aridisols are a combination of lack of water available to mesophytic plants for much extended periods, one or more pedogenic horizons, a surface horizon or horizons not significantly darkened by humus and absence of deep, wide cracks and andic soil properties. Aridisols lack water in most of the time, causing the soils to be warm enough for plant growth (warmer than 5^{o}C) however, they can lack water for about 90 days consecutively when the soil temperature is above 8^{o}C. Aridisols are primarily soils of arid areas. They are found in areas that preclude much entry of water into the soils at present, either under extremely scanty rainfall or under slight rainfall that for one reason or another does not enter the soils. The vegetation in many areas consists of scattered ephemeral grass and forbs, as well as xerophytic shrubs. Some Aridisols furnish limited grazing. If irrigated, many of them can be suitable for a wide variety of crops.

Entisols

Entisols are soils mainly characterised by dominance of mineral soil materials and absence of distinct pedogenic horizons. Also, they are distinguished by the absence of features of any major set of soil forming processes. Entisols are soils in the sense that they support plants, but they may be in any climate and under any vegetation. The absence of pedogenic horizon may be the result of an inert parent rock materials, such as quartz sand, of which horizons do not readily form; and slowly soluble hard rock, such as limestone, which leaves little residue. It may also result from insufficient time for horizons to form, as in recent deposit of ash or alluvium; they occur on slopes where the rate of erosion exceeds the rate of formation of pedogenic horizons; they form from the late mixing of horizons by animals or by ploughing to a depth of 1 or 2 m; or the spoils from deep excavations.

Gelisols

The unique property of gelisols is the presence of permafrost and soil features and properties associated with freezing and thawing. These features include irregular or broken horizons and incorporation of organic materials in the lower horizons, especially along

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the top of the permafrost table. Freezing and thawing produce granular, platy, and vesicular structures in surface and subsurface horizons. The increase in soil volume on freezing is considered a major soil forming process in gelisols. These soils are confined to higher latitudes or high elevations, but they form about 13% of the soils in the world, second to Aridisols.

Histosols

These have a very high content of organic matter in the upper 80 cm of the soils and they do not have permafrost. The amount of organic matter is at least 20 to 30 percent in more than a half of this thickness, or the horizon that is rich in organic matter resting on rock. Most of the histosols are peats or mucks, which consist of more or less decomposed plant remains that have been accumulated in water. However, some of them are formed from litter or moss, or both and are freely drained.

Inceptisols

These have a wide range of characteristics and they occur in a wide variety of climates. They can form in almost any environment, except in an arid environment, and the comparable differences in vegetation are great. They occur on a variety of landforms. The unique properties of inceptisols are a combination of water available to plants for more than half a year or more than three consecutive months during a warm season and one or more pedogenic horizons of alteration or concentration with little accumulation of translocated materials other than carbonates or amorphous silica. These soils lack one or more of the unique properties of mollisols, which are thick, dark surface horizon and with high calcium supply. Also, they do not have the unique property of andisols, which is the dominance of short-range-order minerals or Al-humus complexes.

Mollisols

These are characterised by a combination of very dark brown and black surface horizons (mollic epipedon) that make up more than one-third of the combined thickness of the A and B horizons, or that is more than 25 cm thick and that has structure or is not hard or very hard when dry. They are also characterised by a dominance of calcium among the extractable cations in the A and B horizons; a dominance of crystalline clay minerals of moderate or high cation exchange capacity; and presence of less than 30% clay in some horizons, above 50 cm if the soils have deep, wide cracks (1 cm or more wide) above this depth at some season. Characteristically, mollisols form under grass in climates that have a moderate pronounced seasonal moisture deficit. Some mollisols, however, are formed under a forest ecosystem, and a few are formed in marshes or in marls in humid climate. Mollisols are extensive soils on the steppes of Europe, Asia, North America and South America.

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Oxisols

The unique properties of oxisols include extreme weathering of most minerals other than quartz to kaolin and free oxides, very low activity of the clay fraction, and a loamy or clay texture (sandy loam or finer). They are commonly found in tropical or subtropical regions, and on land surfaces that have been stable for a long time. Generally, the surfaces are early Pleistocene or much older but oxisols can occur on relatively young surfaces when weathered soil material is deposited. Oxisols develop in a humid climate. However, due to climate changes, some are now in an arid environment.

Spodosols

Spodosols have markers in at least an upper sequum of dominant processes that translocate humus and aluminium or humus, and iron amorphous materials. The B-horizon in spodosols consists of an accumulation of black or reddish amorphous materials that have a high cation exchange capacity. This horizon is the spodic horizon. The spodic horizon has a course texture, high pH-dependent change, and few bases. The cation exchange capacity is related to the amount of organic carbon rather than to the clay.

Ultisols

Like alfisols, ultisols have markers of clay translocation. However, they have markers of intensive leaching that are absent in alfisols. Moreover, they have an argillic horizon and a low supply of bases, particularly in the lower horizons. The cation exchange is in most cases moderately low. The decrease in base saturation with the increase in depth reflects cycling of bases by plants or addition in fertilizers. They have water but in a small amount. They can be used for shifting cultivation without application of fertilizers. However, they can be made highly productive if fertilizer is applied. They are commonly warm and moist.

Vertisols

Vertisols have markers of processes related to the failure of soil materials along shear planes (slickensides). They have a high bulk density when the soils are dry, and they have low or very low hydraulic conductivity when the soils are moist. Also, they are characterised by having a high content of clay, pronounced changes in volume with change in moisture, and cracks that open and close periodically. Moreover, they contain evidence of soil movement in the form of slickensides, and evidence of wedge-shaped structural aggregates that are tilted at an angle from the horizontal.

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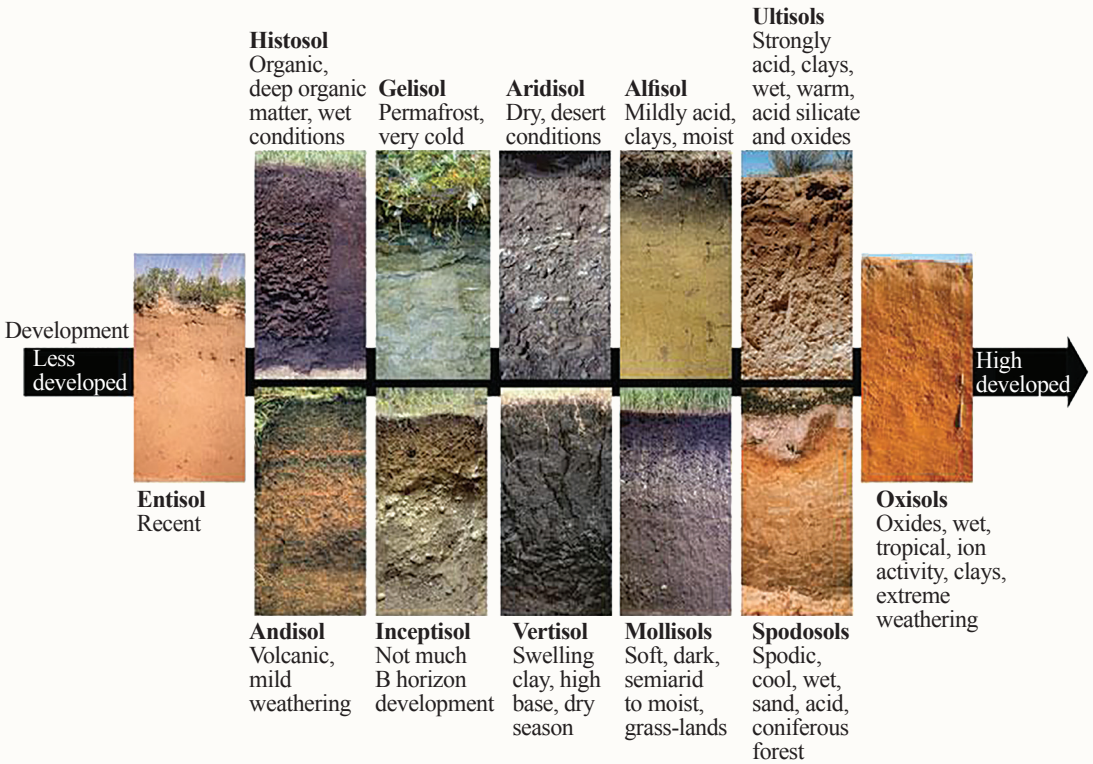


Figure 5.20: *Types of soils according to USDA taxonomy*

Soils of Tanzania

Tanzania has adopted the World Reference Base (WRB) for soil resource classification system in identifying the soils in the country. The WRB as the system of classification and correlation recognizes 19 dominant soil groups whose development and distribution corresponds largely to the geological, hydrological and meteorological variations across the country. Out of 19 identified soil groups, only 11 are covered in this section.

Histosols

Histosols are commonly developed mainly from incompletely decomposed plants and animal remains, normally with more or less admixture of sand silt or clay. Poorly drained environments in which they are formed may to the large extent account for their incomplete decomposition. As they contain high amount of organic matter, histosols area also called organic soils. In Tanzania histosols are common in Kagera, Kigoma, Shinyanga and Kilimanjaro. They are useful in forestry, horticulture, and some arable farming.

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Andosols

Andosols are soils which commonly develop in volcanic parent rock materials ejected during volcanic processes, such as cinder, pumice and ashes in relief ranging from undulating to mountainous tropical regions. In Tanzania, andosols are common in Kilimanjaro, Arusha and Mara, and support a wide range of crops including tea, coffee, vegetables, sweat potatoes and wheat among others due to the high amount of nutrients they contain.

Arenosols

Arenosols are commonly developed from unconsolidated parent rock materials particularly residual Sandstone and siliceous weathered rocks or after weathering of quartz-rich soil material. Arenosols normally have low nutrient and water storage capacity and may develop in arid humid regions. Normally, they are liable to leaching and erosion which result into mineral depletion. They are commonly found in Tabora, Iringa, Mbeya and Rukwa regions. Despite of their susceptibility to leaching, arenosols are agricultural productive as they support cereal crops, ground nuts and Bambara ground nuts.

Vertosols

Vertosols develop from clay mineral-rich parent rock materials, particularly smectite clay in depression, lowly elevated and undulating tropical semi-arid and Mediterranean regions. They have a changing tendency with water regime by alternate shrinking and expanding in dry and wet seasons respectively. In wet seasons vertosols tend to absorb water, expand and become sticky whereas in dry seasons, they tend to lose water, shrink and develop deep cracks. Normally they are associated with tillage difficult due to high degree of hardness during dry seasons and plasticity in wet seasons. However, they support annual crops such as rice, maize, cotton, sugarcane and vegetables. They are commonly found in Mwanza, Tabora, Kigoma, Mara, Lindi and Coastal region.

Fluvisols

Fluvisols develop in areas which experience periodic flooding such as alluvial plains and river valleys in all climates. Because of the geological and geomorphological setting in which they are formed, fluvisols are usually rich in organic matter and water content, and sometimes saline. They are found in important and major river plains in Tanzania such as the Rufiji, Ruaha, Ruvu, and Kilombero basins among others. They are economically potential soils as are highly supporting annual crops and grazing. Saline tidal lands support mangrove plants and other salt supported species.

Gleysols

Gleysols develop from the unconsolidated rock material resulting from fluvial,

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marine and lacustrine sediments with poor drainage. These are the parent rock materials from which gleysols develop. Due to poorly drained environments, which they are found, gleysols are normally associated with the formation of peats, especially in wetlands. When drained, they can support a wide range of crops, dairy farming and horticulture. In Tanzania, Gleysols are commonly found in Mbeya, Rukwa and Morogoro.

Leptosols

Leptosols develop mainly from mechanical weathering in mountaneous landscapes with steep slopes, which may account for their shallow soil profile, low water content and vulnerability to erosion. They are useful however for forestry and nature conservation. They are common in Dodoma, Lindi, Mbeya and Iringa.

Ferralsols

Ferralsols are strongly weathered soils ranging in colour from red to yellow developed commonly in warm humid tropics. They are normally with a deep well drained profiles rich in sesquioxides and kaolinite clay minerals. They are common in Kigoma, Morogoro, Tanga Kilimanjaro Mtwara and Dar es salaam regions.

Acrisols

Acrisols develop mainly from the old land surface with undulating or hilly topography in acidic weathered clay parent rock materials in subtropical or monsoonal warm temperate climate. They are commonly found in Tanga, Kilimanjaro, singida, Morogoro, Lindi Mtwara Dodoma, Mbeya, and Ruvuma.

Solonetz soils

Solonetz soils develop in areas with flat land and hot dry summer climates characterized by fine textured sediment parent rock materials that are likely to develop solonetz with high amount of sodium or magnesium ions. Most of them have a much shallow surface horizons and are strongly alkaline. Solonetz soils are commonly found in Arusha, Rukwa, Dodoma, Iringa, Morogoro and Mbeya regions, Tanzania.

Luvisols

Luvisols are dominantly characterized by marked textural differentiations in their profile developed from the wide range of unconsolidated material especially glacial drifts, wind deposited, material as well as alluvial and colluvial parent rock materials, in cool to warm climates. Therefore, areas with flat or gentle sloping land are best sites of luvisols, which may account for their potentiality. In Tanzania they commonly occur in Dodoma, Arusha, Manyara, Kilimanjaro, Tanga and Ruvuma regions.

The above major soil groups in Tanzania are presented in Table 5.6 whose information has been extracted from Figure 5.21 of Map of Tanzania.

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Table 5.6: *Major soil groups of Tanzania*

No.	Map code	Major soil group	Sq. km	Percent
1	AC	Acrisols	81642.50	8.63
2	AN	Andisols	15904.46	1.68
3	AR	Arenosols	21926.33	2.32
4	CM	Cambisols	337353.69	35.64
5	CH	Chernozems	4734.96	0.50
6	FR	Ferralsols	59852.62	6.32
7	FL	Fluvisols	26223.13	2.77
8	GL	Gleysols	1486.19	0.16
9	HS	Histosols	3791.45	0.40
10	LP	Leptosols	76738.02	8.11
11	LX	Lixisols	46888.61	4.95
12	LV	Luvisols	68706.15	7.26
13	NT	Nitisols	21001.11	2.22
14	PH	Phaeozems	22190.10	2.34
15	PL	Planosols	28197.84	2.98
16	RG	Regosols	1196.15	0.13
17	SC	Solonchaks	2750.92	0.29
18	SN	Solonetz	19626.46	2.07
19	VR	Vertisols	47497.85	5.02
20	Water bodies		58836.73	6.22

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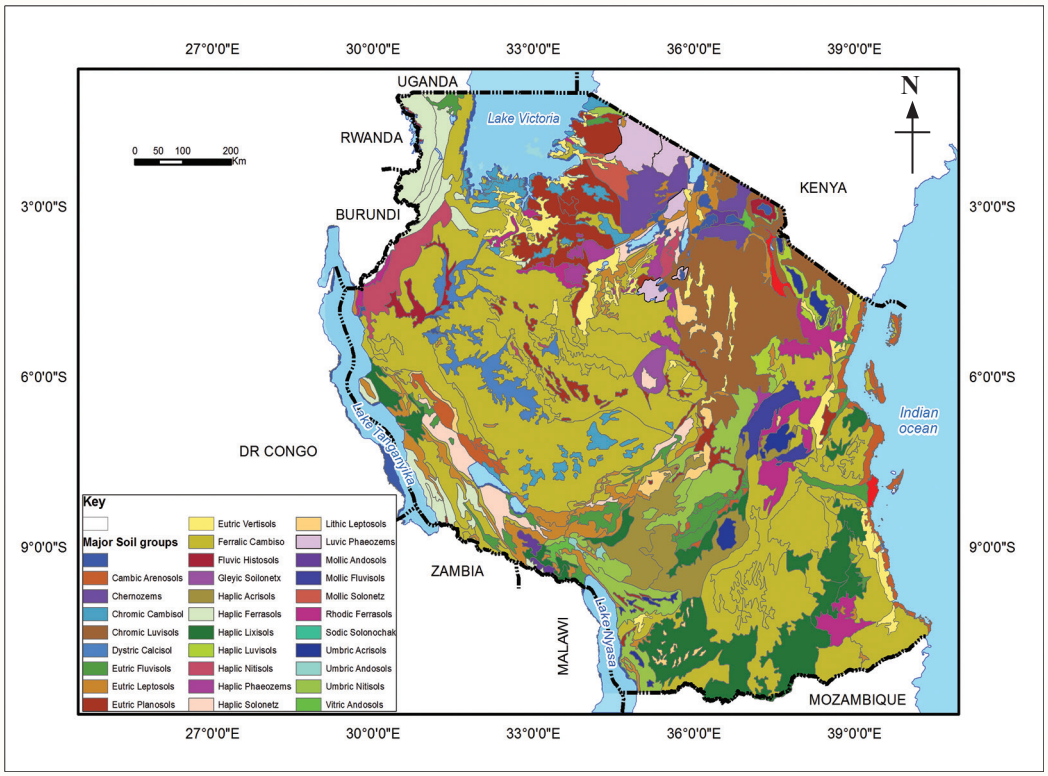


Figure 5.21: *Distribution of major soil groups in Tanzania*

Advantages of soil classification

Soil classification facilitates communication among the world soil scientists which brings common understanding in classifying the global soils. For instance, the world reference base for soil resource WRB acts as the reference system that unifies the world soil scientists in decision making among other things when dealing with the global pedological issues. Soil classification is the basis of land use planning in any country. It is through soil classification that much of the details about soils are learned and by which quality of soil both physical and chemical properties of the soil are identified. This then becomes the basis of allocating soils for different uses. For instance, poorly drained soils are likely to discourage settlements but can be used for forestry.

Soil classification provides knowledge on how to deal with a particular soil. Through soil classification, it is possible to know how susceptible a particular soil is in terms of its erodibility, leaching, drainage, and water retaining capacity among other factors. This draws attention on the sustainable use of the soil by applying appropriate techniques including planting trees, mulching and contour farming depending on the

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circumstances. It helps to understand the existing natural relationship between pedology and other disciplines such as geology, meteorology, plantology, anthropology and hydrology, in the sense that soil results from the interaction of environmental variables which determines most of its properties. Variation of soils with space and time is reflected by the varied soil characteristics. Also, soil classification provides the basis for estimating the value of the soil and its productivity.

Limitations of soil classification

Soil classification is a very expensive process as it requires high financial support and qualified soil specialists. Soil has no absolute sharp boundary where one soil type starts and end, this results in complexity of the process. Most of the soil classification systems are from foreign countries and were developed in circumstances that do not accurately match with our local situations. Furthermore, soil classifications consider too many criteria to handle which may sometimes bring confusion.

Activity 5.4

In a group of five students;

(a) Read from library and other internet sources about the historical perspectives of soil classification,

(b) With the guide of subject teacher, present the findings before the class and address all emerging questions, and

(c) Write notes in your exercise book and submit to subject teacher for assessment.

Exercise 5.8

1. Giving the basis for classification and the resultant soil types, explain the hierarchal order of soil classification for USDA Taxonomy.
2. How do gelisols differ from all other soil orders?
3. Discuss the benefits of soil classification.
4. Compare the USDA and the WRB soil classifications.

Soil fertility

Soil fertility refers to the ability of a soil to provide or supply necessary nutrients for the optimum growth of plants. The ability to produce high or low yields depends upon the nutrient content, structure, texture, drainage, acidity and organic content of a particular soil. Also, it depends on the relief, climate and farming techniques. For ideal plant growth, it must have access to

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nine primary and secondary mineral and several trace elements. The four primary elements which are needed in considerable quantities includes; carbon (C), hydrogen (H_2), nitrogen (N_2), and Oxygen (O_2). Besides, there are five secondary elements which are calcium (Ca), magnesium (Mg), potassium (K), sulphur (S), and phosphorous (P). These elements are needed in smaller amount and several trace amount elements like molybdenum (Mo), Copper (Cu), Boron (B) and Zinc (Zn) are required in minute amount. Calcium helps the growth of roots and new roots, while magnesium is a compound of chlorophyll. Potassium and nitrogen help in the formation of starches and oils; molybdenum activates enzymes. Among these elements, nitrogen, potassium and calcium are most likely to become deficient in areas of cultivation.

Soil nutrients may be obtained in different ways such as organic matter decomposition, precipitation, biological nitrogen fixation, inorganic fertilizer application and weathering of soil rocks and minerals. Under normal recycling these nutrients will be returned into the soil as vegetation dies and decomposes. Plants, animals and microorganisms cannot use nitrogen in its inert form. Nitrogen must be converted into its usable form like ammonia which can be used by plants and other organisms. All organisms use ammonia to form Amino acids, proteins and other nitrogen containing compounds. Biological nitrogen fixation is a process which converts nitrogen into ammonia which can be utilized by the plants. When bacteria die in soil, they release nitrogen containing compounds which can be used by plants for their growth and development. The production of fixed nitrogen from di-nitrogen for chemical fertilizer accounts for about 25% of the Earth's newly fixed N_2, and biological processes account for about 60%. As nutrients are taken out in the soil system and not replaced, there will be shortage of macro- nutrients. Soil need to be managed carefully if they are to produce maximum agricultural yield and cause least environmental damage.

Soil productivity

Soil productivity refers to the capacity of the soil in its normal environment to support plant growth to ensure the attainment of reasonable yields. Soil productivity is reflected in the growth of forest, agriculture, and vegetation or the volume of organic matter produced onsite. Soil productivity is largely determined by its ability to provide water and nutrients to allow deep rooting of agricultural plants. The measure of soil productivity is usually crop yield per millimetre of available water. It is an inherent capacity of soil to support the growth of specified plants, communities, or a sequence of plant communities.

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Fertile soil has the following properties; it is rich in nutrients necessary for basic plant nutrition, including nitrogen, phosphorus and potassium. It contains sufficient minerals (trace elements for plant nutrition, including boron, chlorine, cobalt, copper, iron, manganese, molybdenum, sulphur and zinc). It contains soil organic matter that improves soil structure and moisture retention. Soil pH is in the range between 4.0 and 9.0 for most plants but some prefer acidic or the alkaline condition. A good soil structure creates a well-drained soil, but some soils are watery (suitable for producing rice) while others are moist (for producing a variety of crops or plants). Fertile soil contains a wide range of microorganisms that support plant growth through nitrogen fixation and decomposition of organic matter. It often contains large amounts of top soil which is optimal for deep rooted crops. Therefore, the fertility of the soil is influenced by some of the following aspects: texture of the soil, structure of the soil, climate of the area, soil pH, depth of the soil, nature of the parent rock materials, vegetation cover, human activities, and relief.

Loss of soil fertility

Loss of soil fertility and productivity refers to inability of the soil to provide the required nutrients for plant growth. Loss of soil fertility occurs when the quantities of nutrients removed from the soil in a harvested farm exceed the quantities of nutrients being applied. In this situation, nutrient requirements for the crops are met from soil reserves until these reserves cannot meet crop demands. This results in a reduction of plant growth and yield. The soil loses its fertility and productivity through the process called *soil degradation*. Soil degradation as a phenomenon refers to a decrease in soil productivity and quality, often due to human activities through either its misuse or overuse. It leads into reduction of soil quality and decrease in a future potential for the survival of living organism. Soil degradation consists of soil erosion, salinization and soil pollution (soil contamination). The degradation or deterioration of a soil may be caused by chemical, physical and biological factors.

Causes of soil degradation

Soil degradation arises from both natural and anthropogenic causes. The major causes of soil degradation include overpopulation, climate change, land use and urbanization. However, the most recognized causes of soil degradation are deforestation, poor methods of farming, shifting cultivation, overcropping, monoculture, the use of agrochemicals and overgrazing.

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Chemical factors that cause soil degradation

Salinization

Salinization or development of salt, is one of the processes of soil degradation. The salt accumulation may lead to a partial or complete loss of the soil capacity to provide the required amount of water to plants, and therefore, a change of fertile lands to deserts. Frequently, the salinization processes create a practically irreversible chemical or physical internal soil degradation. The salinity problems appear as a consequence of salt accumulation in zones and depths where lie soil moisture regime is characterized by strong losses of water by evaporations and transpiration, and by reduced leaching of the remaining salts. Although these processes of salinization may progressively develop under natural conditions where a combination of aridity and restricted drainage exists. This may only be accelerated when the soil moisture regime is drastically changed with the introduction of irrigation and without appropriate drainage conditions.

Soil acidification

Soil acidity is potentially serious soil degradation issue. It occurs when the concentration of hydrogen ions in the soil increases. Soil acidification is a natural process, but can be increased by some agricultural practices. Acidification occurs in agricultural soils as a result of the removal of plant and animal products, leaching of excess nitrate, addition of some nitrogen based fertilizers, build-up in mostly plant-based organic matter. When soil becomes too acidic can decrease the availability of essential nutrients, such as phosphorous, calcium, magnesium, and molybdenum. The increase of the impact of toxic elements, decrease plant production and water use. Also, can affect essential soil biological functions like nitrogen fixation, making the subject soil vulnerable to decline of soil structure and increased erosion. Without treatment, soil acidification can impact agricultural productivity and sustainability of farming systems. Also, acidification can extend into subsoil layers, and impair plant root development.

Water logging

This occurs when most of the pore spaces in the soil are filled up with water. In this case almost all the air is driven out of the soil. This causes the plant roots to suffer from insufficient air and finally die. Also, waterlogged organic matter breaks down very slowly because micro-organisms necessary for decomposition are inactive in areas with insufficient oxygen. Water logging result to the formation of a soil hardpan called duricrust, which make soils difficult to till.

Leaching

Leaching occurs when nutrients are dissolved in water and then carried

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away downward in the soil profile from plant roots zone. In this case, the plant roots suffers from shortage of nutrients from deeper soil, this weakens plant growth.

Soil erosion

Soil erosion is among the processes of soil degradation. It involves physical removal of soil materials by the influence of the moving agents such as water, wind, ice or wave, and other natural forces. It is the major contributor to nutrients loss because most of the soil nutrients are in the top layer (5 to 10 cm) of the soil. Soil erosion is mainly a naturally occurring process that affects all landforms, however, in many developing countries soil erosion is caused by anthropogenic activities. Largely from poor crop farming practices such as tillage and unsustainable livestock grazing.

Types of soil erosion

There is no universal classification of soil erosion. However, the following are some of the categorise of soil erosion.

Natural or geological or normal soil erosion: This takes place steadily, but long time slowly and develop features like valley, channels and plains.

Accelerated soil erosion: This kind of erosion results from disturbances of natural equilibrium due to human and animal's activities. These activities include deforestation, overgrazing, and poor methods of farming. These activities may cause the removal of top soil.

Soil erosion due to agencies: This type of soil erosion is caused by agencies like water, wind and biotic factors. In these agencies, water is more adverse as it contributes largely on eroding soil. Soil erosion caused by water particularly rainfall is influenced by energy from two different sources which are falling of rain drops and surface flow. The two energies detach soil particles and remove the top soil of the bare land. The following are the forms of soil erosion caused by runoff of rainwater.

Splash erosion: This occurs when raindrops hit bare soil. The explosive impact breaks up soil aggregates so that individual soil particles are splashed onto the soil surface. It is a type of erosion that is influenced by rain droplets.

Sheet erosion: This is the gradual uniform removal of the earth's surface by water without the formation of rill or gullies. It is a general removal of the surface soil over a large area as it slips gradually down the slope (Figure 5.15). It results in loss of the finest soil particles that contain most of the available nutrients and organic matter in the soil. Soil loss is so gradual that

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the erosion usually goes unnoticed, but the cumulative impact accounts for large soil losses. Overgrazed and cultivated soils where there is little vegetation to protect and hold the soil are most vulnerable to sheet erosion. Early signs of sheet erosion include bare areas, water puddling as soon as rain falls, visible grass and tree roots, and exposed subsoil or stony soils.

Rill erosion: This occurs when surface water runoff concentrates, forming small yet well-defined channels (Figure 5.22). These distinct channels where the soil has been washed away are called rills when they are small enough such that they cannot interfere with field machinery operations. In many cases, rills are filled in each year as part of tillage operations. When rills develop or grow, they form gullies.

Gully erosion: Gully erosion is an advanced stage of rill erosion. Gullies are formed when surface channels are eroded to the point where they become a nuisance factor in normal tillage operations. Surface water runoff causes gully formation or the enlarging of existing gullies. This is a result of improper outlet design for local surface and sub-surface drainage systems. The soil instability of gully banks, usually associated with seepage of groundwater, leads to sloughing and slumping of bank slopes. Gully formations are difficult to control if corrective measures are not designed and properly constructed. Control measures must consider the cause of the increased flow of water across the landscape and must be capable of directing the runoff to a proper outlet.

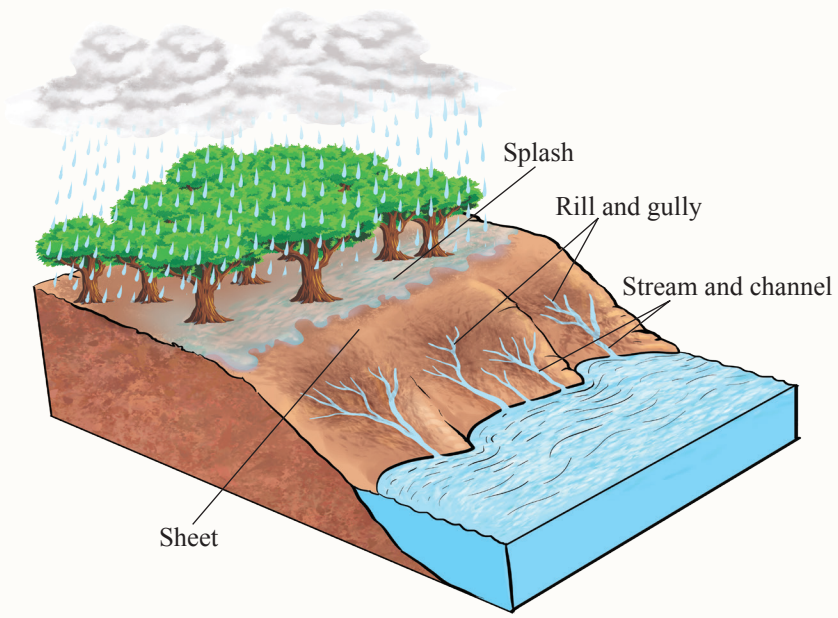


Figure 5.22: *Erosion due to agencies*

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Causes of soil erosion

Soil erosion can be a slow process that continues relatively unnoticed, or can occur at an alarming rate, causing serious loss of top soil. Other factors that accelerate soil erosion include soil de-compaction, low organic matter, loss of soil structure, poor internal drainage, salinization and soil acidity.

Deforestation

Deforestation is the conversion of forest to an alternative permanent non-forested land use such as agriculture, mining, grazing or urban development. Destruction of natural vegetation cover is a major factor that subject soil to agencies of erosion mostly water and wind. Forests play a significant role of holding the soil firmly and stabilize it against surface runoff and rain drops that affect the top layer of soil. Absence of vegetation, the rain splash easily loosens the topsoil, and later easily removed by sheet wash or wind.

Poor methods of farming

Under poor methods of farming there are several sub causes of soil erosion such as *poor cultivation methods.* Method like deep ploughing destroys the soil structure by breaking up compacted soil, making it easy to be eroded by wind and water. Also, poor cultivation methods, especially on steep slopes increase the rate of surface runoff and leads to either rill, sheet or gully erosion. *Shifting cultivation.* This is an old method of farming where a slash and burn technique is used to clean land followed by a long fallow period. The fallow period is important for the restoration of soil fertility. Slash and burn has harmful effect on the soil because it reduces soil nutrients and increase susceptibility to soil erosion. *Monoculture practices and over cropping.* Monoculture is the practice of growing same type of crop on the same piece of land year after year. Continuous monoculture leads to the fastest depletion of soil nutrient, compared to other method of farming. It leads to decrease in soil organic matter, affects soil structure and increases need for fertilizers as well as more water contamination compared to crop rotation thus, soil becomes exhausted and leads to poor plant growth.

Overgrazing

Soil erosion from overgrazing is the most direct cause of grassland degradation. If there are too many animals that exceed the carrying capacity of pasture, it results to weak recovery of vegitation. Due to this, land surface can easily be eroded by rain and wind. Overgrazing is more common in drier areas of the tropics where pasture degraded by overgrazing are subjected to soil erosion.

Population increase

Population increase in a given locality leads to massive population pressure on land in terms of cultivation, firewood, and timber. These activities lead to the removal of the vegetation cover and consequently expose the soil to the

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agents of soil erosion such as water and wind.

Effects of soil erosion

On-site effects

The implications of soil erosion by water extend beyond the removal of valuable top soil. Crop germination, growth and yield are directly affected by the loss of manure nutrients and applied fertilizers. Seeds and plants can be disturbed or completely removed by erosion. Organic matter from the soil, residues andany applied manure can be relatively or completely removed. Soil quality, structure, stability and texture can be affected by the loss of soil. Textural changes can in turn affect the water holding capacity of the soil. Moreover, on-site effects of soil erosion include destruction of infrastructures such as road and buildings due to removal of the top soil.

Off-site effects

The off-site impacts of soil erosion by water are not always apparent as the case of onsite effects. Eroded soil deposited down slope, inhibits or delays the germination of seeds and buries small seedlings. Also, sediments can accumulate on down slope properties and contribute to road damage. Sediments that reach streams or water course can accelerate bank erosion, obstruct stream and drainage channels, fill in reservoirs, damage fish habitat, and degrade downstream water quality. Pesticides and fertilizers, frequently transported together with the eroded soil, contaminate or pollute downstream water sources, wetlands and lakes.

Soil pollution

Soil pollution refers to the presence of the pollutants into the soil, that impair the quality of the soil. It is one of the forms of soil degradation. Soil is polluted in the same way as groundwater. The sources of soil pollution include *Industrial wastes* results from most industrial wastes containing poison which kills both macro and micro-organism found in the soil. *Agricultural chemicals and domestic wastes* occurs when these wastes and chemicals are deposited in the soil as a result lead to soil pollution. Agricultural activities through application of industrial fertilizers and pesticides are not beneficial if applied repeatedly over long periods. *Mining activities* may also cause soil pollution, the extraction of petroleum for example, may cause soil pollution due to oil spillage. Moreover, oil spill may occur in the process of transporting petroleum through pipes and tracks, thus causing soil pollution. The chemicals in the mineral oil increase the soil pH level and reduce the phosphorous concentration in soil. Both solid and sewage wastes from homesteads may cause soil pollution if not well managed. *Acid rain* occurs where the atmosphere is highly polluted by harmful gaseous impurities emitted from the industries such as Sulphur, Ammonia and Carbonic gases. When harmful gases introduced in the atmosphere are washed back to

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the surface and a combined with water vapour pollute the soil and retard the overall soil quality.

Impacts of soil pollution

Pollution of soil exerts high damage to the soils, and results into numerous effects which include; death of vital soil organisms which in turn retards decomposition of organic matter.Also, it can result to deterioration of both physical and chemical properties of soil which are important for determining soil productivity. Furthermore, it can cause loss of soil fertility due to leaching caused by excessive application of fertilizers and pesticides.

Biological factors that cause soil degradation

Biological factors are affecting the micro-flora and reduce the microbial activities of the soil which reduces the yield. This includes loss of biodiversity, decline in soil organic matter, loss of carbon sink, loss of vegetation cover, increased soil pathogens, and loss of resistance to diseases.

Natural factors that cause of soil degradation

Climate change may cause land degradation in different ways including drought, and heavy rainfall. Drought leads to the disappearance of vegetation cover which exposes soil to agents of erosion. Heavy rainfall leads to increase in surface runoff which eventually speeds up the rate of erosion, leading to the development of rills and gullies.

Soil conservation and management

Generally, soil is considered as a living entity as it supports life of living organisms. It is made from parent rock (mother rock) which gives soil nature and point of originality. Through the process of soil formation, soil can be created and destroyed. For instance, through bad methods of farming soil can be easily destroyed just like any other living organisms. Soil passes through different simple and complex processes in its formation, just like living organism. The formation of soils needs time, the longer the time the mature the soil. Soil water takes 25% of the total soil volume, which comes from either rain, rivers or ocean. This is similar to living organisms such as people whose bodies are made up of 75% of water. Moreover, soil is made up of soil temperature, and soil air which comes from atmosphere and organisms. Therefore, all these life living facts justify why soils are so important to all living organisms. It covers and supports life of many living entities, hence conservation and management of soils is of paramount importance.

Soil conservation is the mechanical protection process of maintaining and improving of soil resource by involving all aspects of land use planning, development, and management. This is the process of preserving, protecting or restoring the soil and its resources, especially for future use. It involves prevention of soil erosion in order to improve its quality and productivity.

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Also, it involves introduction of sound methods of farming which not only prevent erosion but also keep the soil moist and preserve its healthy state. The conservation of soil includes prevention of top most layer of the soil from erosion. *Soil management* is the application of operation, practices and treatments to protect soil and enhance its performance.

Methods of soil conservation

Since people are so dependent on the soil for the supply of food, fuel and fibre, it is vital that great care is taken to conserve, protect, renew and maintain soil fertility. The proper farming practices for soil conservation are crucial to increase infiltration. Some of the important methods for preserving soils include the following:

Contour farming

In contour ploughing the furrows in which the crops are planted follow the contour lines (Figure 5.23). These contour lines create a water break which reduces the formation of rills and gullies during times of heavy precipitation, and allow more time for the water to settle into the soil. This practice can increase crop yield through soil moisture retentions in arid and semi-arid regions. In contour ploughing, the ruts made by the plough run perpendicular rather than parallel to the slopes, generally furrows curve around the land. This method is most important for preventing erosion.



Figure 5.23*: Contour farming*

Terracing

Terrace is one of the oldest techniques for conserving water and soil. Terracing is common in hilly and mountainous regions. Terraces are built along contour lines to increase the arable surface area and conserve soil water and soil on hillslopes. Terraced fields can be of different shapes and sizes and consist of a flat section and a near vertical riser protected by a wall of dry stones, soil, grass, or trees. The height of the riser or wall can be from several decimetres to a few

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meters, with a continuous or intermittent structure comprised of single walls or a complex series of walls. The flat surface created by terracing is generally used for cultivation (Figure 5.24). The creation of terraces on sloping land can reduce slope steepness by dividing the slope into smaller, gently sloping sections resulting in reduced soil and water loss.

Terracing with correct field management can reduce both runoff and sediment loss on average by over 41.9% and 52%, respectively. For example, in the hills of East Usambara Mountain in Tanzania, the *fanya juu* and *fanya chini* terraces have reduced both runoff and sediments loss. Though terraces are considered as advisable conservation practices to avoid soil and water loss the construction and management of terraces often disturb carbon flux between the atmosphere and soil via shifting land-use type and topography, which potentially alter soil organic carbon (SOC) dynamics. Proper land use, for examples, terraced reforestation and afforestation could markedly increase SOC accumulation. For example, in China's landscapes terraces increased SOC sequestration by 32.4% compared to that of the sloping lands on average. Among the ecosystem services provided by terracing are the increase in crop productivity, expansion of land for cultivation and creation of aesthetically pleasing landscapes.



Figure 5.24 *Terracing*

Field strip cropping

Field strip cropping is the production of the regular farm crop in more or less uniform parallel strips laid out cross wise of the general slope but not parallel to the contour strip cropping (Figure 5.25). Field strip is applicable to uniform gradual slopes on soil which are resistant to erosion. This conservation method is simple and can be used in connection with grassed water ways where the true contour cannot easily be followed. Also, the method prevents soil erosion by wind.

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It works even better when high-growing crops are intensified in the side where wind blow most frequently than low-growing crops.



Figure. 5.25 *Stripping method*

Crop rotation

This is the process of alternating different types of crops on a piece of land in a year or each growing season. In a four years' cycle, for example, maize, grass, beans and cotton may be grown. When crops with shallow rooted system are rotated with deep rooted crops, water and nutrients are utilized fully. Plants with deep roots absorb water and nutrients from the lower layer of the soil profile. Also, crop rotation is used in controlling weeds. Some weeds grow well when a certain crop is grown in a field, but when another crop is grown such weeds grow with difficulty. Crop rotation is a good way of controlling plant pests and diseases. Plants of the same family are usually attacked by similar pests and diseases. If a crop of a different family is grown a pest or disease may disappear as it may not attack the crop. Some plants take in a lot of nutrients from the soil. Such plants are called heavy feeders, others take in only little and they are called light feeders. By doing crop rotation of such plants on the field, the level of nutrients in the soil is maintained at a reasonable level.

Mulching

Mulching is the placement of any organic or inorganic material over the top of a soil surface to retain soil moisture and protect it from erosion. The practice can involve covering the soil with a layer of grass, straw, plant remains or even polythene sheets. Cover crops should be grown in empty space in between rows of plants specifically to cover such space. It is used mainly in tree crops, vegetable gardens and pineapple plantations. When straws or grass are used, it is advisable to make sure that they are free from seeds which may cause weeds to develop. Mulching helps to preserve moisture in the soil by preventing or reducing evaporation, reduce loss of soil by erosion, control weeds, prevent use of weed killers and insecticides, which could be hermful to other life forms (Figure 5.26).

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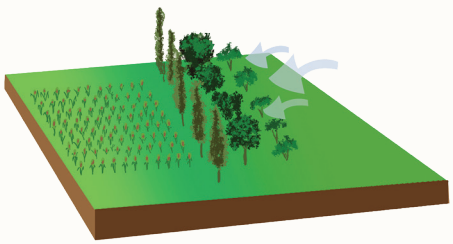
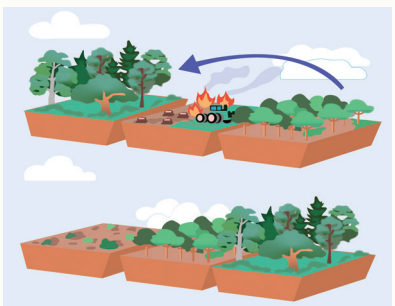
Figure 5. 26: *Mulching method to control soil erosion*

Moreover, there are other methods of soil conservation (Figure 5.27) like *wind breakers* which is a conservation practice used to reduce the power of wind and its destructive effects on soil. It involves planting of trees or maintaining bushes to shelter crops. *Cover crops is* a soil conservation technique used to protect bare land or soil prone to erosion by planting cover crops as secondary species to control agents of erosion such as wind, and water. In agriculture, cover crops are plants that are planted to cover the soil rather than for the purpose of being harvested. *Buffer strips* is a technique of controlling soil erosion which involves planting of trees and bushes along the banks of water bodies to prevent water wash offs. Their roots fix the soil and prevent slumping and erosion. *Afforestation and reforestation* methods ensure soil catchments and prevent soil erosion. The former refers to process of planting trees where none has existed before, while the latter is a process of planting trees where they once existed. *Building of gabions* involves construction of ripraps encased in galvanised steel wiremesh cages or cylinder. They are used to stabilize slopes, shorelines, and stream banks. *Ripraps* is the process of pilling off rock pieces to create a structure known as rip-rap. The pilled rocks consist of different rock types of different size to protect shoreline, stream beds, and bridge abutments. *Reno mattresses* are rectangular baskets made of heavenly galvanized, double twisted steel woven wire mesh. They are used for retaining walls, channel lining, slope stabilization, and dams. *Drop structures* are also known as grade control, sill or weir. They are man-made small structures, usually built on minor streams or as a part of a dam's spill way, to pass water to a lower elevation. Drop structures control the energy and velocity of water as it passes over, thus reduces soil erosion. *Chute spillway* are open channels like structures constructed on steep slopes of gullies face with a suitable inlet and outlet. It consists of an inlet, vertical curve section, steep-sloped channel and outlet. The major part of

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the drop in water surface takes place in a channel. Water flow passes through the inlet and down the paved channel to the floor of the outlet. Chute spillway is used to control gully head and convey the runoff from upstream into the gully. *A check dam* is a small barrier that is placed across a river or channel to slow the movement of water and sediments and to reduce channel erosion. These are tiny, sometimes temporary dams built across a drainage ditch or channel to lower the velocity of flow of water. The slowed runoff velocity reduces erosion in the channel. A check dam can be built by stones, sand bags filled with gravels or logs.

No.	Figure	Figure
1	 *(a) Wind breakers*	 *(b) Cover crops*
2	 *(c) Buffer strips*	 *(d) Afforestation and reforestation*
3	 *(e) Building of gabions*	 *(f) Ripraps*

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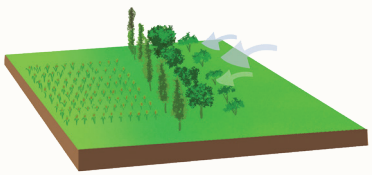
4	 *(g) Reno mattresses*	 *(h) Drop structures*
5	 *(i) Chute spillway*	  *(j) Check dams*

Figure 5.27: *Other methods of soil conservation*

The role of institutions in conserving and managing soils

Tanzania is institutionally committed to ensuring that it effectively implements soil conservation. In fulfilling this obligation through the responsible ministry for agriculture and associated agencies and departments it has formulated policies and implements them, creates enabling environments for implementation of soil conservation plans, programs and strategies. It also collaborates with local and international institutions in implementation of soil conservation.

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The government of Tanzania works with the World Wide Fund (WWF) for nature. The WWF is an international non- governmental organization founded in 1961 that collaborate with the country in wilderness preservation and reduction of human impact on the environment.

Another organization is the African Wildlife Foundation (AWF) which is the international conservation organisation which in collaboration with the country focuses on Africa's wildlife and wild lands. The AWF's programs and conservation strategies are designed to protect the wildlife and wild land of Africa and ensure a more sustainable soil and water conservation strategies in Africa.

Again, the International Union for Conservation of Nature (IUCN) is an organisation which collaborates with the country in nature conservation and sustainable use of natural resource. It is involved in data gathering and analysis, research, field projects, advocacy and education. A good example can be drawn from East Usambara mountains, since 1980s, the government of Tanzania in collaboration with Non-Governmental Organisations (NGOs) and various donors have been addressing land degradation problem in East Usambara mountains.

In 1987 the European Economic Community (EEC) and the International Union for Conservation of Nature (IUCN) in collaboration with the government of Tanzania established the East Usambara Agricultural Development and Environment Conservation Programme (EUADECP). The programme aimed at conserving forest catchments and agricultural land by introducing contour strips planted with guatemala grass (Tripsacum laxum) and agro-forestry. In 1991 the government of Tanzania in collaboration with the government of Finland through Finland International Development Agency (FINIDA) introduced the East Usambara Forest Conservation Project (EUFCP). The aim of the project was to conserve forests and control erosion on arable land by planting contour strips and provide tree seedlings to the farmers in order to reduce pressure on forest resources.

In the year 2000, Muheza District Development Programme (MDDP) with the support from Irish Aid introduced Contour Farming Project in East Usambara mountains. The objectives were to control runoff and soil loss from the agricultural lands and to improve soil fertility, by using land management practices and locally available nutrients sources such as farm yard manure and crop residues. The broad target was to increase land productivity thereby improve household food security and income. Other country initiatives include soil conservation in Dodoma that aimed at saving the region from severe erosion. In this region the country in collaboration

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with various institutions it implemented soil conservation initiative known as Hifadhi Ardhi Dodoma (HADO) since 1973. The main objectives of HADO, among others, was to protect land from degradation and to rehabilitate the already depleted soils. The activities carried out include reclamation of land already destroyed by soil and gully erosion, raising and distribution of tree seedlings, and planting of demonstration woodlots and protection. The land reclamation methods used involved distocking and removal of people from non-agricultural areas.

Other methods involved introducing zero grazing; construction of contour ridges and planting of vegetation such as Agave, Eucalyptus, and Leucaena on the ridges; construction of the stone-check dams to control gully erosion; and planting of vegetation in the gully bottoms. Moreover, included protection of grazing, settlement, establishment of new agricultural farms, discouraging illegal tree cutting, and bush fires. This was achieved by carrying out regular patrols and labourers and control fire outbreak. HADO was successfully in many ways including substantial vegetation recovery, take off of the gully healing processes, rivers now follow more defined water courses, and arable land were accessible. Despite the above achievements of the project, it was generally challenged for not being participatory in nature rather it was considered as top-down. This is revealed in the local people dislikes that have led to many court cases and fines. Such a situation brought strain and conflicts between the HADO staff and the local communities that the project is supposed to serve.

Soil conservation case study

Farmers at farm level play great role in soil conservation and management. For example, in 1990s northern Tanzania's Arusha region was encountering serious threats to farming and food security. To overcome this problem, farmers in Likamba launched their own self-help organization, the Eotulelo Farmer Field School (FFS). *Eotulelo* translates to "come and join us" in the local Maasai language. The original motivation to start the Eotulelo FFS came from experiences of the neighboring village, Ngorbob, where the Regional Land Management Unit (RELMA) had started working with the community on conservation agriculture. Conservation agriculture carried out in the area entails a system of farming that conserves, improves, and makes more efficient use of natural resources, through integrated management of available soil, water, and biological resources. It combines three principles: which are disturb the soil as little as possible rather than plowing and keep the soil covered with cover crops, crop residues, or mulch and rotate or mix crops (planting a cereal such as maize and a legume such as pigeonpea or lablab).

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The Eotulelo Farmer Field School participants strive in increasing yields dramatically and improved resource management through erosion-control technologies, sustainability measures, improved cattle and goat sheds, fodder planting, and new income sources.

Extension officers at various administrative levels deliver extension education to famers on soil conservation and conservation agriculture in general. The ministry of agriculture has 14 agricultural training institutes in the country to mention few are MATI-Tumbi-Tabora, Hort Tengeru- Arusha, Inyala and Uyole-Mbeya. These institute offer certificates and diplomas in general agriculture. Besides that, the institutes conduct research and offer extension services to farmers. In addition, the Department of Soil and Geological Sciences of the College of Agriculture at the Sokoine University of Agriculture (SUA) offers undergraduate and graduate degree programmes in soil science. Its mission is to train and provide advisory services to farmers on soil and geological sciences. Furthermore, the ministry has established the Tanzania fertilizer Regulatory Authority (TFRA). The authority ensures that farmers obtain fertilizers in time through provision of subsidies such as the input voucher system.

Another important national institution in soil conservation and management is the National Environmental Management Council (NEMC). The council is the principle institution for the implementation of the National Environmental Management Act (2004). The Act prescribes among other things, the establishment of the National Environmental Standards Committee and formulation of environmental regulations that ensure soil protection in agriculture and habitat. The main objectives of the soil quality standards are to set limits for soil contaminants in agriculture and habitat, and enforce minimum soil quality standards.

The Ministry of Land Housing and Settlement is concerned with the preparation of village land use plans, urban planning, and land surveying and mapping. For example, village land use planning is prepared by national land use planning commission (NLUPC), district participatory land use management team and village level land use management committee. The plans are prepared for the sake of minimizing conflicts, enhancement of land tenure security, increased agricultural productivity through identification of areas for commercial agricultural investment and to ensure land allocation for investment and facilitate conservation of water and soil. Proper implementation of these plans will enhance soil management and conservation both in the rural and urban areas.

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Activity 5.5

In a groups, visit a neighboring farming community and walk around their farms and then;

(a) Identify water conservation practices used in their farms.

(b) State the advantages and disadvantages of each practice identified.

(c) Present the findings in the class and allow your fellow students to ask questions and make contributions.

(d) Write notes in your exercise book and submit to the subject teacher for marking.

Revision exercise 5

1. Examine the indicators of soil fertility.
2. What are the factors which affect soil fertility in a given geographical area?
3. Describe the consequences of soil degradation based on the sectors of your choice.
4. Soil is referred to as a living entity. Justify the statement geographically.
5. Differentiate between soil conservation and soil management.
6. Give an account of the farming practices that preserve soil fertility.
7. With examples, describe the role of various institutions in conserving and managing soils in Tanzania.
8. With the aid of diagram describe the process of nitrogen fixation and explain on how it helps in plant nutrient uptake.

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Chapter Six

Atmospheric dynamics

Introduction

Weather and climate amongst other factors influence people's lifestyles and the activities carried out on one hand, and on the other influence their decision over time. Also, understanding of weather and climate of a particular place can be a good indicator of understanding peoples' way of living in that place. In this chapter, you will learn about weather and climate, and thier dynamics, the world's climate regions and climate change altogether linked with the human activities. The competencies obtained from this chapter will enable you to plan and carry out various economic activities such as agriculture, business and other production enterprises based on climatic element such as precipitation, clouds, sunshine, humidity, wind and temperature.

Weather and climate

Weather refers to the state of the atmosphere at a particular geographical area for a short period of time, it can be hourly, daily, weekly, monthly or seasonally. Weather describes atmospheric conditions that principally guide individual decision when planning for outdoor activities. For instance, knowing when it is sunny or rainy, warm or cold, helps an individual (s) to decide what type of clothes to wear, and re-organize domestic activities.

Climate is the average weather conditions of the geographical area recorded for a long period of time. Usually, thirty to fourty years are considered to be the minimum period of time for establishing an adequate summary of a particular climate of an area. Climate constantly varies with varying geographical locations and time. Although weather and climate are related, yet they are neither, synonimous nor be interchangeably used. Weather is '*what you get'* while climate *'is what you expect'*.

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Elements of weather and climate

Although weather and climate are not identical, they share the same elements which are temperature, humidity, clouds, precipitation, air pressure, wind, and sunshine. These elements are very much interrelated in terms of variation as a change in one of them will bring about changes in others. At the weather station, each of the elements is recorded by a specific instrument.

Atmospheric temperature

Atmospheric temperature originates from the Sun whose interaction affect the incoming and outgoing solar radiation. Atmospheric temperature refers to the degree of hotness or coldness of the atmosphere. Temperature is measured by a thermometer and expressed in Celsius (°C) or Fahrenheit (°F) or Kelvin (K). Emission of solar radiation into the atmosphere leads to scattering, reflecting and/or absorbing of solar radiation which is needed in energy balance. This means that, when short-waves are emitted by the Sun, as they pass the atmosphere, three processes may occur which are *absorption, reflection,* or *scattering*.

Absorption refers to the process in which solar radiation is retained by a substance and converted into heat. It is the consumption of solar energy by various atmospheric components such as water vapour, clouds cover, and carbon dioxide. As a result, the heat gained by those substances, will enable them to emit their own radiation (infrared). In general, the absorption of solar radiation by substances in the earth's atmosphere results in temperatures of utmost 1800° celsius. About 19% of the solar radiation is absorbed by the atmospheric contents particularly, carbon dioxide, water vapour, ozone, and particles of dusts and ice. The absorbed proportion of solar radiation is so small (low) because they are forms of short waves which pass with little check through the atmosphere. An object or substance that is good radiator is also a good absorber, and the vice versa is true. For example, mineral materials like rocks and soils are generally excellent absorbers; snow and ice are poor absorbers, and dark coloured surface are much more efficient absorbers 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 particle (Figure 6.1). It occurs when the radiation hits the particles 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 is expressed in percentage. The albedo varies with cloud type from 30 – 40% in thicker stratus clouds and 90% in cumulo-nimbus clouds, only 10% reaches the atmosphere below cloud level. Also, albedo varies over different land surfaces. The ocean, and dark soil have an albedo of less than 10%, coniferous forest and urban areas

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15%, grassland and deciduous forest 25%, light-coloured deserts 40% and fresh snow 85%. The occurance of deforestation and overgrazing practices result to the increase of the albedo, this reduces the chance of cloud formation and precipitation triggering the risk of desertification.

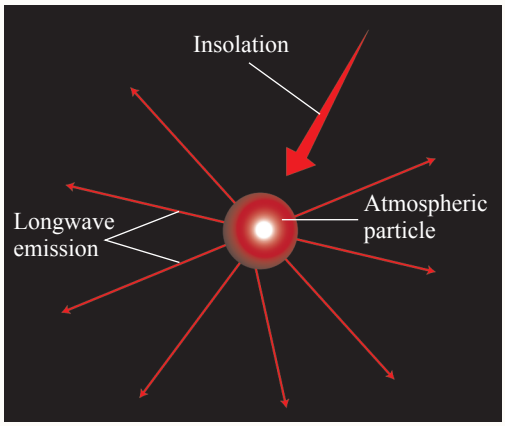


Figure 6.1: *Reflection of solar radiation*

Scattering is a process whereby sunlight is diverted from its straight path on striking obstacles like dusts, gases molecules and water vapour. Scattering takes place in all directions, and some of the solar radiations reaching the earth's surface as diffused radiations. About 8% of the incoming solar radiation is lost by scattering. Scattering therefore, reduces the amount of incoming solar radiation reaching the earth's surface. A significant proportion of scattered shortwave is redirected back to space (Figure 6.2). 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. Basing on such grounds, scattering is categorized as 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. It 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 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.

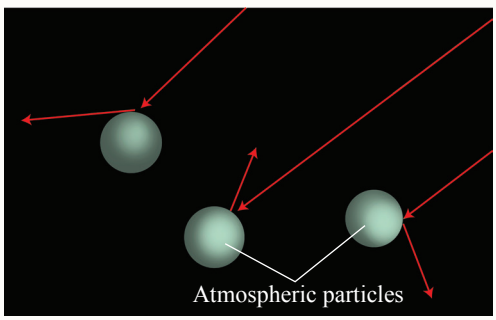


Figure 6.2: *Scattering of solar radiation*

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It should be noted that, the presence of absorption, reflection and scattering processes of solar radiation, results to only about 46% of incoming solar radiation to reach the earth's surface directly, and as diffused radiation (Figure 6.3). 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 form of long waves back into the atmosphere where 6% is absorbed mainly by water vapour and carbon dioxide which are greenhouse gases that mostly cause greenhouse effect. Without greenhouse effect, much of the outgoing radiation would have been lost, consequently, the world temperature would be colder 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*.

Solar energy and radiation balance

The sun is the main source of energy to the planet Earth. The solar radiation also known as short wave or insolation travels through space from the sun in form of electro-magnetic energy. Insolation in this regard, refers to the solar energy that reaches the earth's atmosphere and surface which can be reflected, scattered or absorbed and often the occurance of all processes. Energy from the sun controls weather and climate aids photosynthesis process. This energy is converted into food substances that supports all forms of life on Earth. 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). Solar energy accounts for 46% of the solar radiation that passes through the atmosphere to become available on the earth's surface. This energy is used for three main purposes which are heating the earth's surface and the lower atmosphere, evaporating and melting of ice, snow, and glacier, as well as running photosynthesis processes in plants.

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, and reaching a 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.

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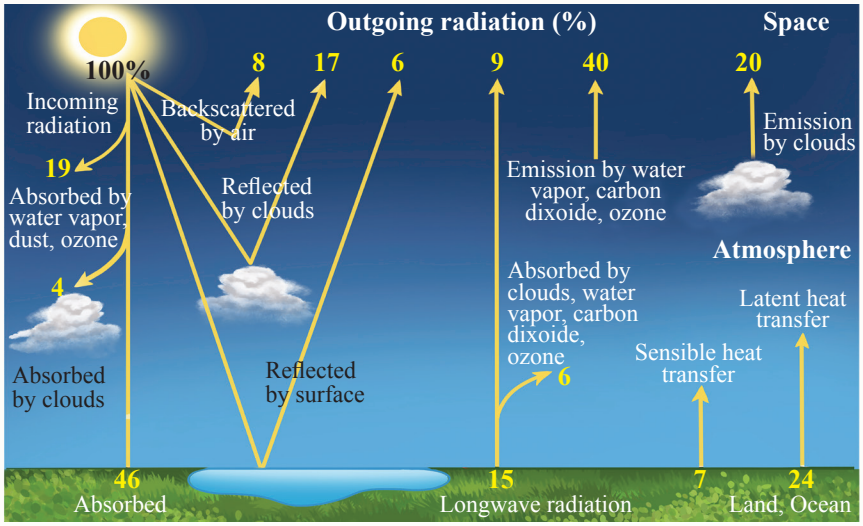


Figure 6.3: *Solar energy transfer*

However, it has to be clear that, the incoming solar radiation varies with time and geographical locations across the globe (Figure 6.4).

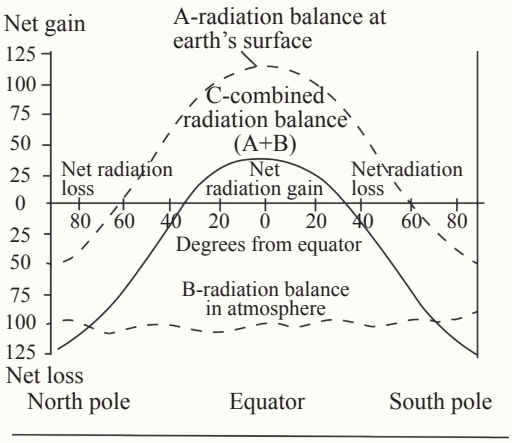


Figure 6.4: *Heat budget*

As shown in Figure 6.4 net gain of radiation exist everywhere on the earth's surface as illustrated in Curve A, except in polar latitudes where albedo is very high. There is also a net loss in radiation throughout the atmosphere as indicated in Curve B. After balancing the incoming and outgoing radiation there is a net surplus between 35°S and 40°N. The difference in latitude is due to the larger land masses of the pole ward sides of those latitudes shown in Curve C. This means that, there is a positive heat balance within the tropics and a negative heat balance both at high latitudes and altitude.

Heat transfer

Heat transfer refers to the vertical and horizontal flow of heat energy along the thermal gradients normally resulting from differential heating. The amount of heat contained in the atmosphere can always be transferred from one location to another as well as from one atmospheric component to another.

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Heat transfer occurs in order to avoid overheating and overcooling of parts of the surface of the Earth.

Mechanisms of heat transfer in the atmosphere

Mechanisms of heat transfer are basically the means by which heat energy is carried from either one molecule to another or one geographical area to another. Heat transfer in the atmosphere can either be horizontal or vertical.

Horizontal heat transfer

The heat is transferred horizontally away from the tropics preventing the Equator and polar belts to become hotter and colder respectively. It involves transfer of heat from mid-latitudes area where there is heat surplus to high latitudes area where there is heat deficit in order to avoid overheating and overcooling of mid and high latitude areas respectively. Generally, winds are responsible for about 80% of this kind of heat transfer while the ocean currents account for only 20%.

Vertical heat transfer

Heat can be transferred upward to prevent the earth's surface from becoming very warm and the atmosphere to become colder. It involves transportation of heat from low altitude to high altitude areas in order to avoid overheating and overcooling of low and high altitude areas respectively. There are three processes of vertical heat transfer namely radiation, conduction, and convection.

Radiation

Radiation is the transfer of heat energy between two objects by electromagnetic waves. Solar radiation in the atmosphere is absorbed by gases, water vapour, particles, while on the earth's surface it is absorbed by trees, flowers, soils and water bodies which then warm up. Dark objects on the surface absorb and warm faster than light coloured objects which reflect the radiation back to space. All substances tend to emit radiation (infrared). However, a substance's temperature will determine which wave length of radiation the substance will emit and the emission rate. Therefore, the higher the substance's temperature, the shorter the wave length of the emitted radiation. Similarly, the higher the substance's temperature, the greater the emission rate of the radiation.

Conduction

Conduction is a mechanism of heat transfer in the atmosphere whereby the heat moves from areas of much more heat to areas of less heat by direct contact of molecules. Warmer molecules vibrate rapidly and collide with other nearby molecules leading to the transfer of their energy. Heat transfer through conduction can be

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demostrated by holding a metal bar between fingers and place it to a flame, the bar will absorb energy from the flame and the molecules inside it will begin to move, and the fingers will heat up, indicating that heat is transfered from the bar to fingers. This is one of the good examples of heat transfer through conduction. When heat is transferred through conduction, it flows from warmer to colder regions through air molecules and dusts. The transfer becomes more rapid when temperature differences increase. The rate of heat transfer through conduction depends on the nature of substances which can be good or bad conductor of heat. In the atmosphere, conduction is more effective at lower altitude where air density is relatively higher, and transfered upward to low density areas in which the molecules are spread further apart.

Convection

Convection is the transfer of heat through movement of water or air molecules. This type of heat transfer can occur in liquids and gases because their free movement of the molecules, making it possible to set up warm or cold currents. Convection occurs naturally in the atmosphere on a sunny day. As the earth's surface absorbs sunlight, proportionally certain portions of the surface absorb more of it than other portions. The earth's surface and the air near the surface heat unevenly. The warmest air expands and becomes less dense than the surrounding cooler air making them rise and become buoyant. These rising "bubbles" of warm air, called *thermals* transfers heat up into the atmosphere. Cooler, heavier air then flows onto the ground surface to replace the warm air that has risen. When the cooler air reaches the surface, is warmed as well, eventually rises as a thermal. This circulation is referred to as a *convective circulation* or *thermal cell*.

Variations in the radiation balance

The variations in radiation balance occur at different spatial and temporal scales. Regional differences are caused by uneven distribution of land, sea, altitude and the direction of prevailing winds. Local variations can be caused by aspect and the amounts of cloud cover while seasonal and diurnal variations are related to the altitude of the sun and the length of night and day.

Global factors affecting temperature

Factors affecting amount of temperature received at a given place and its radioactive balance vary considerably over time and space. This means that the temperature of a place depends on both *long term, short term* and *local factors*.

Long-term factors

Nature of the surface

Amount of temperature is not homogeneous all over the surface. The

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nature of the surface includes both land and sea. Land and sea differ in their ability to absorb, transfer and radiate heat energy. The water surface is more transparent than the land, it is capable of absorbing heat down to a depth of 10 metres. It can then transfer this heat to greater depth through the movements of waves and currents. Concerning land, it reflects high proportion of the solar radiation. For example, burnished silver reflects 95% of the solar radiation, while darker earth substances absorb more solar radiation. Water has a greater specific heat capacity than the land, therefore, land surfaces heats up more rapidly and more intensively than water surfaces, and cools more quickly compared to the water surface. As a result of differential thermal response, the land is hotter during the summer but cold in winter, while the sea is warmer during the winter but cold in summer. Similarly, the land is hotter in the day but cold in night while the sea is warmer in the night but cold in the day.

Distance from the sea

The continents tend to be warmer in summer than oceans in the same latitudes, but appreciably colder in winter. Therefore, the larger the land-mass the greater the contrast. During summer, the sea heats up more slowly than the land, while during winter, the opposite is the case. This causes areas near larger water bodies to be warmer in winter compared to those areas which are in the continental, the reason is that, the winds (on-shore winds) lose their moisture content before reaching continents. Instead they reach as dry cool winds.

Oceans, act as efficient '*thermal reservoirs*'. This explains why coastal environments have smaller annual range of temperature than locations at the centre of the continents. The climates whose temperatures are influenced greatly by the sea are called *Maritime or Oceanic or insular climates*. These climates occur on coastal regions which lie under prevailing wind (on shore wind). The climates whose temperatures are greatly influenced by remoteness from the sea are called *continental climates*. These occur most frequently in the interior of continents. This can be well understood through the concept of *land and sea breezes* which will be discussed in the next section.

Altitude

Altitude has an immediate influence on temperature. Water vapour and dust in the air prevent heat formed at the surface of the Earth from rapidly passing back into space. But at high altitudes, for example on the tops of high mountains, the air is rarefied and it contains very little dust or water vapour. The heat from the tops of high mountains rapidly escapes and the air remains cold. As altitude of an area

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increases, temperature decreases, and so does the density or pressure of the air. Air temperature in the atmosphere decrease at the rate of 0.6°C in every 100 m of rising. This is because the molecules in the air which receive and retain heat become fewer and more widely spaced as height increases. The effect of altitude on temperature can be well understood through the concept known as '*lapse rate*' (Figure. 6.5). Generally dropping tendency of temperature with the increase in height is caused by the changes in the concentration of dust and soot particles, and water vapour molecules which are carriers of heat and are usually more concentrated in lower elevation level, due to gravitational attraction. Therefore, the higher the concentration of particles, the higher the temperature and vice versa. Highly elevated areas like mounteneous regions normally experiences their own climatic patterns compared to low land areas.

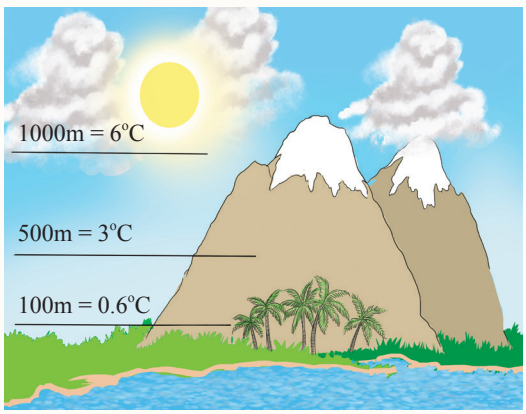


Figure 6.5: *Effect of altitude on temperature*

Temperature lapse rate

It expresses the physical condition whereby atmospheric temperature changes in response to the change in altitude which is a height from the mean sea level. It is the process decribing decrease or increase in temperature as the altitude increases or decreases respectively. The temperature in lapse rate is caused by the expansion and compression of air as it either descends or ascends at an altitude. Therefore, the loss of temperature is brought about by air expansion as it ascends into the upper levels of the atmosphere, while the increase of temperature is brought about by air compression (contracted) to high pressure down the slope, descending as it losses altitude.

Types of temperature lapse rates

The temperature lapse rates are categorized into environmental and adiabatic.

Environmental lapse rate (ELR)

This is the average decrease of temperature in a still air (stationary air) with change in altitude (increase in altitude) without being affected by the surrounding air or water vapour. It is a vertical distribution of temperatures at a given geographical location and time. The ELR can also be understood as the decrease in temperature experienced with gain in height through the troposphere at an approximate rate of 0.6ºC for every 100 m depending on

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the local conditions. Factors affecting ELR are;

(i) *Height:* ELR is lower at the ground level.

(ii) *Season of the year*: ELR is lower during winter and rain seasons than during summer.

(iii) *Surface characteristics*: ELR is lower over mainland areas than over the oceans, seas, lakes and dense forests.

(iv) *Air-mass*: ELR varies with differences in the characteristics of air masses. ELR decreases with the increase in the amount of water vapour (humid air) and increase with decrease in the amount of water vapour (dry air).

Adiabatic lapse rate (ALR)

This is the rate at which temperature of an air parcel changes in response to the compression or expansion associated with elevation change without gaining or losing any heat to the environment surrounding the parcel. This describes what happens when a parcel of air (air mass) rises. The temperature decrease with an increase in altitude either below or above normal. When an air mass rises, increases its volume while decreasing its pressure and temperature. The ALR also describes a situation where the descending air mass decreases its volume while increasing its pressure and temperature down the slope with the decrease in altitude. In either of the two processes of air mass (descending or ascending) the mixing with the surrounding air mass is negligible. Adiabatic lapse rate can be categorised into the following types:

Warm adiabatic lapse rate: This is a type of adiabatic lapse rate which occurs as a result of dynamic compression which usually takes place due to descending air masses in an area with high pressure. *Cool adiabatic lapse rate:* This occurs due to dynamic expansion of air which tends to scatter air molecules away from each other, hence reducing its pressure and temperature. Cool adiabatic lapse rate includes dry and wet adiabatic lapse rate.

Dry adiabatic lapse rate (DALR): It occurs when an unsaturated air mass ascends vertically and expands together with losing its pressure, which results in cooling and loss of its temperature adiabatically. The meteorological constant loss of temperature is 1ºC for every 100 m of ascent. In this process, the upward movement of air does not lead to the condensation. Therefore, the energy used by expansion will cause the temperature of the air parcel to fall.

Wet or saturated adiabatic lapse rate (SALR): It is the one which occurs when upward movement of air mass is sufficiently prolonged to enable the air to cool to its dew-point temperature, allowing condensation to take place. At this point the loss of temperature

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with the gain in height (altitude) is compensated by the release of latent heat. The saturated air mass which therefore cools at a slower rate than unsaturated air mass, loses heat at the saturated adiabatic lapse rate. The released latent heat reduces the rate at which the ascending air mass cools. The saturated or wet adiabatic lapse rate can take place anywhere between 0.3ºC and 0.9ºC per 100 m of ascent depending on the amount of water vapour present and the temperature of the air.

Temperature inversion

This is an increase in temperature with increase in altitude. It is the reverse of the normal temperature lapse rate where temperature decreases with increase of altitude. On the earth's surface, temperature inversion lasts only for a short period of time but below and within the ozone layer the condition may be permanent. Sometime due to differences in density, the warm air overlies the cool air mass at different levels of the atmosphere. Temperature inversion can occur in the stratosphere and troposphere, that is, near the ground-level and high in the troposphere. High level temperature inversion occurs in the stratosphere due to presence of the ozone layer. It also occurs in the thermosphere as a result of presence of atomic oxygen and ionized particles. It also involves temperature inversion in upper troposphere. High level inversions are found in the depressions where a warm air-mass overrides a cold air mass at the warm front, or is undercut by colder air at the cold front.

Low level or ground inversions usually occur under anti-cyclonic conditions when there is a rapid loss of heat from the ground due to radiation at night or when warm air is advanced over a cold surface. This explains why fogs and frosts form along the valleys and hollows or depressions, especially during early morning.

The increase in temperature is experienced from about 15ºC to 29ºC (60º – 80ºF) at about 50 km in the atmosphere, especially in the stratosphere due to the presence of the Ozone which causes the absorption of shorter ultra violet rays. The ultra violet rays constitutes the radiant energy from the sun which result in heating the thin layer of the atmosphere, leading to the formation of a hot layer. Inversion also occurs below the Ozone layer due to accumulated greenhouse gases which act as a blanket that absorbs heat normally, the long waves. As the absorption of long waves takes place, heat waves below the ozone layer increase, causing the lower part temperature to increase as well. Hence, when some one moves from the ground towards the troposphere, will start experiencing a temperature lapse rate of about -80ºC (-112ºF) and then the temperature inversion as you approach the Ozone to about 20ºC (68ºF).

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Temperature inversion in the atmosphere is generally caused by number of factors including the following;

(i) Convergence of air masses. When two heterogeneous air mass with contrasting humidity and temperature converge, the warm humid air mass is forced to rise over a cold dry air mass causing the upper part of the atmosphere to be warmer than the lower parts. This also results into the formation of frontal rainfall and frontal fog among others.

(ii) Land breezes. Due to differential cooling between the land and the sea, land experiences high pressure in the night due to low temperature while the sea develops low atmospheric pressure since it is warm. This results into movement of winds from the land towards the sea. The cold air from the land then replaces warm air (less dense) over the surface of the sea, forcing it to rise, leading to temperature inversion.

(iii) Terrestrial radiation. The cloudy atmosphere especially during the night tends to absorb the outgoing long wave radiation and progressively getting warmer than the ground since the ground keeps on losing heat. This creates thermal inversion since the ground gets cold while the atmosphere gets warmer (Figure 6.6).

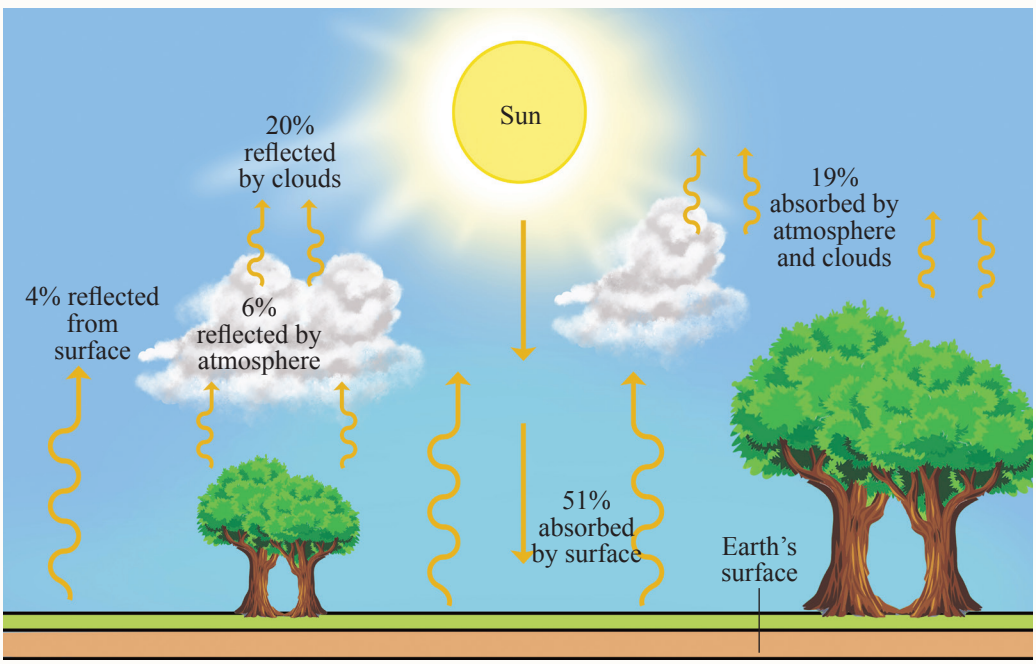


Figure 6.6: *Terrestrial radiation*

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(iv) Air subsidence. When the large mass of air especially in high pressure parts of upper atmosphere is down lifted, it normally becomes compressed making its air molecules to rub against each other leading to generation of heat and hence warming (Figure 6.7).

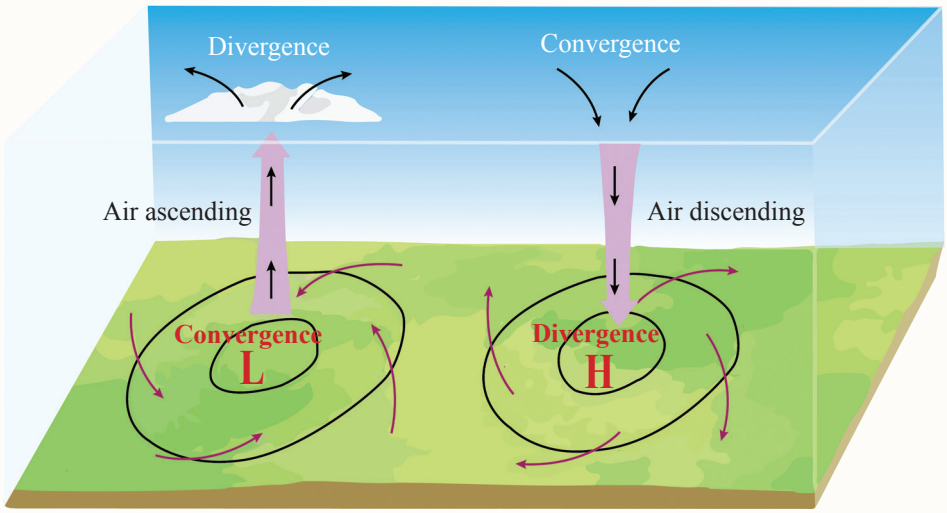


Figure 6.7: *Air subsidence*

(v) Advection. Temperature inversion is experienced when a warm air mass moves over the cold surface of the ground or sea. Such a horizontal movement of air result to the transfer of heat to the surface cold winds. This will eventually make the upper part of the atmosphere to appear warmer than the lower parts (Figure 6.8).

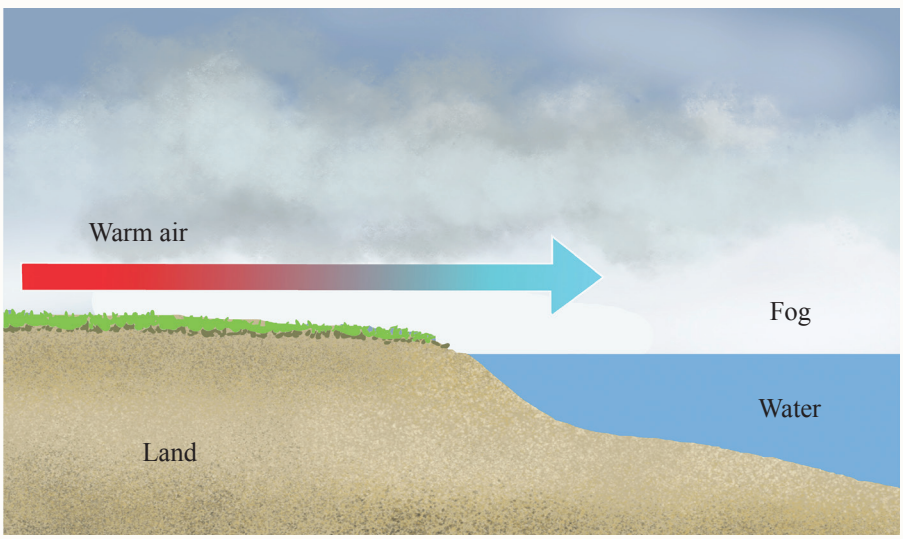


Figure 6.8: *Advection of airmass*

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Exercise 6.1

1. Write short notes on the following;
   (a) Weather
   (b) Climate
   (c) Albedo
2. Explain the key elements of weather and climate.
3. Differentiate weather from climate.
4. Differentiate between atmospheric temperature and heat.
5. Describe the process of solar energy interaction with atmospheric matters.
6. What is a lapse rate? In what ways does its study assist the understanding of weather and climate?
7. Explain the implications of temperature lapse rate on weather.
8. How does temperature inversion determine weather changing?
9. Explain any four causes and effects of temperature inversion.

Ocean currents

Ocean currents are the continuous, predictable, directional movement of seawater driven by gravity, wind, and water density. Wind tends to drag water along the barometric gradient leading to the movement of surface water of the ocean or sea. The coldness or hotness of the ocean currents depends on the source region. Density and gravity determine the upwelling and down welling of ocean or sea water. Basing on the origin, ocean currents can be warm or cold which rises or lowers the temperature of an area subjected to them respectively. The surface temperature of water affects the temperature of the air above it, in the sense that cool water cools the air while warm water warms it. Warm and cold ocean currents often raise and lower the temperature of coastlands respectively, especially if the winds are onshore.

Ocean currents and winds have the ability to transfer temperatures because ocean currents travelling away from the equator contain warm water, while those travelling towards the equator contain cool water. Cold ocean currents have less effect on the temperatures of coastlands because they are mainly located in areas where the winds are off-shore. But there are exceptions, for example, during summer, winds along the east coast of Canada are onshore and they are cold because they have crossed "*the cold Labrador current*". When this current moves, it usually lowers the summer temperature. Similarly, along the coasts of California and Peru where onshore winds cross the cold Californian and Peruvian currents, summer temperatures are lowered. Moreover, the cooling influence of the Southward-flowing cold

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Canaries current can be felt as far as South Cape Verde, on the West Coast of Africa. Warm ocean currents moving towards the poles carry tropical warmth into the high latitudes, and this warming influence is marked between latitudes 40º and 65º on the West sides of continents. For instance, the warmth of the North Atlantic Drift is carried to the land by the prevailing Westerly Winds, mainly in the winter (Figure 6.7).

Activity 6.1

In a group of five students;

(a) Search for up-to-date digital or hardcopy world maps indicating world's ocean currents.

(b) From the map, identify warm and cold ocean currents in the world.

(c) Share with fellow students to see how exhaustive your list is.

(d) Write in your exercise books.

(e) Submit the exercise books to the subject teacher for evaluation.

Exercise 6.2

1. What do you understand by the term ocean current?
2. With examples, explain the effects of ocean currents.

Prevailing winds

Onshore winds in the tropics blowing from the cooler ocean tend to modify temperatures on the coast margins. The onshore winds such as the Westerlies may carry mild temperatures from the oceans to the continental margins in winter. Local winds such as the warm Sirocco, the cold Mistral, Bora, and Föhn or Chinook on the leeward side of mountains may produce rapid temperature changes. Usually, onshore winds influence coastal temperatures when the winds have crossed ocean currents. But even if there are no ocean currents, onshore winds tend to lower summer temperatures and raise winter temperatures in temperate latitudes. Similarly, such winds have a cooling influence on day temperatures in tropical latitudes. This is noticeable along the coast of West Africa when the South West monsoon winds blow. Sometimes, this influence extends up to 100km inland. During the northern winter, such as from November to February, the cool Harmattan blows out of the Sahara towards the coast of West Africa, and this lowers the temperature, especially in those regions bordering the Sahara. During the hot seasons, the Harmattan winds are hot dry and dusty, often causing the temperature to rise sharply.

Length of the day and night

Insolation is only received during daylight hours and reaches its peak at noon. The axis of the Earth about which

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it rotates is tilted at an angle of 66½° to the plane of the path it traces during its revolution. As a result, the position of the overhead midday sun varies throughout the year. The sun appears to "decline South" in the northern winter and to return to North in summer. The angle of incidence at which the sun's rays fall upon the surface of the earth influences their heating effect. During spring and autumn equinoxes, around 21st March and 22nd September every parallel is half in daylight and half in darkness. This makes day and night to be almost equal throughout the world and almost equal amount of sunshine over all areas.

During summer and winter solstices (21st June and 22nd December) when the sun is overhead at the tropics due to the Earth's tilt, the hemisphere experiencing "summer" will receive maximum insolation (Figure. 6.9). All places nearby the equator experience equal day and night all the year. Northwards or Southwards towards the poles, the length of day and night vary with latitude. For example, in the northern hemisphere when Earth is inclined toward the sun days are longer than night and southern hemisphere when the earth inclined towards the pole nights are longer than days (Table 6. 1).

Table 6.1: *Duration of day and night*

Months	Diurnal duration of daylight hours (in terms of monthly mean hours)			
	Equator	50°N	60°N	70°N
March	12.13	11.81	11.70	9.55
June	12.13	16.22	18.59	No night
September	12.13	12.60	12.86	15.50
December	12.13	8.09	5.93	No day

Latitudes

The curved nature of the earth's surface causes the distance from the Sun to the earth's surface and the angle of incidence of sun rays to the Earth to vary. The variation results into differential in heating between the tropics as compared to the polar areas. Relatively, there is long distance between the Sun and the earth's polar areas in which radiation reaches at acute angle leading to relatively low temperature, which may be reflected by pressure of the ice sheets over there.

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However, this is not the case in the tropical areas. Hence, heat intensity and duration of sunlight vary with latitude (Figure 6.9).

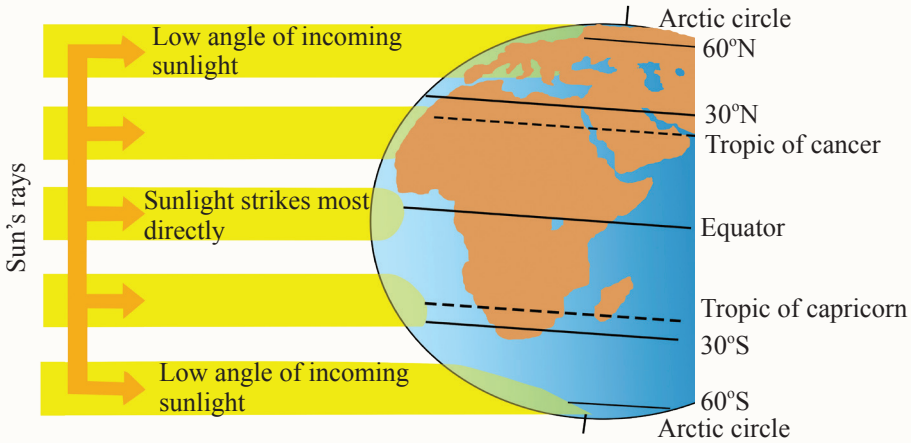


Figure 6.9: *Impact of latitude on temperature*

Elliptical orbit of the Earth on revolution

Elliptical orbit of the Earth affects the temperature of the earth's surface and atmosphere mainly by *earth's revolution*. Through revolution, the earth has an elliptical orbit around the sun, this causes the earth to tilt or incline towards the sun. Its farthest position from the sun is on July 4th (Aphelion – 152 million km away from the sun) and its nearest position is on January 3rd (Perihelion – 147.3 million km away from the sun). Therefore, the amount of solar energy received is 6% more at the perihelion as compared during aphelion (Figure. 6.10).

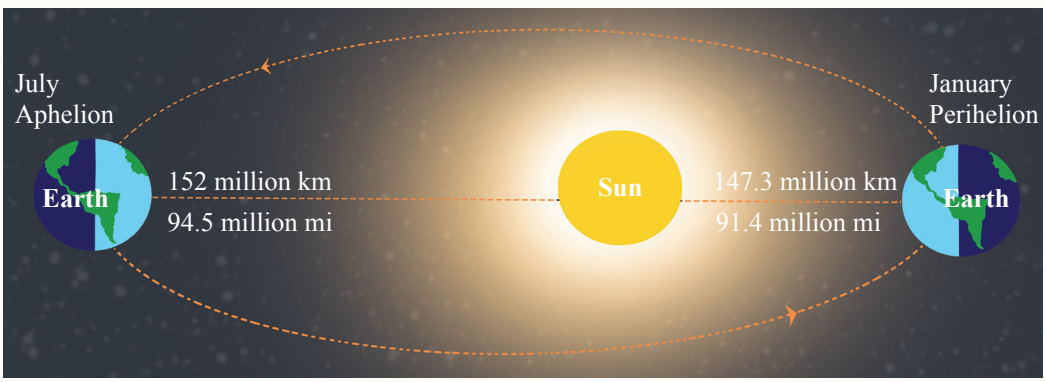


Figure 6.10: *Aphelion and perihelion*

Local factors

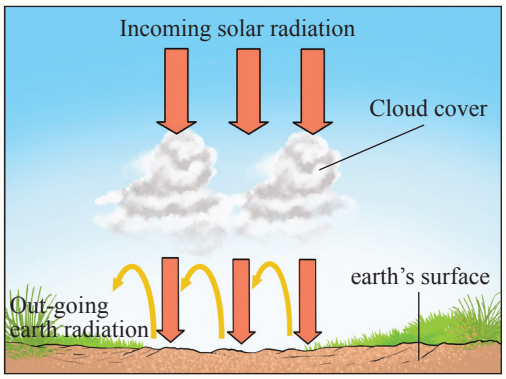
Cloud cover

Clouds reduce the amount of solar radiation reaching on the earth's surface and the amount of radiation leaving the earth's surface. When there are no clouds,

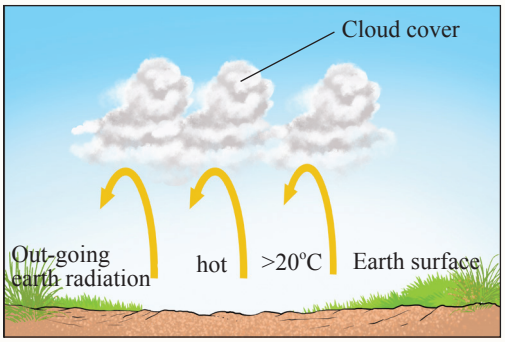
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both types of radiation are at the maximum. For instance, most parts of equatorial Africa, there is a fall in temperature during the rainy season. This is because heavy cloud cover reduces the amount of solar radiation reaching the earth's surface. The heavy cloud cover in the equatorial regions explains why the day temperature rarely exceed 30°C. Normally, cloud act as a blanket thus prevents excessive loss of earth radiation. Clouds absorb and reflect a significant amount of solar radiation whereas loss of earth's radiation is checked by clouds (Figures 6.11). The absence of clouds in desert regions results into extremely high day temperature of about 44°C and low night temperature of about 21°C. The absence of clouds during the day results in the maximum solar radiaton reaching the earth's surfaces. By night clear sky allows the earth's heat to escape freely (Figure 6.12). Variations in cloud cover between the desert areas and equatorial regions in particular explain why there is high temperature range in desert and low temperature range in equatorial regions.

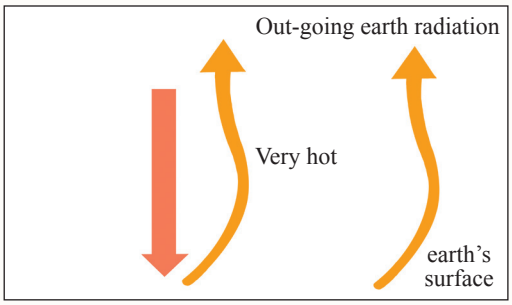


(a) Influences of cloud cover during day

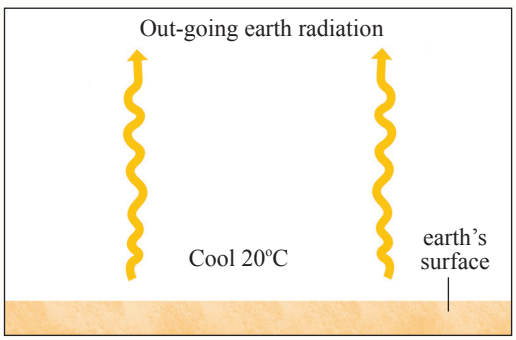


(b) Influence of cloud cover during night.

Figure 6.11: *Influences of cloud cover in the equatorial region*



(a) Influences of cloud cover in hot desert during the day.



(b) Influences of cloud cover in hot desert during the night

Figure 6.12: *Influences of cloud cover in the desert region*

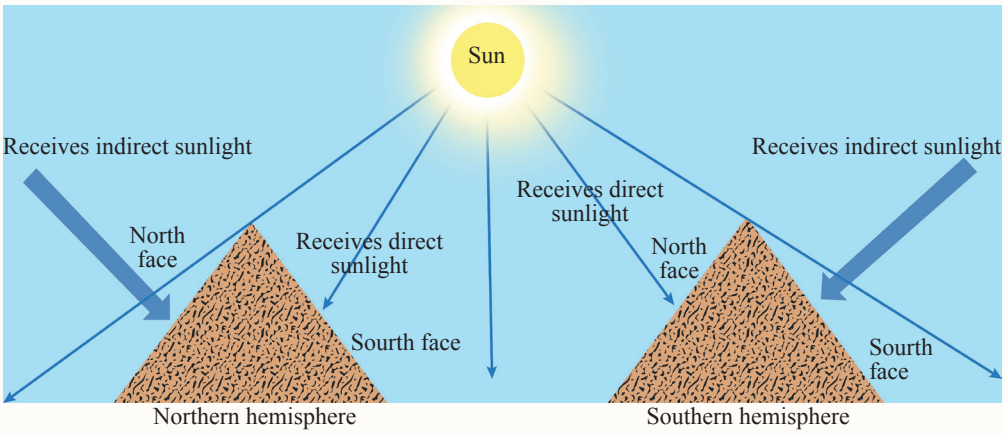
The absence of cloud cover in the hot deserts results in a large daily range temperature (Figure 6.11(b).

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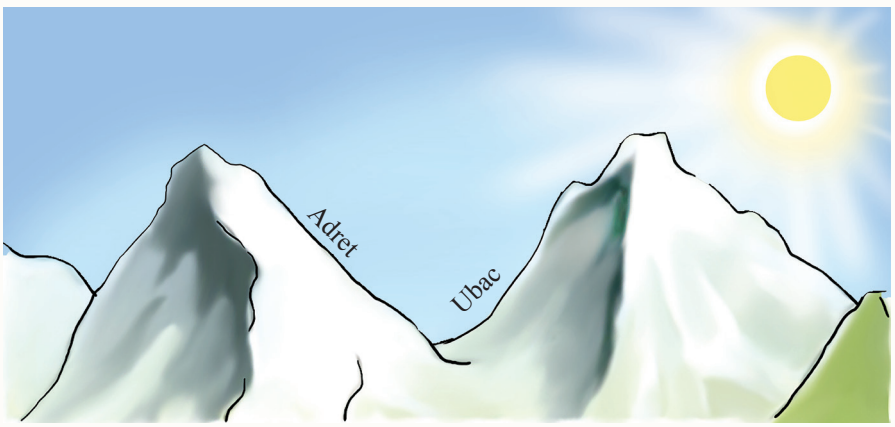
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Aspect

Is the side of the mountain facing the sun rays direction. The hill sides usually affect the angle at which the sun's rays reach the ground. In the northern hemisphere for instance, slopes facing to the North, being in shadow for most or all of the year are cooler than those facing South. The steeper the South-facing slope, the higher the angle of sun's rays to it and therefore the higher the temperature. Radiation involves vertical movement of air from the earth's surface. However, in the southern hemisphere, slopes facing to the South, being in shadow for most or all of the year are cooler than those facing North. The steeper the North-facing slope, the higher the angle of sun's rays to it and therefore the higher the temperature. North and south facing slopes are referred to, respectively, as the *adret* and *ubac* (Figure 6.13).



(a) North and south facing slopes



(b) The adret and ubac slopes

Figure 6.13: *The influence of aspect on temperature*

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Urbanization

Narrow streets with tall buildings are more likely to develop micro-climates than those that are wider with lower buildings. Tower blocks cast more shadow, and normal building materials tend to be non-reflective and so absorb much heat during the day. Dark coloured roofs and tarmac roads have a high thermal capacity which means they are capable of storing heat during the day and releasing it slowly during the night. Furthermore, heat in urban areas is obtained from car fumes, factories, power stations, and central heating, all these result in "urban heat island". Temperatures are the highest in more built-up city centres and tend to decrease towards the suburbs and open countryside. In that regard, temperatures are on average 0.6ºC warmer. Night temperature may be 3ºC or 4ºC warmer due to presence of atmospheric dust and cloud that act like a blanket to reduce radiation. Buildings have a tendency of giving out heat like storage radiators. Altitude of the sun often influences spacing between tall buildings such as blocks of flats (Figure 6.14).

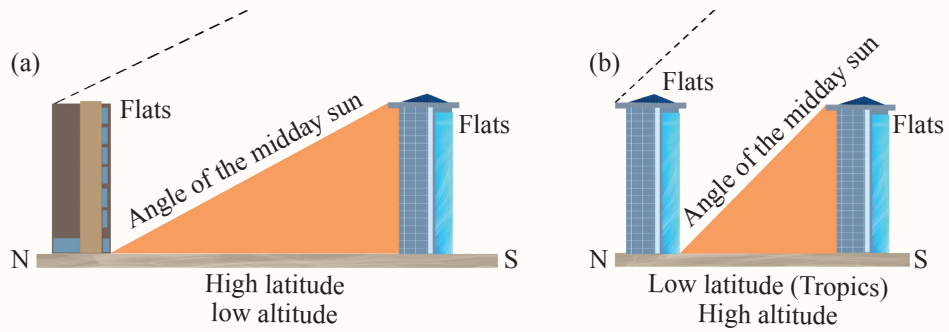


Figure 6.14: *The influence of tall building on temperature*

Exercise 6.3

1. Write short notes on the following terms:
   (a) Absorption (b) Reflection (c) Scattering
   (d) Radiation (e) Emission
2. Latitude is the primary determinant of the climate of an area. Elaborate
3. Clearly explain the mechanisms of prevailing winds in influencing weather.
4. What would be the temperature at the top of Mount Kilimanjaro (5895 m.a.s.l) if the temperature at the foot of the mountain is 32^0C?
5. What are the factors affecting the amount of insolation on the earth's surface?

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Humidity

Humidity refers to the amount of water vapour present in the atmosphere. It is measured by an instrument called *hygrometer*. The amount of water vapour present in the air varies widely from place to place and from time to time. Warm air can hold much more water vapour than cold air. For example, air at room temperature (20^{o}C) can hold almost three times as much water vapour as air at freezing (0^{o}) point. Humidity can be expressed as absolute, specific or as relative humidity. The main sources of atmospheric humidity are water bodies, and vegetation. Humidity is taken into the atmosphere through evaporation and transpiration by the process known as evapotranspiration.

Absolute humidity

This is the mass of water vapour in a given volume of air measured in grams per cubic metre (g/m^3). For example, if the absolute humidity of air is 10 grams, it means that 1 cubic metre of that air holds 10 grams of moisture in the form of water vapour. The capacity of holding water vapour of an air increases with the increase in its temperature. For example, at 10^{0}C, one cubic metre of an air can hold 11.4 grams of water vapour. If the temperature of the same air increases to 21^{0}C, the same volume of air can hold 22.2 grams of water vapour. Change in temperature and pressure conditions of an air results in the change of its volume and consequently there is change in its absolute humidity.

Specific humidity

Refers to the actual quantity of water vapour held by a parcel of air. It can also be defined as the mass of water vapour contained in a given mass of air and is expressed as grams of water per kilogram of air (g/kg). Specific humidity is important in describing how much water vapour is available for precipitation. Generally, humidity depends upon the temperature of the air and changes from place to place, and with change in time. However, there is a limit in the amount of moisture that the air can hold. When this limit is reached, the air is said to be saturated.

Relative humidity

Relative humidity (RH) is the amount of water vapour in the air at a specific temperature compared to the maximum water vapour that the air is able to hold at that given temperature. When the relative humidity is 100%, the air is saturated, when the air lies between 80-99%, it is said to be 'moist', and the weather is humid or clammy, and when it drops to 50% the air is dry. If unsaturated air is cooled and atmospheric pressure remains constant, a critical temperature will be reached when the air becomes saturated (RH = 100%) which is known as dew point or saturation point. Any further cooling will result in the condensation of excess vapour, either into water droplets where condensation nuclei are present, or into ice crystals if the air temperature is below 0^{o}C. Relative humidity of the atmosphere changes in two ways namely

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direct gain or loss and temperature changes. The *direct gain or loss of water vapour* that is the additional water vapour has implication in raising specific humidity and in turn lowers relative humidity. The *changes of temperature* holds that even though no water vapour is added, a lowering of temperature results in the rise of relative humidity.

Significance of humidity

Firstly, climatologists often use specific humidity to describe the moisture characteristics of a large mass of air. For instance, extremely cold, dry air over arctic regions in winter may have a specific humidity as low as 0.2 g/kg in comparison with the extreme warm, moist air of equatorial region which often holds as much as 18 g/kg. Secondly, it is a geographer's yardstick for a basic natural resource. It is a measure of the quantity of water in the atmosphere that can be extracted as precipitation. Thirdly, cold, moist air can supply only a little quantity of rain or snow, but warm moist air is capable of supplying a considerable amount.

Importance of humidity to human life

Water vapour is an important heat absorber in the air and thus affects the energy balance of the atmosphere as it is a key agent in both weather and climate. The release of the latent heat of condensation is an important source of energy for the maintenance of the atmospheric processes. During evaporation and transpiration, latent heat is removed from surface liquid and results in cooling of the earth's surface. It indicates the likelihood of precipitation, dew or fog. A higher water vapour content is necessary for producing clouds and ultmately precipitation. It brings human comfort. Human beings regulate their body temperature mainly by sweating and shivering. It is one of the fundamentals of biotic factors that define any habitat. It determines the kind of animals and plants that can thrive in a given environment which are useful to human life. Humidity is useful in industrial production and storage of goods. Humidity measurements are used to prevent condensation, corrosion, moulding, warping and other spoilage that are highly relevant for foods, pharmaceuticals, fuels, wood, papers and many other products. Humidity measurements contribute to achievement of correct environmental conditions.

Clouds

Clouds are frequent features of the atmosphere formed when air cools to dew point and vapour condenses into water droplets or ice crystals. About a half of the earth is covered by clouds at any given time. Major sources of clouds are the moisture evaporated from land surface, water bodies, as well as moisture from vegetation through transpiration. Clouds can appear in varying *shapes* and *sizes*; from small, white puffy clouds often seen in summer to the dark layers that produce rain. They are often difficult to distinguish as their form constantly

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changes. The general classification of clouds was proposed by Luke Howard in 1803. His classification was a descriptive classification based on clouds *shapes* and *height*. He used four Latin words which are; Cirrus (a lock of curly hair), Cumulus (a heap or pile), Stratus (a layer), and Nimbus (the rain-bearing) (Table 6.2).

Howard compiled composite names using these four terms, such as cumulonimbus and cirrostratus, and added a prefix "alto" for middle level clouds. However, according to the International Clouds Atlas of the World Meteorological Organization (ICAWMO), there are ten types of clouds which are grouped into four (4) families as presented below.

Table 6.2: *Ranks, family, and types of clouds*

Rank	Cloud family	Cloud types
1st	High clouds (7-13 km)	-Citrus -Cirrostratus -Cirrocumulus
2nd	Middle clouds (2-7 km)	-Altostratus -Altocumulus
3rd	Low clouds (0-2 km)	-Stratus -Nimbostratus -Stratocumulus
4th	Clouds with great vertical development	-Cumulus -Cumulonimbus

On the basis of their form, clouds are grouped into two major classes: *stratiform* (layered) clouds, and *cumuliform* (globular) clouds. These are described below:

Stratiform clouds

These are blanket-like clouds which cover a large area. Stratus may cover the entire sky. They occur when the moist and rising air continue to rise, leading to the formation of dense thick clouds which produce abundant rain or snow.

Cumuliform clouds

They are globular masses of clouds that are associated with small and large parcels of rising air. They occur when warmed rising air cools adiabatically, leading to condensation. Sometimes the upward movement yields dense tall clouds that produce thunderstorms.

Condensation

This is the process by which water vapour in the atmosphere is changed into a 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

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to form radiation fog and dew. If the temperature is below freezing point, frost is formed.

Advection cooling occurs when warm, 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 raise relative humidity and clouds.

Convective or adiabatic cooling occurs when air is warmed during the daytime and rises in pockets as thermals. As the air expands, it uses energy and loses heat, and consequently, the temperature drops. Because air is cooled by the reduction of pressure with height rather than by loss of heat to the surrounding air, it is said to be adiabatically cooled. This kind of cooling results into formation of thunderstorms and convectional rainfall especially in equatorial and tropical regions. Since both orographic and adiabatic cooling involve vertical movement of air, they are more effective mechanism of condensation.

Frontal cooling. This 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 condense into liquid. The higher the dew point rise 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^{o} C. They mostly begin to form when water vapour condenses into tinny liquid water droplet suspended in the air. The term fog is used when visibility is less than 1 km, while mist is used when visibility extends from 1 to 2 km. Fogs are formed under different

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atmospheric conditions near the ground. Based on the genesis fog can be classified as; *Radiation fog (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* which 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 (sea fog) which 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 (precipitation fog)* forms when two air masses of contrasting temperature and humidity converge cooling process of the warm moist air which causes fog formation among other things. 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 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* 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 and industrial areas, such as the Ruhr industrial region in Germany.

Major environmental hazards caused by fog

Fog may cause significant environmental hazards. In industrialized countries, dense fog on high speed highways can cause chain reaction accidents, injury or death. Fog brings travelling inconvenience to thousands of travellers in a single day, as it makes them move in very low speed. Sometimes fog leads to vehicle collision along the road and ship collision in the sea due to very poor visibility. Moreover, polluted fog has side effects to the human health for example, it is one among factors that increases the incidences of asthma and allergies cases. Smog also affects the climate through its cooling effect. Since fog contains SO_2 as one of its components, it causes acid rain. The aviation industry is affected by the severity of an existing fog condition. During extreme fog conditions, safe landings are impossible and airports are closed until fog conditions have improved.

Precipitation

Precipitation is any liquid or solid condensation of water vapour falling from the atmosphere to the surface of the Earth. Precipitation in warmer clouds is formed when fine water droplets condense, collide and coalesce into larger droplets that fall as rain.

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In colder clouds, ice crystals form and grow in a cloud that contains a mixture of both ice crystals and water droplets.

Formation of precipitation

Precipitation forms in the clouds when water vapour condenses and grow bigger enough to form water droplets. When the drops grow in size, they become heavier enough and drop to the ground as precipitation. If a cloud is colder, like it would be at higher altitudes, the water droplets may freeze to form ice. Precipitation includes all forms of water particles that follow onto the ground. These particles then fall to the ground as snow, sleet, drizzle, hail or rain depending on the temperature within the cloud and at the earth's surface.

Forms of Precipitation

Rain is a liquid in the form of droplets whose size is greater than 0.50 mm. It occurs when condensation process takes place at or just above the freezing point. *Snow* is a form of precipitation which is formed when water vapour condenses at a temperature below freezing point, passing directly from gaseous to the solid state forming minute particles of ice. These particles 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. Snow may fall in any latitudes even on the equatorial mountains of East Africa and in the Andes. However, snow is rarely formed at the sea level about 30º North and South of the Equator. The snow line indicates the lowest edge of snow cover and its position depends on the climatic and terrain factors.

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 mm. 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. Hails are almost always accompanied by thunderstorms. They occur widely on the earth's surface except in the polar regions where thunderstorms are rare, in the equatorial zones where the air temperature is so high, causing the hails to melt before they reach the ground, and in hot deserts.

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Sleet forms in cold weather when rain enters a layer of very cold air close to the ground and then 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 2ºC to 4ºC. 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 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 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 on 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 km to 2 km, usually formed when warm humid air cools suddenly forming small water droplets suspended in air. Unlike fogs, mist results in moderate visibility usually occurs in the lower atmosphere.

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. Rainfall is measured by using an instrument called *raingauge*. It is expressed in millimeters (mm) or centimeters (cm). Most air in the atmosphere contains 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 as drizzle or rain. Although the temperature at the level of clouds formation in atmosphere is below 0ºC, the droplets do not turn into ice crystals. In cumulonimbus, for example, raindrops often rise and fall several times in the convection currents before they have sufficient weight to fall to the ground. Sometimes the super cooled water droplets crystalize into ice crystals and then fall to the ground before melting into raindrops. When they reach the ground in form of drops of ice they are called hail.

Types of rainfall

Rainfall is classified into three main types based on the origin. These

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includes convectional, orographic and cyclonic rainfall.

Convectional rainfall

Convectional rainfall is a type of rainfall which is formed by vertical moving warm air, which has been heated by the ground through conduction. As air rises from the heated surface, it expands and thus cools adiabatically. Thus, forms stratocumulus or cumulonimbus clouds with very powerful turbulent currents. 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. convectional rainfall is usually in the summer or the hotter part of the day. Such rainfall is main associated with the hail and graupel. The equitorial region and internal part of continents mainly in northern hemisphere receive convectional rainfall (Figure 6.15).

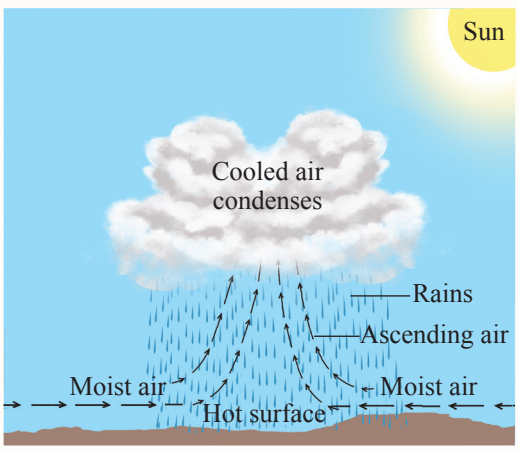


Figure 6.15: *Convertional rainfall*

Orographic rainfall

This type of rainfall is also known as relief rainfall. It develops as a result of the influence of topography, specifically 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 receive relatively little rainfall is called the leeward side or rain-shadow. As the air ascends the mountain ranges it is cooled 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

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further rising cumulonimbus clouds (Figure 6.16).

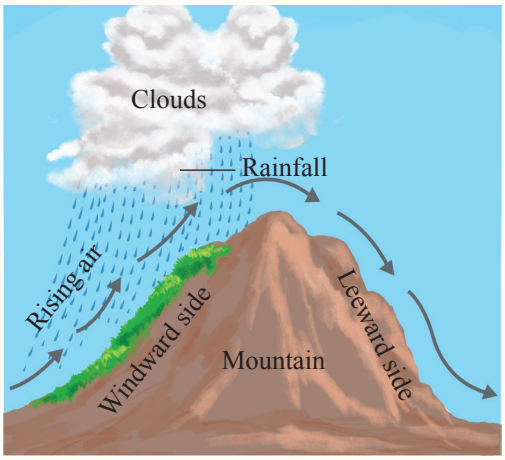


Figure 6.16: *Orographic rainfall*

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 their air. It develops when warm moist air of a maritime (Tm) tropical air mass is forced to rise over the cold air of polar air mass (Pm) when two air masses meets (Figure 6.17). Cyclonic rainfall is sometimes called depression rainfall because it occurs where 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 40º – 60º North and South of the Equator. These areas are convergence zones of both warm moist and cold dense air.

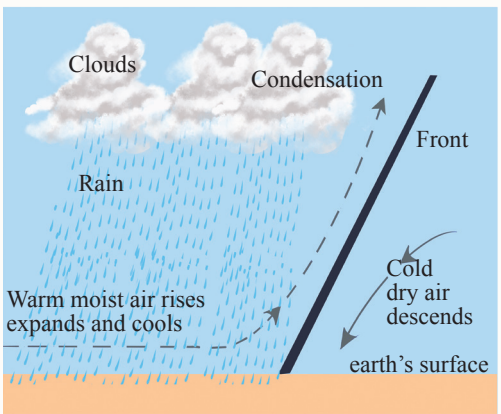


Figure 6.17*: Cyclonic rainfall*

Thunderstorm

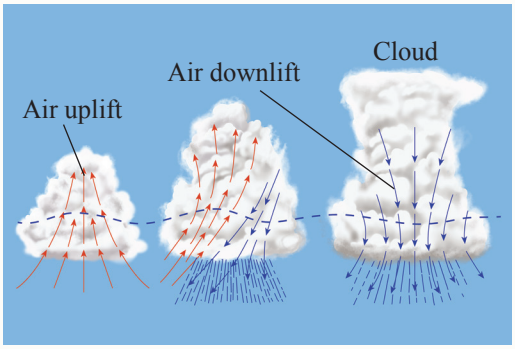
Thunderstorm is an event in which the intense rain and violent winds coupled with lightning and thunder occur. It refers to sound produced when two different air masses meet abruptly. Before the sound is head, light is seen first because it travel first than sound. Therefore, thunderstorm is an intense local storm associated with a tall, dense cumulonimbus cloud in which there are very strong updrafts of air. It is accompanied with lightning (great electric) with a series of gigantic sparks passing between different charged parts of the cloud mass or between clouds and the ground. The development of

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convectional overturning under extreme condition of instability may produce thunderstorms (Figure 6.18). This results as the towering cumulonimbus clouds advance across the sky characterized by rapid fall in pressure producing a very turbulent wind before storms develop. This leads to heavy rain or hail falling as clouds passing overhead accompanied by lightning and thunder. As the hot and expanding air rises from the surface, it absorbs a large amount of moisture. Huge amounts of energy are released when condensation of this warm moist air takes place. This provides the energy to power thunderstorms that are frequently associated with convectional rainfalls and hails.

Thunderstorms can occur whenever land surfaces are greatly overheated. They are common in humid tropical regions. They usually occur in the afternoon when the land is heated by the overhead solar radiation. Thunders are caused by the rapid expansion and contraction of the air resulting from electrical discharges that generate intense heat and pressure, a common feature of convectional rainfall. During a lightning discharge, a current of as much as 60 000-100 000 amperes may develop. The current heats the air intensely, causing it to expand very rapidly like an explosion which sends out sound waves, recognized as thunderclap. Most lightning discharges occur within the cloud but a significant proportion strike the ground. For example, in USA alone, lightning causes a yearly average of about 150 human deaths and property damage of hundreds of millions of dollars. It also causes forest fires.



(a) Thunderstorm development



(b) Thunderstorm

Figure 6.18: *Thunderstorm development and occurrence*

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.

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Activity 6.2

In a group of five (5) students, do the following activities;

(a) Visit the school library and other online sources, search for detailed explanation on the factors affecting rainfall distribution.

(b) Discuss and present your work to the class in the presence of the subject teacher.

(c) Write a brief report on the agreed factors in your exercise books.

(d) Submit your exercise books to the subject teacher for assessment and feedback.

Exercise 6.4

1. Write short notes on the following concepts;
   (i) Condensation
   (ii) Precipitation
   (iii) Dew point
   (iv) Fogs
2. How are clouds formed?
3. (a) Describe different types of clouds.
   (b) What are the criteria for classifying clouds?
4. Elaborate on the forms of precipitation.
5. Describe categories of fogs.
6. Give an account of the ways through which air is cooled.
7. Explain the factors affecting the distribution of rainfall?
8. With vivid evidences explain the importance of humidity in our daily life.
9. Account for air mass ascent and its effects on weather conditions.
10. With the aid of World map, describe the spatial distribution of rainfall.
11. (a) Differentiate absolute from relative humidity.
    (b) Explain the importance of humidity as a climate variable.

Atmospheric pressure

Air has weight and therefore, exerts pressure on the earth's surface called atmospheric pressure. The atmospheric pressure is measured by an instrument called barometer. Actually, 1 bar = 1000 millibars. The line that joins different places with the same atmospheric pressure in the map is called an *isobar*. The isobar indicates the horizontal distribution of the pressure in a certain region. The pressure of a particular place is indicated as high or low, depending on the pressure of the adjoining areas. The atmospheric pressure is not the same to all regions,

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nor the same to one region all the time. This means that in some regions, the pressure is higher for one part of the year than it is for another part of the year. The variation of pressure in different regions is a result of a number of factors which include;

Altitude

Air pressure at sea level is higher than it is at the top of a mountain. This is because at the sea level air has to support a greater weight of air than it does on the top of a mountain (Figure 6.19). The earth's atmosphere consists of different materials in all states of matter such as gaseous, water vapour and solid. These materials exert a downforce (atmospheric pressure) in the strength of which depends on the elevation. Normally, highly elevated parts of the Earth are with high atmospheric pressure as opposed to lowly elevated areas where the pressure is low. Pressure tends to develop at a rate of 10 mb to every 100 m of rising.

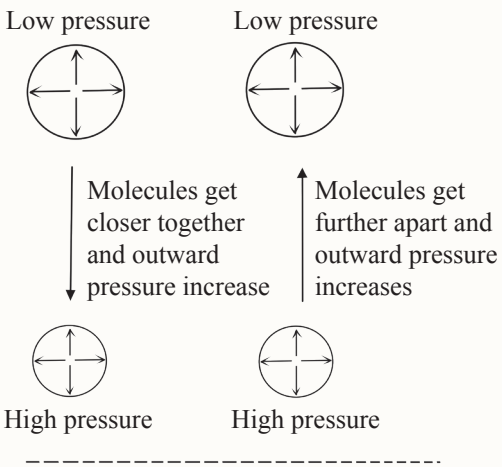


Figure 6.19: *Influence of altitude on pressure*

The molecules of the air at sea level push outwards with a force equal to that exerted by the air above it, whereas the molecules of the air at the top of mountain push outwards, with much less force because the weight of the air above it is less. This explains why air pressure increases when air descends. When air descends, its volume decreases but the number of molecules in it remains the same. The outward pressure of these molecules is spread over a smaller area and pressure increases. Similarly, when air rises, its volume increases and the outward pressure of its molecules is spread over a larger area eventually, its pressure decreases.

Temperature

When air sinks, its pressure increases because it becomes compressed. When air becomes compressed its molecules move more quickly and heat is produced. Apparently, temperature of air rises its pressure falls as well. When air rises, its pressure decreases because it expands, but when air expands, its molecules move more slowly, and heat is used up. The temperature of air falls when its pressure falls. When air is heated, it expands and when this happens the outward pressure of its molecules is spread over a larger area. This means that the pressure of the air decreases. The pressure of the air falls when its temperature rises. When air is cooled it contracts and when this happens the outward pressure of its molecules is spread over a smaller

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area. This means that the pressure of the air increases. The pressure of the air rises when its temperature falls. Low temperature at the poles causes the air to contract, hence high pressure develops. High temperature along the equator causes the air to expand, hence low pressure called the doldrums low pressure, develops.

Rotation

The rotation of the Earth causes the air mass at the poles to be thrown away towards the equator, occupying large area in the mid latitudes (sub-polar) which develop a low pressure. However, pressure remains high in the polar areas due to extremely low temperature. Again, the rotation of the Earth throws air mass from equator polarwards, which then descends in the horse latitude leading to creation of high pressure as air is forced to occupy a small area compared to its original area.

Nature of the surface

The surface of the Earth is normally uneven with different landforms and water bodies. This causes the behaviour of temperature to vary from one area to another. Normally, land and water heat and cool at different rates, affecting the temperature of air masses occupying them. The variation in heating and cooling rates of the land and water masses on the earth surface cause variations in pressure. This causes some areas to have high pressure or low pressure. This is because temperature change causes either expansion or contraction of air-mass, which in turn affects air pressure. The variation of heating and cooling between land surface and water surface leads to local pressure variation which in turn results in *land breeze* and *sea breeze*.

Latitude

The Earth is not a perfect sphere and therefore the force of gravity varies according to latitudes, attaining its maximum gravity at the poles and its minimum gravity at the Equator. Atmospheric pressure is therefore lower at the equator and higher at the poles because temperature at the Equator is high causing low pressure cells while at the poles temperature is low causing high pressure cells. Also, high gravitational pull at polar regions results into high atmospheric pressure because the weight of atmospheric contents increases with the increase in gravitational pull.

Planetary pressure systems

The planetary pressure system is a theoretical concept which helps to understand the distribution and patterns of pressure on the surface. When the pressure of the air mass is low at the centre and increases outward, it is called depression. This is common in temperate latitude areas. Normally, anticyclones form the opposite of depression pressure cells in which the pressure increases towards the centre. The atmospheric

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pressure varies with temperature: it is low in high temperature and high in low temperature. It also varies with altitude and latitude: it is low in high altitudes and latitudes, and high in low altitudes and latitudes. Due to the above variation, the atmospheric pressure can be categorized into four *pressure zones or belts* (Figure 6.20):

Equatorial trough

The equatorial trough also known as low pressure belts is an area lying between 0º and 10º North and South of the Equator. This is a region of low pressure zone with less than 1013 millibars. It is at the Equator where the northern and southern trade winds converge to form a zone called *intertropical convergence zone* (ITCZ). This area is characterized by high temperature and humidity, and the air near the sea level is stationary or moving very slowly. This belt is commonly known as the *Doldrums*. The low pressure in this area is due to heating as the area receives high insolation which causes the temperature to increase. The increase in temperature causes the volume of air pressure to decrease. This change in pressuring along the equatorial belt is actually a generalization since there are also local variations.

Sub-tropical high pressure belt

Sub-tropical high pressure belt also known as horse latitudes occurs along the calm and descending air currents. It is a zone or belt of descending air mass produced dynamically by wind of the upper atmosphere lying between 30º North and South of the Equator. In the northern hemisphere it is called *North sub-tropical high pressure belt* and in the southern hemisphere it is known a *South sub-tropical high pressure belt.* It is difficult to describe these belts but they can generally be caused by two factors. Firstly, they can be caused by general circulation of air towards the poles in the upper part of the troposphere from the Equator. They are influenced by the earth's rotation whereby the centrifugal force throws the air back, causing the currents to accumulate along these latitudes. Secondly, they can be caused by movement of air from high latitudes in the upper part of the troposphere towards the Equator. These air masses descend in the *horse latitude* and they increase air accumulation along the lower latitude areas.

Sub-polar low pressure belts

Sub-polar low pressure belts also known as temperate low pressure belts are found between 40º and 70º North and South of the Equator where the rotation of the Earth causes a *polar whirl* which moves towards the low pressure zones at the poles. However, the intensity of the coldness around the poles causes the thermal effects to overcome these air masses. Consequently, this places these pressure belts around or near the polar circles.

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Polar high pressure belts

This occurs along the Antarctic ice cap above which the intensely cold dense air with a shallow high pressure system over it lies. This belt lies towards the pole between 70º North and South of the Equator. It is produced by the constant low temperature over the polar ice caps with low temperature causing high polar pressure cells. However, this region is complicated since it is an ocean basin with its landmass grouped in about two thirds of its perimeter. Generally, the distribution of the pressure zones over the earth surface has a considerable effect on the formation of winds and wind patterns. Winds normally move from high pressure areas to low pressure areas in an attempt to balance the pressure. This process is called gradient pressure winds. The wind that blows towards the centre of low pressure cell, especially in mid latitude is called depression wind (Figure 6.20).

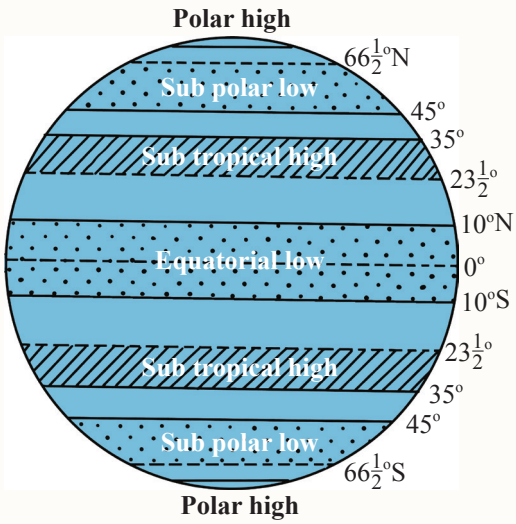


Figure 6.20: *Planetary pressure belts*

Exercise 6.5

1. Explain the factors affecting atmospheric pressure.
2. Using annotated diagram, describe the planetary pressure systems.
3. The distribution of the pressure zones over the earth's surface has a considerable effect on the formation of wind. Discuss.

Wind

Wind is the air in motion which blows from an area of high pressure to the area of low pressure. Wind results from differences in air pressure caused by differences in temperature and force exerted by gravity as pressure decrease rapidly with height. An increase in temperature causes air to warm, expand, become less dense and rise, creating an area of low pressure below. Conversely, a drop of temperature produces an area of high pressure. Winds are characterized with specific origin, direction, and velocity.

Factors affecting speed, direction and the strength of wind

Pressure gradient

Pressure gradient is also known as barometric gradient. Regions of high pressure form centres from which winds tend to blow, that is, they are areas of divergence. Conversely, regions of low pressure are *foci* of winds, which means that they are areas

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of convergence. However, when the difference in pressure between two neighbouring points on the earth's surface is great, it is said to be a steep pressure gradient, and on the pressure map, the isobars appear close to each other. In such a case, the resulting wind is strong. Isobars and pressure maps are thus analogous to contours and relief maps. Conversely, when the barometric gradient is gentle, winds are light, causing air to move from areas of high pressure to areas of low pressure. The succeeding factors, however, considerably modify this generalization (Figure 6.21).

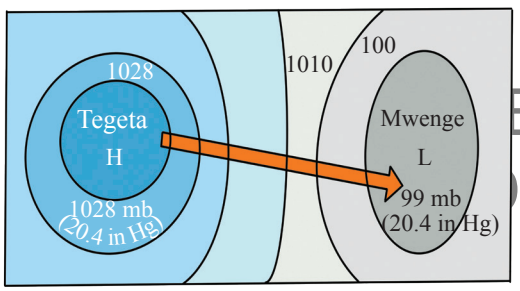


Figure 6.21: *Effect of gradient on pressure*

Coriolis force

The effect of Coriolis force is produced by the rotation of the earth. It may be clearly stated in terms of Ferrell's Law. The Ferrell's Law states that a free body moving on the surface of the earth is deflected to its own right in the Northern hemisphere and to its left in the Southern hemisphere as a result of the earth's rotation. Deflection is stronger near the poles and decreases to zero at the Equator. When a balanced condition develops between the forces exerted by the pressure gradient in one direction and the Coriolis force in the opposite direction, a steady wind will blow. This is known as a state of geostrophic balance, and the air movement is known as *geostrophic flow* or *geostrophic wind*. The wind blows in the direction parallel to the straight isobars. The Coriolis force affects both direction, speed, and strength of winds (Figure. 6.22).

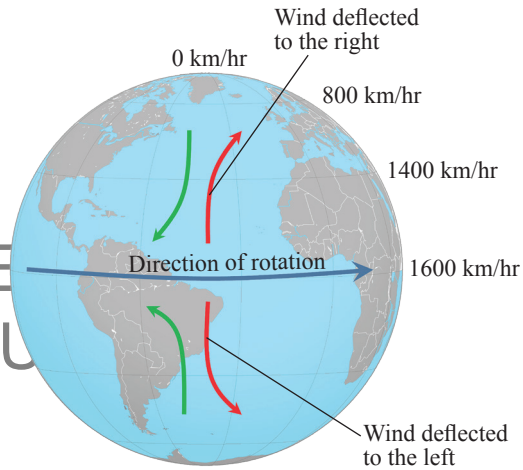


Figure 6.22*: Coriolis force*

Centrifugal forces

Centrifugal force is the force acting outwards from the centre of curvature. When an air-stream moves on a curved course, as in a pressure system with closed or curved isobars, it is subjected to centrifugal force. The air thus, tends to travel along the isobars, in the Northern hemisphere clockwise, around the highs and anti-clockwise around the lows, while in the Southern hemisphere it would tend to move

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anticlockwise around the highs and clockwise around the lows. This relationship of wind and atmospheric pressure was put-forward by a Dutch Scientist, Buys Ballot in the middle of the 19thC.

Frictional forces

In the lowest parts of the atmosphere, normally below 750m, the frictional drag exerted by the ground on the airflow above, has an effect on the balance of the other wind forces. This allows the pressure gradient to assert its greater strength by causing the air to flow more towards low pressure. Thus, the usual situation is that surface winds flow at a slight angle to the isobars near the ground. However, friction tends to reduce the power of the deflection due to rotation, and thus its effect is greater over land than over the oceans and less in increasing altitude.

Air masses

An air mass is a large body of air (parcel of air) with fairly uniform characteristics of temperature and moisture covering an extensive surface area moving horizontally over several kilometers. Air masses only develop over an area which is extensive and which is uniform in size and shape, for example a desert surface or an ocean surface.

General characteristics of air masses

The characteristics of an air mass are obtained from the region where it forms. These characteristics are retained by the air mass when it moves away, even to considerable distances from its origin. The following are the characteristics of air mass;

Firstly, air masses are born from the extended homogeneous earth's surface like ocean, desert surface, and over the forest. *Secondly,* air masses are always mobile, which accounts for their thermal and hydromodification. *Thirdly,* air masses are carriers of amount of heat, which depends on the nature of their source regions. *Lastly,* direction of air masses is dependent of barometric gradient.

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Major types and classification of air masses

Air masses are classified basing on two main approaches which are geographical classification (according to their origin), and thermodynamic classification. Geographical classification considers features of the source regions. Basing on the geographical classification, there are two broad categories of air mass. The first category is Polar air mass (P) which originates in Polar areas and Arctic air masses which originates from arctic region. The second category is Tropical air mass (T) which originates in tropical areas. Equatorial air masses are also included in this category. They are further divided into two types on the basis of the nature of the surface of the source regions (whether continental

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or oceanic areas). Basing on the above fact, air masses are classified into four principal types, namely Polar continental air mass, Polar maritime air masses, Tropical continental air mass, and Tropical maritime air mass.

Polar Maritime (Pm)

This is a type of cold moist air mass originating at high latitude in Polar region. It is characterized by cold and moist air especially in winter, low temperature and high moisture content. It is also featured by light clouds, snow, and moderate rainfall. It is heated by warm water bodies. The heating makes it unstable and consequently causes blustery showers over the oceans.

Polar Continental (Pc)

This is a type of cold dry air mass originating at high latitude over land area. It includes cold and dry air masses with low moisture content. It is stable due to low temperature but dry and warm in summer. It brings the cold, dry, and clear weather on a winter day.

Tropical Maritime (Tm)

This type of warm moist air mass originates in warm waters of the tropics. It is characterized by high temperature and high moisture content. It is unstable due to high temperature, and moisture content. It brings overcast skies with prolonged rains, thunderstorms, and haze of dust. Sometimes it produces warm weather with abundant sunshine.

Tropical Continental (Tc)

This is a type of warm dry air mass originating from sub-tropical and desert regions, especially in summer. It is warm and very dry (high temperature and low moisture contents). It is also unstable due to high temperature, resulting in thick clouds and thundery showers. It causes poor visibility due to picking of air pollutants in Europe or dust storms in the Saharan deserts.

Equatorial maritime air mass is sometimes regarded to be very moist and warm air masses originating within a few degrees of the Equator. According to thermal dynamic characteristics, air masses are categorized basing on heating or cooling from below while passing through different surfaces away from the source region. It considers initial characteristics of the air mass which includes; temperature and moisture content; nature of land or water surface of over which a particular air mass moves; path followed by the air mass from the source region; and time taken by air mass to reach a particular destination. Therefore, this classification gives out two types of air masses which are *cold air mass* which originates in the polar and arctic regions and *warm air mass* which originates in the subtropical regions characterized by anticyclonic conditions.

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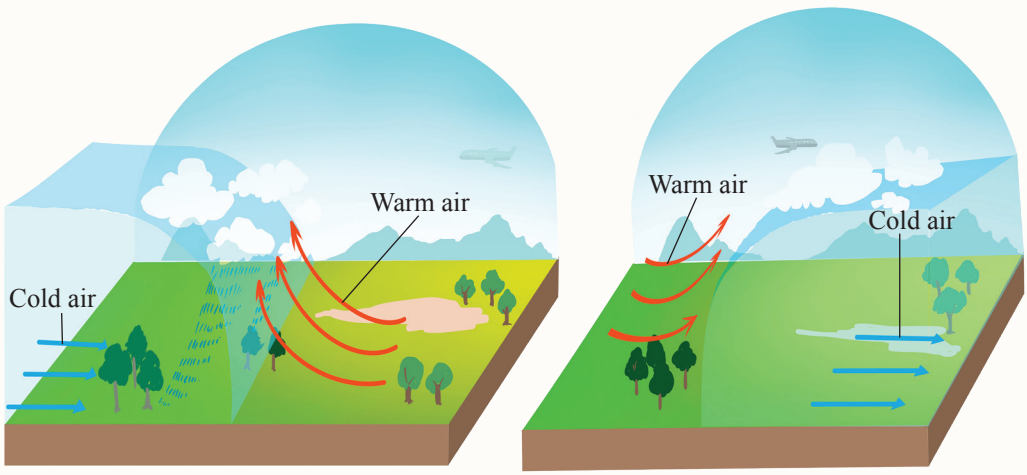
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Fronts

When air masses meet, they do not mix readily due to differences in temperature and density. The point at which they meet is called a *front*. Therefore, a front can be defined as a point at which two air masses of different temperature and density meet. Based on differences in temperature and density, fronts can be grouped into two major types which are; *cold front* and *warm front* (Figure 6.23), others include *occluded* front and *stationary* front.

Cold front is formed when cold air invades warm air. Since the colder air mass is denser, it remains in contact with the ground as it moves forward, it forces the warm air mass to rise above it. If the warm air is unstable, severe thunderstorms may develop. Thunderstorms near a cold front often form a long line of massive clouds stretching out tens of kilometres. Something to be noted is that, cold air is always dense than warm air, so when a warm air mass meets a cold air mass, the warm air will always ascend while the cold one will sink. Once the warm air has risen, it cools and clouds can form.

Warm front is formed when warm air is advancing and replaces the cold air, where a warm air mass is forced to rise over the cold air and the cold air masses remain in contact with the ground because it is denser. The rising motion of air causes stratus clouds to form and often precipitation follows. If the warm air is stable, the precipitation will be steady, but if the warm air is unstable, convection cells can develop, producing cumulonimbus clouds with heavy showers or thunderstorm. Also warm front can be explained as boundaries between air masses when warm air invades cold air.



(a) Cold front *(b) Warm front*

Figure 6.23: *Cold and warm fronts*

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Occluded front occurs when a warm front is overtaken by a cold front, the warm air is pushed away and it is unable to contact the ground. When this happens, abrupt lifting by the denser cold air produces precipitation (Figure 6.24).

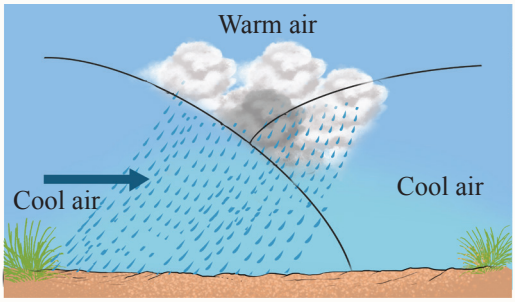


Figure 6.24: *Occluded front*

Stationary front occurs when two air masses are in contact but with little or no relative motion. Often a stationary front arises when a cold or warm front stalls and ceases forward motion. Clouds and precipitation often remain in the vicinity of the front. The most notable front is the polar front which occurs when warm moist (Tm) air meets colder drier (Pm) air and it is at the polar front depression or cyclones (Figure 6.25).

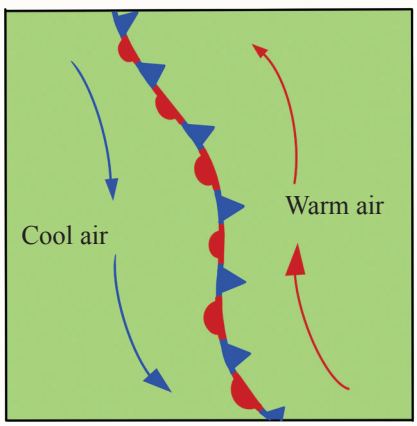


Figure 6.25: *Stationary front*

Planetary wind systems

Wind is the movement of air mass from high to low pressure areas in a horizontal plane. It is principally influenced by unevenly heating of the earth's surface by the sun which causes the pressure differences and the difference in the atmospheric pressure. Although the distribution of pressure zones over the earth's surface has the considerable effects on the formation of winds on the earth's surface, its direction and strength depends on pressure gradient, Coriolis force, centrifugal force, and friction as discussed earlier. The measurement and recording of winds involves both the direction from which they blow and their velocity. *A wind-vane* is used to measure the direction of the wind while *an anemometer* is used to measure wind velocity.

Observation of wind direction and velocity is usually calculated on percentage basis, and a detailed table is used to provide information of wind's direction, velocity and strength. Wind maps are produced, indicating wind directions by means of arrows and symbols. The distribution of winds on the earth surface is similar to that of the pressure belts. Therefore, planetary wind patterns are a result of global distribution of pressure patterns (Figure. 6.26).

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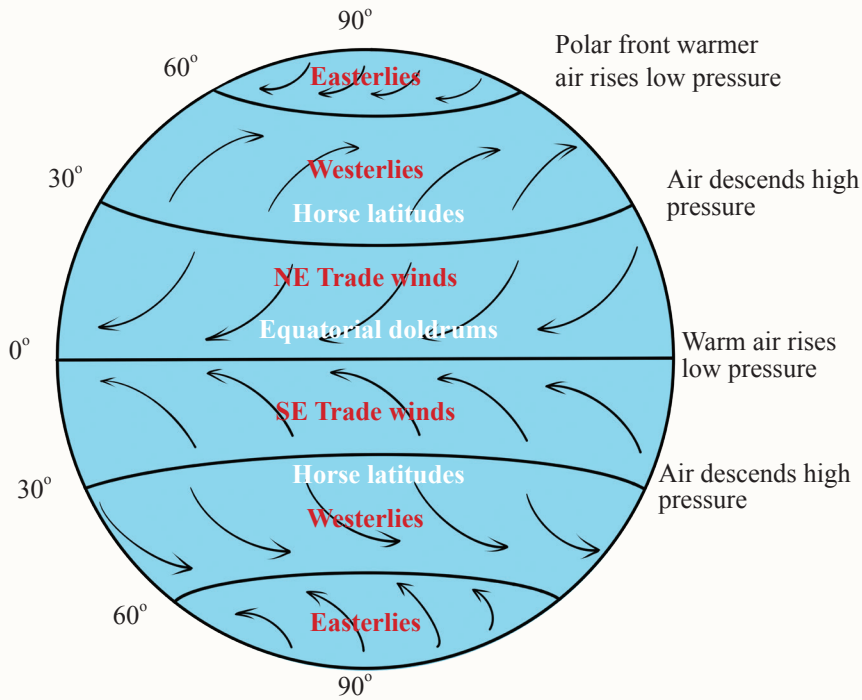


Figure 6.26: *Planetary wind systems*

Types of planetary wind systems

Trade winds

These are winds that blow from sub-tropical highs towards the Equatorial low pressure belts, but they are deflected by the rotation of the earth eastward and blow from North easterly direction in the Northern – hemisphere, commonly known as the *North – East Trade winds*. Also, they blow from South easterly directly in the Southern hemisphere and are commonly called *South–Easterly Trade Winds*. Trade winds occur between 30º North and South of the Equator. The name "trade winds" comes from the phrase "to blow trade", that is, to blow steady in a constant direction. The name originally had nothing to do with trading, although during sailing ships for trade, these winds were of significance. Between the two trade wind systems there is a low pressure belt through which trade winds blow. This area is called the *Inter-Tropical Convergence Zone (ITCZ)*. During summer, especially over the continents where thermal heating is high, a zone of Westerly-winds intervenes between the Trade winds. These intervening winds are called *Equatorial Westerlies.*

Characteristics of trade winds

(i) They blow from a high pressure belt near 30º latitude in each hemisphere called the *sub-tropical high* towards the low pressure belt near the Equator called the *Equatorial low pressure belt*.

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(ii) They blow from North–east in the northern hemisphere and South-east in the southern hemisphere towards the equatorial low-pressure belts.

(iii) They follow a regular path. Though their strength and directions are changed with their location and nature of surface which determine local pressure cells, they are marked to be stronger in the summer than the winter season.

(iv) They are affected by deflection force of the South's rotation called Coriolis force which causes them to blow North-east and South –east of the southern and northern hemispheres respectively.

(v) They are affected by the local pressure disturbances in the western side and near the equators. Additionally, they are dominated by rare calmness and the clear sunny conditions.

(vi) In the Northern hemisphere during winter season, the North – east trade winds cover the zone between the Tropic of Cancer and few degrees North of the Equator while during summer they occupy a belt further North from 30ºN to about 10ºN. Also, during this period, the system of the South-east Trade-winds moves northwards.

(vii) Trade winds are less regular over the land than over the oceans. They are normally constant in motion and direction, especially over the oceans where they are minimally subjected to frictions of the underlying surface.

(viii) They pick-up latent heat as they pass through warm tropical oceans and they are forced to rise by violent convection currents. These unstable, warm moist winds are rapidly cooled adiabatically to produce the towering cumulonimbus clouds which are characterized by frequent afternoon thunderstorms and low pressure traits of the equatorial climate.

(ix) They are the major drivers of the global circulation system since they turn latent heat into sensible heat, turning it later into potential energy.

Westerlies

These are the air-masses flowing from the subtropical highs to the sub-polar lows from about 35º to 60º North and South of the Equator. These belts extends North and South with the seasonal change of the pressure belts.

At about 30º from the Equator in both hemispheres lies the Horse latitude with high pressure belts. In the polar side of this Horse latitude, the atmospheric pressure diminishes towards low pressure centres in the middle and high

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latitude. As the wind is set in motion towards the poles by these pressure systems, they are deflected eastward by earth's rotation.

Characteristics of the westerlies

(i) They consist of two separate circum-polar vortices increasing in both speed and constancy with altitude. As they move towards the poles, they are disrupted by Jet streams in the upper troposphere.

(ii) Within these belts, both wind direction and velocity are far from constant due to the influence of local pressure systems.

(iii) They form the most frequent winds in the northern hemisphere where a westerly component is predominant from the south-west. Due to this, they are commonly known as "*South-Westerly variables or Disturbed Westerlies*".

(iv) They normally blow with strength and constancy between 40º – 60º South in the Southern hemisphere where there is a continuous open ocean.

(v) They normally blow from Horse latitude or sub-tropical high pressure belts to sub-polar or temperate-low-pressure belts and they are deflected to the right to become South westerlies in the Northern hemisphere and to the left to become North westerlies in the Southern hemisphere.

(vi) They are extremely variable both in direction and velocity, giving rise to both cyclones and anticyclones, which are strong enough to overcome the main direction and velocity.

Polar easterly winds

Polar easterly wind also known as polar easterlies are the cold air masses that move towards the equator from the polar high-pressure areas to low pressure temperate regions. They are better developed in the southern hemisphere than in the northern hemisphere. Their movement is pronounced much in the southern hemisphere where both the high over the Antarctic plateau and the sub-polar low over the Southern Ocean are clearly defined.

Characteristics of the easterly winds

(i) They are deflected to the left as the air moves towards the equator, developing a belt of winds. These wind belts develop spirals from the polar region in an easterly direction forming a polar vortex.

(ii) They are generally weak.

(iii) These winds are irregular in the northern hemisphere because they blow over the land and they are known as *continental winds*, while they are regular in the southern hemisphere because they blow over the surface water and they are known as *oceanic winds*.

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Exercise 6.6

1. Elaborate the determinants of strength and direction of wind.
2. The origin of planetary wind systems is an interplay of several conditions. Discuss
3. 'Each air mass is unique'. Discuss
4. Describe the major types of fronts.
5. Using a well labelled diagram, describe the planetary wind systems.

Cyclones and anticyclones

Cyclones

Cyclones are areas of low pressure or convergence centre. They are also called 'depressions'. Cyclones are mostly formed over the ocean mid-latitudes and spread eastwards, bringing cloud and rain to western margins of continents (Figure 6.27).

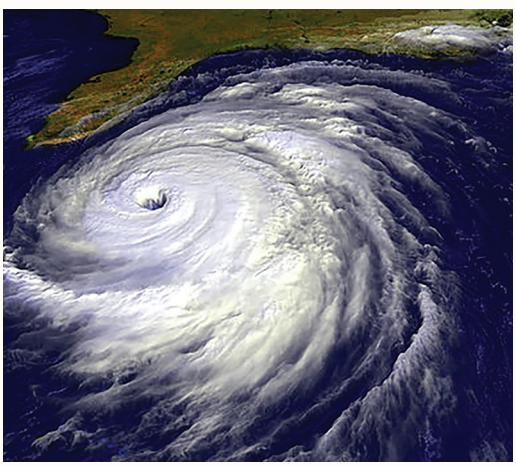


Figure 6.27*: Cyclone movement*

Cyclones or depressions are usually associated with high winds, warm air, and atmospheric lifting which produces clouds cover, storms and precipitation.

Types of cyclones

There are three types of cyclones, namely wave cyclones, tropical cyclones and tornadoes. These are described as follows;

Wave cyclones

Wave cyclones are common in mid latitude areas, including Arctic and Antarctic zones. Their intensity ranges from a weak disturbance to a powerful storm. They constitute a large spiral of air that repeatedly forms, intensifies and then dissolves along the polar front.

Tropical cyclones

A tropical cyclone is the most powerful and destructive type of cyclone. Tropical cyclones are common in tropical and sub-tropical areas. They are known by various names in different regions, including hurricane in western hemispheres (America), typhoons and willy-willies in warm Pacific (Asia), and cyclones in the Indian Ocean. They travel between 5º and 20º North and South of the Equator. The areas that are much affected by tropical cyclones are Southern and Eastern USA.

Stages of tropical cyclones development

There are three main stages of cyclones development, these are; embryo,

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maturity and decay depression. An *embryo depression* begins as a small wave on the polar front. Here warm moist tropical air masses meet with colder and drier polar (Pm) air. The convergence of the two air masses results in the warmer, less dense air being forced to rise in a spiral movement. The upward movement results in less air at the earth's surface, creating an area of below-average or Low Pressure (LP). A *mature depression* is recognized by the increasing amplitude of the initial wave and the pressure continues to fall as more warm air, in the warm sector is forced to rise. As pressure falls, the pressure gradient steepens, that is, the inward blowing winds increases in strength. Therefore, the rise of warm air results into cooling to dew point and some of the water vapour condenses to form clouds which eventually develop precipitation. The *decay depression* begins to decline when the cold front catches up the warm front to form an occlusion or occluded front.

Characteristics of tropical cyclones

(i) They always move in circular motion due to the strong pressure gradient and winds that spiral inward at high speed.

(ii) Convergence and uplift are intense producing very heavy rainfall.

(iii) Air descends from high altitudes and adiabatically gets warmed.

(iv) As they pass over a site, calm prevails and the sky clears.

(v) The storm diameter can range from 150 – 500 km and its speed may be 65 – 135 miles per hour.

Conditions necessary for the development of tropical cyclones

Tropical cyclones tend to develop over warm tropical oceans, where temperature exceeds 26ºC and where there is considerable depth of warm water. They develop in autumn, when sea temperatures are at their highest. They also develop in the trade wind belt, where the surface winds warm as they blow towards the Equator and between latitude 5^{o} – 20^{o} North and South of the Equator where Coriolis force is insufficient to enable the future to spin.

Impacts of tropical cyclones

Tropical cyclones are one of the major natural hazards which often cause considerable loss of assets and life. There are four main causes of damage associated with cyclones. Tropical cyclones produce *high winds* which often exceeding 160 km / hour or in extreme cases 300 km/hour. With this wind, the whole village, town or city can be destroyed and thus a country may suffer serious economic problems such as damage of transport and communication infrastructure. *Ocean storms (tidal) surges* resulting from cyclones destroy coastal areas which are in most cases densely populated. Good example is in Bangladesh where about 40,000 people were washed out to sea at the Bay of Bengal in 1994.

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Flooding caused by storm surge or torrential rain causes a lot of damage. For example, in 1974, about 800,000 people died in Honduras as their homes were washed away.

Landslides. Due to heavy rainfall, the buildings which have been constructed on steep and unstable slopes, such as those in Hong Kong, get destroyed easily.

Hurricanes

Hurricanes are the tropical cyclones of the Atlantic, and most powerful and destructive form of cyclone storm, with wind speeds ranging from 160 to 300 km per hour. These are formed after the ITCZ has moved to its most northerly enabling air to converge at low levels and can have a diameter of up to 650 km. ITCZ is the area encircling the Earth near the Equator, where the northwest and southeast trade winds come together.

Conditions for development of hurricanes

Hurricanes develop near the earth's surface due to intense low pressure, strong winds and continuous source of heat to maintain rising air currents. There should be enough supply of moisture to provide the latent heat released by condensation to drive the storm and provide the heavy rainfall. It is estimated that in a single day a hurricane releases an amount of energy equivalent to that released by 500 000 atomic bombs. Therefore, it is the area of air subsiding which increases instability by warming and exaggerating the storm's intensity. However, hurricanes rapidly decline once the source of heavy air is removed. When air moves over colder water on land surface, it increases friction and cannot supply sufficient moisture. The average life span of tropical cyclone is 7 – 14 days.

Tornadoes

A tornado is a small-diameter of violently rotating column of air that is in contact with both the surface of the earth and a cumulonimbus cloud. Tornadoes are often referred to as 'twister' in the USA. Thus, they are intense and enormously powerful winds in which air spirals at tremendous speed. They are smaller in size compared to other cyclones, commonly related to convectional activity. They occur within cumulonimbus clouds travelling in advance for a cold front and are mostly common in spring and summer. They are associated with thunderstorms and can occur over both land and sea. They usually appear as a dark funnel cloud hanging from the base of a dense cumulonimbus clouds, travelling at the speed of 225 km per hour. USA is the country mostly affected by Tornadoes. Other countries or regions frequently hit by tornadoes include South Africa, Uruguay, Brazil, Netherlands and Far Eastern Asia (Figure 6.28).

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Figure 6.28: *A tornado*

Anticyclones

These are areas of high pressure which develop in a region where the air is descending. They are associated with outward blow in a clockwise direction in northern hemisphere and an anticlockwise direction in the southern hemisphere. In an anticyclone, a downward motion causes air to descend and be warmed adiabatically hence condensation does not occur (Figure 6.29).

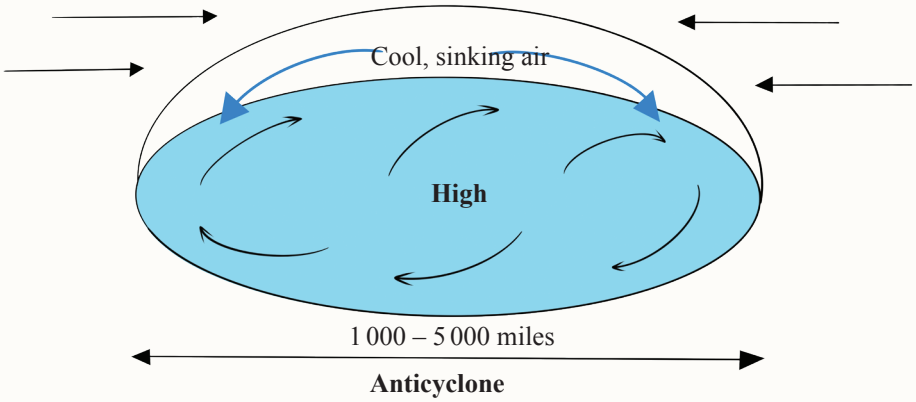


Figure 6.29: *Anticyclone*

Anticyclones have low pressure gradients that is the air pressure in it does not change rapidly. This means that the winds are gentle. As air sinks, it warms, leading to warm and dry weather. Anticyclones are much larger than depression and therefore can lead to many days or weeks of settled and calm weather. They often block the path of depressions either slowing down bad weather or forcing it round the outside of the high pressure system. They are then called blocking highs. Thus, as air descends, air pressure increases. Therefore, the earth's rotation makes the air change direction. In the Northern Hemisphere, the air is pushed clockwise while in the Southern Hemisphere, it is pushed anticlockwise.

Weather conditions associated with anticyclones

Weather conditions can vary between summer and winter, thus causing formation of weather related anticyclones namely *summer* and *winter anticyclones* are formed. Summer anticyclones are characterized by hot days with few or no clouds,

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and very light winds. They have cooled grounds which leads to morning mist. Warm moist air rising from the ground forms thunderstorms while cloud cover over eastern England caused by light winds blow over the cooler North Sea. Winter anticyclones are characterized by cloudless skies but less radiation due to the low angle of the sun. Their temperature drops, making the days cold and the nights even colder due to lack of cloud cover. Due to the coldness during night fogs and frost are formed at night. The weather conditions associated either by cyclones or anticyclones may differ depending on among other reasons, the season of the year.

Local winds

Local winds are types of winds which occur in the small spatial scale. They occur either regularly or periodically, affecting only limited areas, and blow for short periods of time. Local winds have distinctive characteristics and they produce important effects on the weather of the areas over which they blow. They include land and sea breezes, mountain and valley winds, descending winds (föhn), monsoon winds, depression winds, and convection winds. Such winds affect small area on the earth's surface and they lack specific direction.

Land and sea breezes

Land and sea breezes constitute one of the diurnal circulation systems resulting from differential heating and cooling between land surfaces and adjacent sea areas. The resultant pressure differences, although small and localised, produce gentle breezes which affect coastal areas. They are also called the *coastal winds* as they normally affect coastal areas both at night and during day hours.

Land breeze is the local wind which moves from the land to the see during the night when the sea retains heat longer than the land. During land breeze, there is a reversal of the pressure gradient which affects wind direction. During night, low pressure develops in the sea, resulting in the movement of wind towards the land (Figure 6.30).

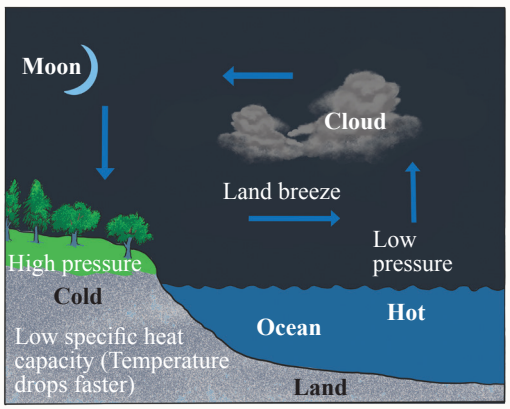


Figure 6.30: *Land breeze*

Sea breeze is the local wind which moves from the sea to the land during the day time when the land heats up rapidly than the sea. When the land is hot, lower pressure forms and a gentle breeze begins to blow from the sea (Figure 6.31). Sea breeze is capable of lowering coastal temperatures.

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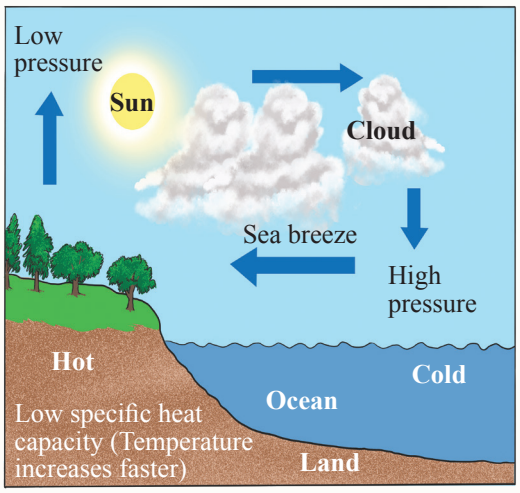


Figure 6.31: *Sea breeze*

Mountain and valley winds

Mountain and valley winds are special category of local or tertially winds that are directly related to the topography of the area. These winds are categorised into the following:

Anabatic winds

A term anabatic is derived from the Greek word '*Anabatos*' meaning moving upward. Anabatic wind are the local winds which blow in highland regions caused by ascending air masses along the mountain valley. During the day time, when the slope is heated by the sun, the air in contact with it becomes warmer than the air at the same level in a free atmosphere. The heated air mass expands and becomes less dense (rarefied) and thus rises up. The rising warm air mass is replaced by the cool air mass down the slope (Figure 6.32). Anabatic winds develop in areas where the general global wind circulation is not strong enough to obscure these local winds. The mountain or up-valley winds blow during the daytime as the result of differential heating by the sun. Anabatic winds develop near the mountain slopes where the air is heated by conduction to a greater extent than air at the same level above the valley. This causes the convectional rising of air from above the slopes which in turn causes the down slope air from the valley to take place. These winds sometimes rise to the level of condensation, which later leads to mountain rainfall.

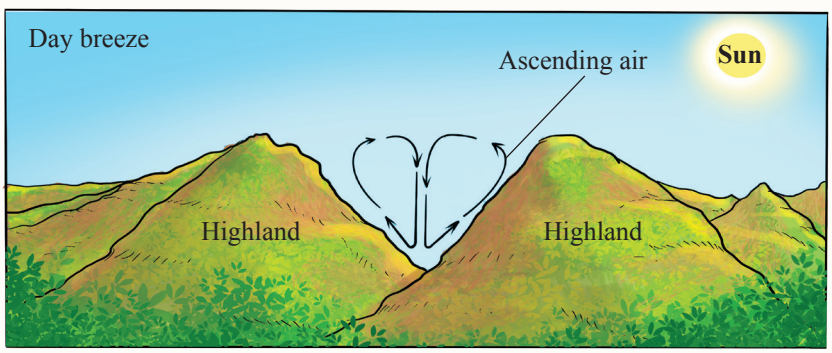


Figure 6.32: *Anabatic winds*

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Katabatic winds

The term Katabatic is derived from the Greek Word '*Katabatikos*' meaning flow downhill. Therefore, katabatic winds are the valley winds that blow down a valley during night where the general circulation of winds is not strong enough to obscure local influences. These winds develop when the upper slopes are chilled rapidly at night by radiation and the cool dense air flows down the hill by gravity, following the valley because of less resistance. These winds are more common in areas where cold air blows off an ice cap over which chilling is high. Katabatic winds blow cold, dense air down the slope into the valley, leading to cold temperature at night. The cold temperature brought about by the cold dense air results in the condensation and formation of mists and fogs (Figure 6.33).

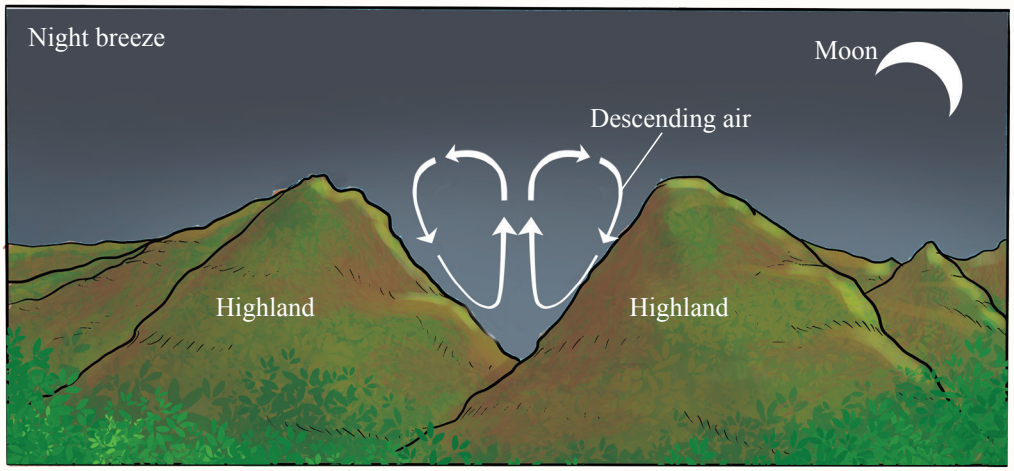


Figure. 6.33: *Katabatic winds*

Föhn wind

Föhn is a strong, warm and dry wind which blows periodically to the leeward side of a mountain range. It is a rain shadow wind that results from the adiabatic warming of air that has dropped most of its moisture on windward slopes. It is common in the Alps when a depression (LP) passes to the north of the mountainous area and draws in warm, moist air from the Mediterranean. As the air rises, it cools at the dry adiabatic lapse rate of 1^{o}C per every 100 m. This wind is also known as the Chinook in Alberta, USA, on the American prairies, and it has considerable effects on human activity. It causes snow to melt, especially in spring. It is very notorious in the Alps where the winds add difficulty in ascending an already difficult peak. Also, it is associated with the rapid spread of wildfires in fire prone regions as it blows (Figure 6.34).

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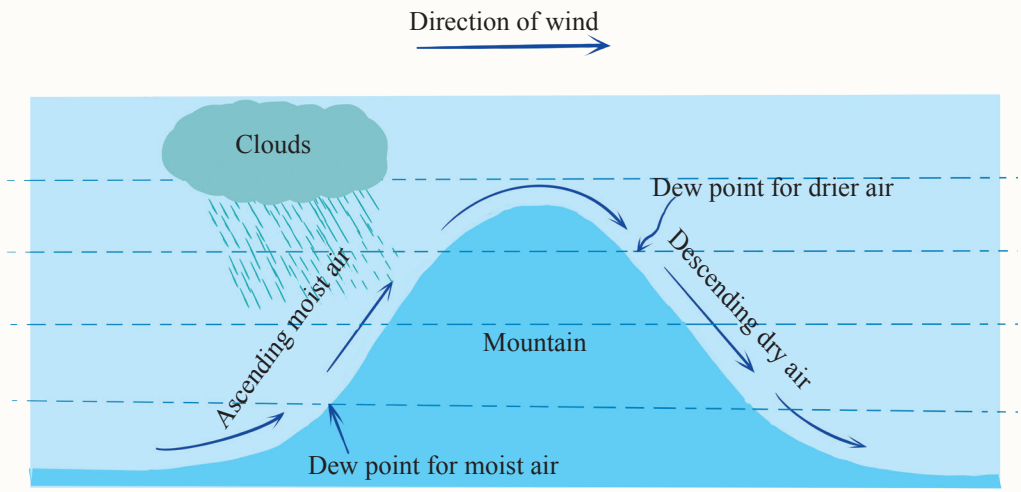


Figure 6.34: *Föhn wind effect*

Monsoons winds

The word 'monsoon' is derived from the Arabic word '*Mausim'* meaning season. These are winds which develop due to seasonal changes in temperature, which cause reversal changes in pressure, especially in Central Asia. Monsoon winds are common in Central Asia because Indian Ocean has no meridional extent (does not extend from North to South) as it is interrupted by Asia continent which cause extreme thermal contrast. In summer (between May and October), a low pressure belt develops over north western India, which is so intense that it becomes more effective and pronounced than those of the equatorial low pressure belt. This phenomenon leads to the development of an interrupted pressure gradient from the subtropical high in the Southern hemisphere across the Equator to north Western India. The wind blows from the southern hemisphere (Australia) high pressure cell as the South east (SE) but yet deflected to the right which then flows as South west (SW) winds towards the Indian sub-continent. The time taken to reverse the direction of these winds is six months. These winds are prominent within the tropics on the eastern side of the landmass and Indian Ocean (Figure 6.35). Normally, the south – east trade winds cross the equator, but on the way, they are affected by the rotation of the Earth, and consequently, turn into the south-west monsoon in most parts of Asia, blowing towards the heated continent. Due to changes in the overhead sun at different points and seasons, the surface temperature and pressure change seasonally. This causes a reversal movement of winds following the seasonal change in the temperature and pressure between northern and southern hemispheres. In winter, the intense high pressure

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develops over central Asia, while the southern hemisphere experiences low pressure with its centre over the Australian landmass. Then, wind blow along thermos barometric gradient from central Asia as North east (NE) wind and get deflected to the North-westery direction after crossing the equation. For instance, along the East African coast, monsoon winds cause moderate rainfall in Mombasa, Kilwa, Malindi and Dar es Salaam.

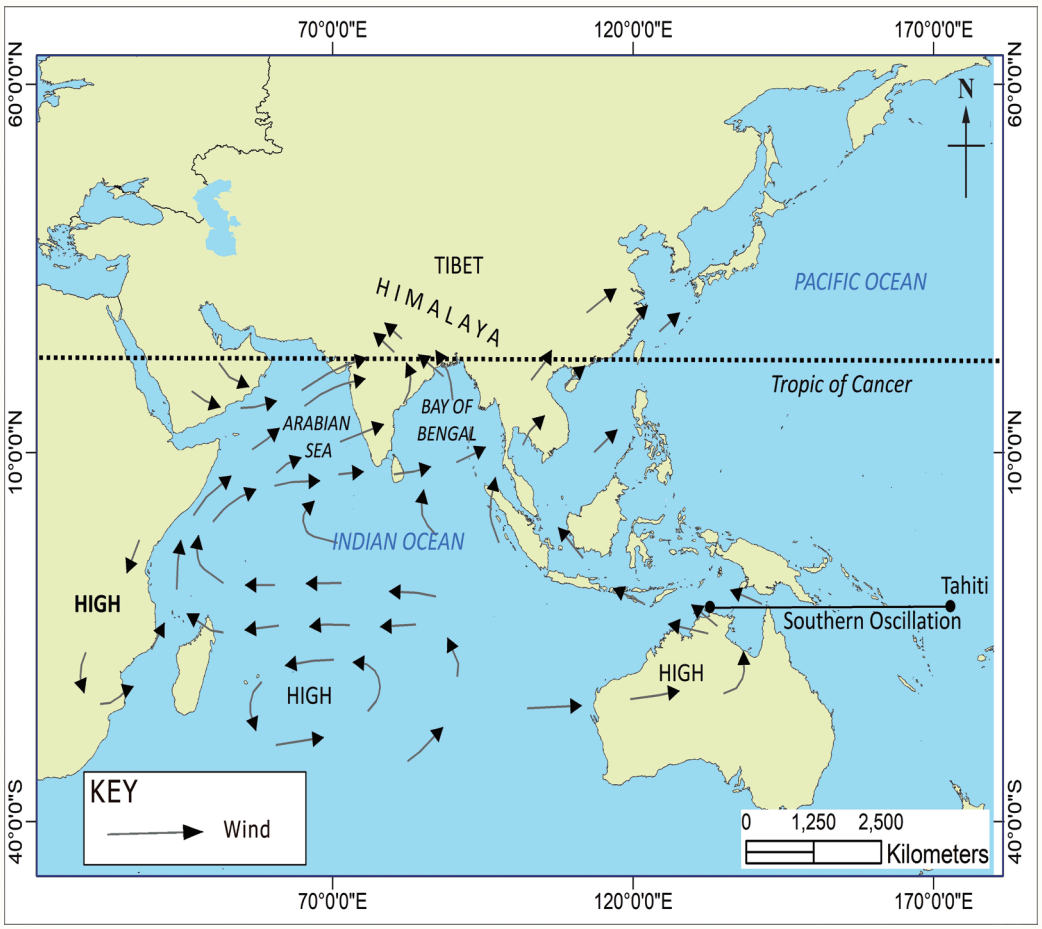


Figure 6.35: *Summer monsoon winds*

During winter, an intense low pressure develops over the Australian continent and high pressure in Asia minor, leading to the reversed direction of winds moving from Asia high pressure belt to Australian continent as North-East winds which then, flow as North-West wind after crossing the Equator (Figure 6.36).

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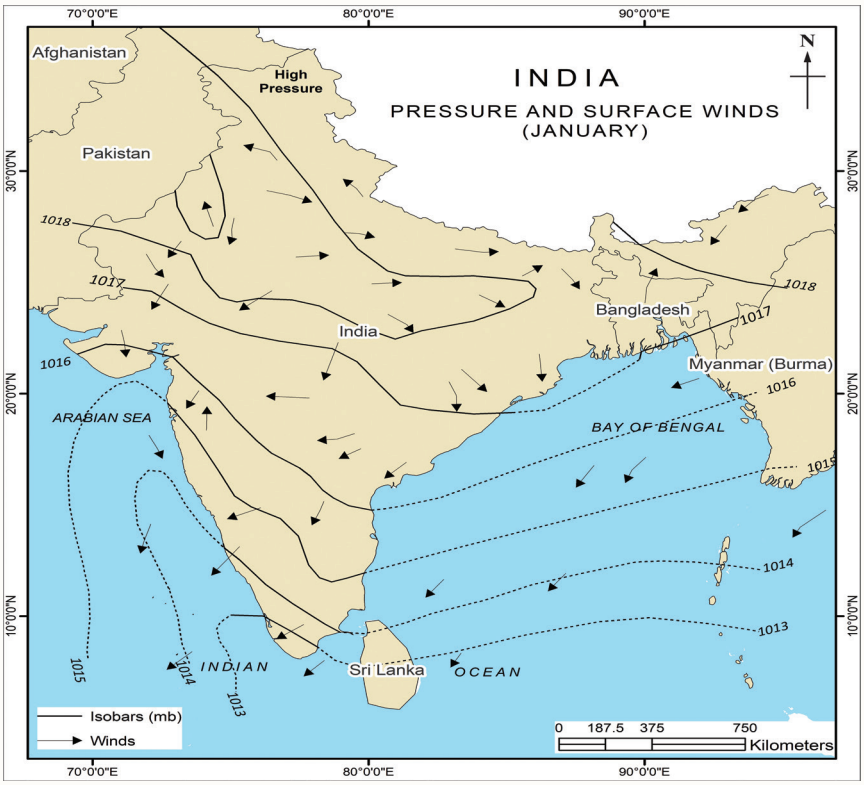


Figure 6.36: *Winter monsoons*

Activity 6.3

In consultation to the subject teacher, organize a study tour to the beach (sea, lake, ocean) or any lowland area during the day;

(a) Observe the pattern/direction of the wind blowing.

(b) Provide a sketch diagram from the observed pattern of the wind pattern.

(c) What could be the reason (s) for the observed wind pattern?

(d) Write a report about your observation and submit to the subject teacher for evaluation.

Exercise 6.7

1. Write short notes on the following concepts;
   (i) Cyclones and Anticyclones
   (ii) Anabatic and Katabatic winds
   (iii) Sea and Land breezes
   (iv) Monsoon winds
   (v) Föhn winds/chinock winds
2. Describe the stages of tropical cyclones development.
3. Explain the weather condition associated with;

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(a) Cyclones
(b) Anticyclones

4. Explain the influence of monsoon winds to the climate of Tanzania.

Atmospheric stability and instability

A parcel of warm air rises through the lower atmosphere cools adiabatically. The rate and maintenance of any vertical uplift depends upon temperature – density balance between the rising parcel and the surrounding air. In a simplified form, this balance is the relationship between the environmental lapse rate, and the dry and saturated adiabatic lapse rates.

Stability

The stability of the atmosphere occurs when a rising parcel of dry air (unsaturated air) cools more rapidly than the air surrounding it. It occurs when adiabatic lapse rate is dominant than environmental lapse rate that result to limited rising of warm airmass vertically that cause stable atmospheric condition. For example, the environmental lapse rate is 6.5ºC per 1000 m and the dry adiabatic lapse rate is 1ºC per 1000 m. By the time the rising air has reached 1000 m, it has cooled to 10ºC, which leaves it colder and denser than the surrounding air, which has cooled to 14ºC. If there is nothing to force the parcel of air to rise, such as mountains or fronts, it will sink back to its starting point, resulting into the stable atmosphere. A stable atmosphere is characterized by the clear atmosphere and sunny days. This is due to the limited cloud formation prevented by inability of air parcel to reach condensation point (the dew point), low atmospheric dampness resulting from limited or no condensation process. High temperature range due to extreme day and night temperature, since absence of clouds cause maximum day temperature and very low night temperature. Presence of calm atmosphere due to absence of thunderstorms lightening and precipitation, and temperature inversion resulting from descending of air parcels that are associated with dynamic compression. Pockets of air are forced to rise in fair ways:

Firstly, when the earth's surface is heated up, the overlying air mass is warmed by conduction, hence air rises. *Secondly,* when wind blows against a mountain side, the pocket of air is forced to rise up mechanically. *Thirdly,* when a cold air mass meets a warm air mass, the cold air, because it is denser than the warm air, descends, forcing the warm air to ascend. *Lastly,* vertical ascent may take place as in a tropical cyclone.

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Instability

Atmospheric instability is a condition where the earth's atmosphere is generally considered to be unstable and as a result the weather is subjected to high degree of variability through distance and time. The instability of the atmosphere occurs when a rising parcel of dry air cools less rapidly than the surrounding air. It is common on hot days when localized heating of the ground warms the adjacent air by conduction, hence creating a higher lapse rate. Instability is common in saturated air than unsaturated air, since the rising air cools much less rapidly and so remains warmer and lighter than the surrounding air. A warm damp air mass may therefore rise to great heights and cause very unstable atmospheric conditions, building up great clouds and possibly causing heavy rainfall, hail and thunderstorms. When the air-mass reaches a height at which it has the same temperature as the surrounding air, the vertical rise ceases and it becomes neutral or indifferent equilibrium state. Weather conditions associated with atmospheric instability include: deep convective current which leads to thunderstorm development (when enough moisture is present), over warm oceans which can lead to tropical cyclone and turbulence. Again, in dry atmosphere inferior mirages, dust devils, steam devils, and fire whirls can form. For example, fire whirls can spread fire beyond its previous bounds. Furthermore, small scale tornado like circulations can occur over or near any intense surface heat source, which would have significant instability in its vicinity, and cumulonimbus clouds and heavy rainfall may occur when sufficient moisture reaches dew point.

Conditional instability

Conditional instability occurs when Environmental Lapse Rate (ELR) is lower than the Dry Adiabatic Lapse Rate (DALR) but higher than the Saturated Adiabatic Lapse Rate (SALR). If a mass of dry air rises as a wind up a mountain slope, it cools at the dry adiabatic lapse rate until it reaches its dew point. Then condensation begins, and it now cools at the saturated adiabatic lapse rate. This may mean that even though the initial cause of the uplift was mechanical, the lower rate of cooling results in the air mass remaining relatively warmer than its surrounding and so it will continue ascending on its own accord. It is a conditional instability because instability depends on the presence of sufficient water vapour. Conditional instability is a common cause of storms and heavy rain.

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Exercise 6.8

1. Account for conditional instability in the atmosphere.
2. Describe weather conditions associated with;
   (a) Atmospheric stability
   (b) Atmospheric instability.

Sunshine

This is the visible light from the Sun to the surface of the Earth. The duration of sunshine is partly a function of latitudes as hours of light vary with season in different latitudes. It is also a function of daytime cloudiness as cloud cover limits sun rays from penetrating and reaching the surface of the Earth. For example, equatorial climate is characterized by rainfall and considerable cloud throughout the year. However, there is usually bright sunshine in the mornings, and the sky becomes overcast in the afternoons and early evenings. In cool temperate latitudes, the skies are frequently cloudy and drizzle or rain is common, thus less bright sunshine or sunshine duration. In the interior of continents, the sky is dry and less cloudy, experiencing more sunshine. Sunshine duration is the length of the time that the ground surface is irradiated by direct solar radiation. The World Meteorological Organization (WMO) defines sunshine duration as the period during which direct solar irradiance exceeds a threshold value of 120 watts per square metre (W/m^2). Normally it is expressed in hours per year or in average hours per day. Sunshine duration influences other elements of weather and climate including temperature, humidity as well as air pressure. Geographic pattern and cloudiness are among other factors affecting sunshine duration. Sunshine duration is recorded by Campbell-Stokes sunshine recorder.

Weather forecasting

Weather forecasting is the application of science and technology to predict the state of the atmosphere for a given location and time. It entails predicting how the present state of the atmosphere will change. Besides the prevalence of modern weather forecasting, eversince nineteenth century, human being has attempted to predict the weather informally for several millennia. The informal weather forecasting is termed traditional weather forecasting which uses indigenous knowledge in weather forecasting.

Types of weather forecasting

There are two major types of weather forecasting, which are traditional and modern weather forecasting.

Traditional weather forecasting

The traditional weather forecasting predicts weather through such methods as observation of types of birds' voices, crocking of frogs, rainbow, migration of birds, insects' voices, changes of wind direction, position of the moon and general body feeling. These behaviours of plants and animals and changes of

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environmental elements are associated with weather messages and meanings such as onset of rainfall, drought, and spring seasons. The methods are still widely used in predicting weather among the indigenous communities.However, the weaknesses of traditional weather forecasting largely lies on its limited coverage and reliability. Also, its short fall on being too narrative and context specific.

Modern weather forecasting

The modern weather forecasting involves the use of modern equipment such as satellites, electronic computers, radar, aircraft, balloons, ship, sub-marines, rockets and daily recordings from weather stations. These methods of weather forecasting are most reliable compared to traditional weather forecasting.

Importance of weather forecasting

Provides early warning information to the population. This helps the government and other stakeholders to prepare and respond to extreme weather events more effectively and efficiently and reduce damage to property and loss of lives, such as warnings against hurricanes and storms. Forecasting based on temperature and precipitation are important for various planning purposes including agricultural activities. This is especially important in countries where agriculture is the main livelihood activity for the majority of the population. Planning outdoor activities: Since outdoor activities are severely interrupted by heavy rain, snow and wind chill, forecast can be used to inform appropriate planning of activities or measures in relation to predicted weather. Navigation and air transport: Weather forecast is crucial for water and air transport as their safety depends on the state of weather on a given route. Weather forecasts also help to determine the type of cloth people wear in a given day. This is more important in the Arctic or Equatorial regions where temperature is highly variable. Fishing activities: Both local and modern fishing activities largely depend on the state of weather of a given day because it affects the movements of sea water. Geographic expeditions and military operations both largely rely on weather in conducting their activities. for example, flying drones can be prevented by strong winds. Contractors and engineers are very keen on weather for successful construction activities. For example, construction of roads and bridges can be prevented by heavy rain.

Activity 6.4

Visit a weather station in your geographical setting, among other things, observe the following;

(a) How elements of weather are recorded?

(b) What are the specific instruments used in recording weather and climate elements?

(c) Ask for permission to take photos and short videos.

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(d) Get to know how are the recorded data, stored, and presented.

(e) How weather data are used to forecast the atmospheric conditions.

Summarize your findings and submit to the subject teacher for assessment and feedback

Exercise 6.9

1. Explain how forecasted weather are a function of human plans and activities.
2. Discuss the importance of weather foresting in Tanzania?

World climate regions

Although it is possible to study climatic phenomenon in isolation, an understanding of the development of soil and vegetation necessitates an appreciation of the interrelationship between soil, vegetation and climate. The integration and interaction of climate, soils and vegetation gives the world its major ecosystems or biomes.

Classification of climate

The classification of climate represents targets to distinguish various combinations of climatic elements throughout the world. By studying the weather, it is possible to make generalizations about the climate of a given place. Generally, there are two ways or methods of classifying climates namely; empirical classification and genetic classification.

Empirical Classification

This is based on statistics, experiments or physical characteristics related to climate. It is, therefore, based on observation and hence it is more stable overtime than genetic classification. It focuses on temperature and precipitation.

Genetic classification

This approach is based on the causes or genesis of climatic variations. In this scheme of classification, climatic conditions or phenomena as they are obtained in different areas on the earth's surface, are organized according to their causes or origin. Basing on knowledge of the causes and relationship between different climatic variables, this type of classification is easy to use. However, genetic classification suffers from the uncertainty of our understanding of causes and origins of climatic conditions or behaviours as they may change at any time. It is done for a specific purpose, or for certain climatological activities. The earliest classification of climate types was made by the Greek philosophers who distinguished three latitudinal temperature zones namely; Torrid (within the tropics), Frigid (within the polar circles) and Temperate (between the two).

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Köppen's climates classification system

The widely used classification system of climates is the empirical system developed by Vladimir Köppen in 1884 which uses statistical data of temperature, precipitation, and vegetation distribution. It is based on the identification of the close relationship between vegetation and climate distribution. The system uses values of temperature and precipitation in relation to vegetation distribution on the surface of the Earth as criteria for climate classification. The system is an empirical because it is based on the mean annual and monthly temperature and precipitation respectively. It uses *capital* and *small* letters to designate climate groups and types. Table 6.2 indicates Köppen's climate groups and their characteristics.

Table 6.3: *Climates Groups by Köppen*

Group	Characteristics
Tropical climates (A)	Average temperature of the coldest month is 18°C or higher.
Dry climate (B)	Potential evaporation exceeds precipitation.
Temperate climates (C)	The average temperature of the coldest month of the (Mid-latitude) climate years is higher than -3°C but below 18°C.
Cold snow forest climates (D)	The average temperature of the coldest month is -3°C.
Cold climates (E)	Average temperature for all months is belows 10°C.
Highland climates (H)	Cold due to elevation

The capital letters A, C, D and E represent humid climate while the letter 'B' represents dry climates. The climatic groups are further sub-divided and represented by small letters based on seasonality of precipitations and temperature characteristics.

The seasons of dryness are indicated by small letters *f, m, w* and *s*: where *f* corresponds to no dry season, *m*-for monsoon climate, *w*-for winter dry season, and *s*-for summer dry season. The small letters *a, b, c* and *d* refer to the degree of severity of temperature (Table 6.3). The B-Dry climates are sub-divided using the capital letters S-for steppe or semi-arid and W-for desert.

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Table 6.4: *Types of climates according to Köppen*

Group	Type	Letter code	Characteristics
A-Tropical humid climates	Tropical wet	Af	No dry season
	Tropical Monsoon	Am	Monsoonal, short dry season
	Tropical Wet and dry	Aw	Winter dry season
B-Dry Climates	Sub-tropical steppe	BSh	Low-latitude semi-arid or dry
	Sub-tropical desert	BWh	Low-latitude arid or dry
	Mid-latitude steppe	BSk	Mid–latitude semi-arid or dry
	Mid latitude desert	BWk	Mid-latitude arid or dry
C-Warm Temperate (Mid-latitude) climates	Humid –subtropical	Cfa	No dry season, warm summer
	Mediterranean	Cs	Dry hot summer
	Marine West Coast	Cfb	No dry season, warm and cool summer
D-Cold snow Forest climates	Humid continental	Df	No dry season severe winter
	Sub-arctic	Dw	Winter dry and very severe
E-Cold climates	Tundra	ET	No true summer
	Polar Ice Cap	EF	Remedial Ice
H-Highlands	Highland	H	Highland with snow cover

Significance of the Köppen climates classification system

This classification provides an efficient way to describe climatic conditions defined by temperature and precipitation and their seasonality. Being ecologically relevant, it has been widely used to map geological distribution of long term climate and associated ecosystem conditions. It helps to predict the dominant vegetation type based on the climatic data. It provides reasonable correlation globally with major vegetation regions. It requires a minimum amount of calculation, and it is widely used in educational circles throughout the world.

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Limitation

Despite its significance, yet it is not universally applicable as it only relies on data or mean monthly temperature and precipitation to classify climate. Again, there is no provision for variations in the strength or constancy of winds, temperature extremes, precipitation intensity and range, amount of clouds cover, and net radiation balance. Furthermore, its great inadequacy perhaps lies in its application to humid dry boundaries and impractical to land management and planning purposes where more precise and varied factors need to be utilized.

Miller's classification

In 1946 A. A. Miller developed workable classification of climate. Such the climate classification is most applicable to geographers because of its applicability to regional description by combining a map of temperature zones with that of the seasonal distribution of rainfall. Miller thus, developed a five temperature zones of climate classification that is hot climate, warm temperate (sub-tropical), cool temperate, cold climate, and Arctic climate. He also added desert climate and mountain climates to these zones based on temperature (Table 6.4).

Table 6.5: *Miller's classification of climates*

Tempera-ture °C	Description	Climate type
Below (-10)	Very cold	Arctic
(-10) to 0	Cold	Cold climate
0 to 10	Cool	Cool temperate
10 to 21	Warm	Warm temperate
21 to 30	Hot	Hot climate
Above 30	Very hot	Desert

Activity 6.5

In a group;

1. Read books and other sources to find out the basis for each climates classification systems and the specific type of climates proposed.
2. Present findings to the class for discussion.

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Exercise 6.10

1. Discuss the features of Köppen's classification of World climates.
2. Examine the strength and weakness of Köppen's climates classification system.
3. Compare and contrast Köppen's and Miller climates classification systems.

Types of climate

Generally, the integration of Köppen and Miller's climate classification has resulted to the emergence of nine types of climate along their respective characteristics which are widely accepted climates in the world as follows.

Equatorial climate

This climate is usually found within latitudes 0° and 5° North and South of the equator. This type of climate covers the Amazon basin, the Congo basin, southern Ivory Coast, South western and South central Ghana, Western coastal Nigeria, and Eastern coastal Madagascar. Highlands located between these latitudes are known as modified equatorial climate, for example the East African Highlands.

Climate characteristics

The equatorial climate lies under the doldrums of low pressure system with high monthly mean temperature from 26° to 28°C, while annual range of temperature is between 2° to 3°C. It has no seasonal rainfall as rain is almost throughout the year. The area experiences high humidity and heavy rainfall accompanied by lightning and thunderstorms. The area receives abundant rainfall with annual rainfall of about 2000 mm, with two maxima. Also, it is the zone where wind converge at the Equator, popularly known as Inter Tropical Convergence Zone (ITCZ).

Equatorial monsoon climate

This type of climate is found within latitudes 0° and 5° North and South of the equator. This type of climate is common in South East Asia especially in Malaysia, Singapore and Indonesia. It also occurs on a smaller scale in western Cameroon and Southeastern Nigeria.

Climate characteristics

It is characterised by high temperature, between 26° - 28°C throughout the year. Humidity is very high accompanied with heavy rainfall over 2500 mm. The region experiences no dry season almost throughout the year, but has a well-developed double maximum rainfall in May and October.

Tropical marine climate

This climate is found within latitudes 5° and 15° North and South of the equator, particularly on the East coast regions which come under the

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influence of onshore Trade Winds. This type of climate is found on the East coast of Brazil, the eastern coast of Madagascar, the lowlands of Central America and West Indies, the coast of Queensland, and the southern Islands of the Philippines.

Climate characteristics

It is characterized by high temperature of 29°C, high rainfall between 1000-2000 mm with no dry season, high humidity throughout the year, and onshore Trade Wind blowing throughout the year. Tropical cyclones, and hurricanes or typhoons often affect the region.

Vegetation

The uniform climatic characteristics developed in Equatorial, Equatorial Monsoon and Tropical Marine regions are abundant rainfall, lack of a dry season and uniformly high temperature which create excellent conditions for vegitation growth. The lowlands have a natural vegetation of tall, broad leafed evergreen trees which make up a forest complex known as rain forest or *selvas* (Figure 6.37). The main features of rainforest or selvas include the following;

(a) The forest consists of three layers, namely top layer, middle layer and bottom layer: The *top layer* consists of tall trees with buttress roots. The height of the trees ranges between 32- 45 m. The *middle layer* consists of tree ferns, lianas (thick stemmed creepers), for example, rattan and epiphytes (which use the trees for support). The height of the trees is between 19-34 m. The *bottom layer* consists of ferns, herbaceous plants and saprophytes (plants which live on dead plants), with trees up to 17 m tall.

(b) Nearly all plants are broad leaved evergreens because high temperature and evenly distributed rainfall permit growth throughout the year.

(b) Absence of climatic season results in some plants being in flower, others in fruit, and others in leaf-fall at once.

(d) The leaves of the tall trees form almost continuous cover which shuts out most of the sunlight from the ground, thereby preventing the growth of many plants on the forest floor. But where the forest is more open, along river banks, and in forest clearings, sunlight reaches the ground and a thick undergrowth of ferns, bushes and creepers develops.

(e) Mangrove trees form dense forests in coastal swamps and in the lower valleys of tidal rivers.

(f) Most of the trees are hardwoods, such as mahogany, ebony ironwood, rosewood and greenheart. Trees, ferns and palms are also common in equatorial forests.

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(g) The climates contain a large variety of plants which usually grow close together.

(h) When a part of a tropical evergreen forest is cleared, either for shifting cultivation or for lumbering, a less luxuriant forest growth takes place. This is called secondary forest and it consists of short trees and dense undergrowth.

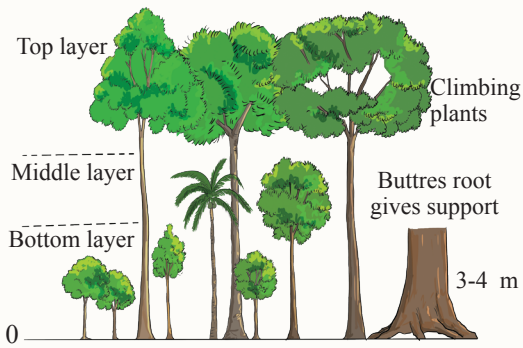


Figure 6.37: *Tropical rainforest*

Tropical monsoon climate

The tropical monsoon climate is found along the coastal regions of south-east Asia, south China, the Indian sub-continent, and the northern parts of Australia. It occurs in small scale, particularly in coastal areas. This climate covers areas such as southern Senegal, Guinea-Bissau, Guinea, and Sierra-Leone in the West Africa.

Climate characteristics

(i) The seasonal and ocean winds operate on a very large scale affecting both continents and oceans. These seasonal winds are called monsoon winds.

(ii) Seasonal reversal of winds is the main characteristic of this climate. For one season, the winds blow from the sea to the land, bringing heavy rain to coastal regions and for another season they blow from the land to the sea, giving little or no rain except where they cross a wide stretch of sea.

(iii) Wind reversal is caused by pressure changes over the land masses.

(iv) Temperatures range from 25^0C in cool season to 32^0C in hot season.

(v) Annual rainfall varies greatly due to relief and the angle at which onshore winds meet. Annual rainfall varies greatly, for example about 620 mm around Delhi, and as much as 1250 mm on south-facing slopes of Khari Hills, in Assam.

A typical tropical monsoon climate has three seasons which are;

Cool, almost dry season (November-February) which is characterized by no rain due to offshore winds, with temperature ranging between 12^0C and 25^0C.

Hot dry season (March-May) which is characterized by high temperature reaching 28^0C or higher, and dry condition. *Hot, wet season* (June – October). This season is characterized by high rain because of onshore wind. It is dominated by cloudy skies, high humidity, and temperature between 25ºC and 31º C.

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Main features of Monsoon forest

Most of the trees are deciduous and leaves fall off during the hot, dry season. There is rapid growth of trees in the hot and wet season, and the trees soon become covered with leaves. Trees are tall, often as high as 30 m, but they are not as close as in tropical evergreen forests. On the other hand, undergrowth is denser, bamboo thickets are common. The number of species is smaller than in the rain forest. Stands of one type of tree are very common, for example, teak forest of Thailand and Burma, the Sal of India and the eucalyptus of northern Australia. In West Africa, this type of vegetation is known as casamance woodland, the name derived from the Casamance district of Senegal where it is well developed (Figure 6.38).

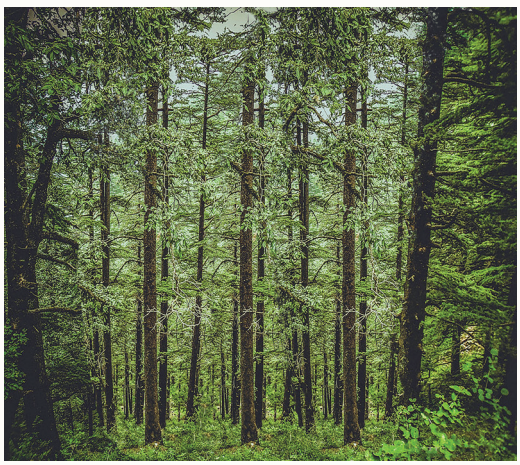


Figure 6.38: *Tropical monsoon forest*

Tropical continental climate

This type of climate is located between 5º and 15º North and South of the Equator. Areas covered by this climate include West, East and Central Africa, South America (especially Guiana Highlands, Orinoco Basin and Brazilian Highlands), India (around Deccan plateau), and the areas neighbouring the North and East of the Australian Desert.

Climate characteristics

The major feature of this type of climate is the existence of high temperature during summer (32ºC) and winter (21ºC). The annual range of temperatures is about 11ºC. The wet season may be as short as three months in some areas and as long as seven or eight months in others. The area closer to the Equator tends to have longer wet seasons and may experience over 1000 mm of rainfall per year. The climate experiences the trade wind. Sometimes experience strong, hot and dusty winds, such as the Harmattan of West Africa.

Vegetation

In areas which experience a tropical continental climate, the seasonal rainfall tends to give rise to a distinct type of vegetation known as tropical grassland or savannah. The term savannah refers to open grassland, usually with some scattered trees or bushes. It contains tall grasses often reaching 2 m in height and scattered trees mainly located near to water courses. Trees are more common than grasses in the areas bordering the equatorial forest. The dry season in this type of climate lasts for three months, and the vegetation is known as Savannah woodland. In the areas bordering the tropical desert, the vegetation consists

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mainly of thorn bushes, low shrubs and thorn trees with dry season lasting for nine months. High temperatures and heavy rainfall in the summer result in rapid and luxuriant plant growth (Figure 6.39). Most of the grasses wither and turn brown in the dry season, and fires are common. Roots remain dormant and when the rains come, they produce new shoots and leaves. Tropical grasslands have different names depending on their location, such as Campos (Brazil), Llanos (Guiana), Highlands and Savannah (Africa and Australia).

Trees in this type of climate survive the dry season in various ways, which include, storing water in their trunks, like baobab trees, some store water through loss of leaves, most of the trees have long roots and develop an umbrella shaped crown which provides shade around the trunk and roots which help to conserve soil moisture.



Figure 6.39: *Tropical continental vegetation*

Tropical Desert

This type of climate is located in the area between the latitudinal belt of 15º and 30º North and South of the Equator. This region is the driest and hottest place on Earth. Rainfall is very minimal and in some years there is no rainfall at all. Deserts are typically found in continental interiors of the sub tropics. Tropical dessert climate occurs on the Western side of land masses in the belt of permanent trade winds. The principal tropical deserts include: The Sahara, Kalahari and Namib deserts in Africa; the Jordan, Syria, Iran, Iraq, Saudi Arabia and Israel deserts in South West Asia; the Thar Desert in Indian subcontinent; the Mohave, Colourado and Mexican deserts in North and Central America; the Atacama Desert in South America; the Great Australia desert in Australia; and the Somalia desert in the Horn of Africa.

Climate characteristics

Trade winds blow towards the sea across tropical deserts for most of the year (off-shore winds). Likewise, the high and low-sun monsoon winds blow parallel to the coast, so moisture laden maritime can penetrate over land infrequently. In most low-latitude deserts, clouds cover is uncommon, resulting in low rainfall, rarely exceeding 120 mm (often no rain at all). Sudden downpour of rainfall may give rise to flash floods. Temperature is high with a monthly mean range of 21º-32ºC. Daily temperature variations are extreme, ranging from 35º-40ºC

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and above. The region experiences high humidity during night.

Vegetation

The region is characterized by very poor vegetation cover. Cactus, thorny plants and grasses (Figure 6.40) are the major natural vegetation found in desert region. The scarcity or absence of vegetation is due to high temperature, excessive evaporation, and insufficient rainfall. All plants are adapted to high temperatures, high evaporation, and long periods of dryness. Most of the desert vegetation have long taproots which go far deeper to the water table to collect water from the deep surface. They have capacity to store water in their stem and leaves. Other plants grow waxy or needle shaped leaves which reduce transpiration (loss of water from plant through stomata) rate. Most of the plants have strong water storage organs, hence help them to survive. Most of the plants are deciduous plants, thus they have a tendency of shading off their leaves during the dry season in order to cut off the rate of transpiration, while flourishing back during the wet season. Most of the plants have narrow shaped leaves that reduce the rate of transpiration. Some of the plants have spines which usually store water and thorn shaped structure which cut off the rate of transpiration. They have sunken stomata that reduce the loss of water through leaves. Sunken stomata are the stomata that are found below the leaves which reduce the rate of transpiration. The thorns found in most of the vegetation in arid and semi-arid deserts help them to fight parasite vegetation.



Figure 6.40*: Tropical desert vegetation (Cactus)*

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Warm temperate climate

This type of climate is also known as Mediterranean climate or West margin climate. It occurs between latitudes 30ºN – 45ºN and 30ºS– 40ºS of the equator on the western sides of the continents. They are mainly found on the lands bordering the Mediterranean, south West Africa (at Cape Province), central Chile, central California, and South west and southern Australia.

Climate characteristics

The temperature in these regions is generally moderate, and the changes between summer and winter are also moderate. The temperature ranges from 10ºC in winter to 21º C during summer. They have high rainfall in winter due to onshore winds and low rainfall in summer due to offshore winds. Winter rain ranges between 500-900 mm. They are characterised by local winds, such as *Sirocco* which blows across the Sahara Desert towards the Mediterranean.

Vegetation

This climate has warm temperate forests. It occurs where summers are warm, winters are mild without extended periods of snow cover or severe frost, and where there is no marked dry season. In these regions, much of forest and woodland have been cleared for agriculture, settlement and industries; only scattered woodland of trees and shrubs, remain. Common trees in these regions include evergreen oak, cork, sweet chestnut, beech, cedar and pines, cypress, and eucalyptus. Xerophytes manage to adapt to the very hot, dry summer conditions by storing water from the winter rain in their leaves or barks. Such leaves have a waxy surface to reduce transpiration and a thick bark. Some plants have very small, spiny leaves again to reduce transpiration and long roots which can tap underground moisture.

Tundra climate

It occurs on the coastlands bordering the Arctic Sea in North America, and the coast lands of Eurasia.

Climate characteristics

Temperature ranges from -29º C to -40º C in winter, which is usually very long. The sun never rises above the horizon for several weeks. Summers are short and cool, with about 10º C, but during summer the sun remains above the horizon for several weeks. The annual precipitation is about 250 mm, some of which fall as rain in summer, and as snow in winter.

Vegetation

The natural vegetation consists of mosses, lichens and dwarf trees and shrubs. This vegetation is called 'tundra vegetation'. The characteristics of this vegetation include small flowering shrubs such as bilberry and crowberry, flower and fruit in the short summer and their stems are twisted and woody. Mosses, sedges and lichens occupy

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much of the low-lying semi-swamp areas and have a height of only few centimetres. Dwarf and twisted trees such as willow and birch grow in the more sheltered area, especially on south-facing slopes. A large variety of small flowering plants, such as poppy and anemone are able to compete their life cycle in the short summer.

Polar climates

It is found in the interiors of Iceland, Greenland and in Antarctica. This type of climate is permanently characterized by temperatures below 0ºC. Snow storms are very frequent. The winters consist of continuous night and the summers of continuous day. Surface vegetation is almost non-existent.

Mountain climate

This type of climate is also known as Alpine climate, occurs in high mountain areas. Examples of regions where it is found include Ethiopian highlands, East African mountains, the mountains and plateaus of central Asia, the Alps of Europe, the Andes of South America, the Rockies of North America, and the plateau of Tibet.

Climate characteristics

Mountain climate is featured by decrease in pressure and temperature with increase in altitude while precipitation increases. If mountains are high enough there is a height at which maximum precipitation occurs and above which it decreases. There is usually a succession of temperature belts particularly in high mountains, such as the Ander which lies within the tropics. Local winds often develop in most high mountains. These tend to blow up the valley during the day (anabatic) but down the valleys and mountain slopes during the night (katabatic). Other local winds such as Chinook in the Rockies and the Föhn in the Alps are caused by air crossing the mountains and descending down the leeward slopes.

Exercise 6.11

1. Explain the characteristics of tropical rainforest.
2. Explain how trees adapt to the dry season in tropical continental climate.
3. Mountains maintain their own climate. Discuss.

Climate change

Climate change is a statistical change in the state of the climate that persists for an extended period typically decades or longer, whether due to natural variability or as a result of human activity. Climate change explains the invariability of elements of climate over time and space.

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Evidences of the past climate change

Climates have changed and keep on constantly changing at all scales, and over varying time spans (both long and short terms). In understanding the current change in climate, there is a need to understand the past climates. Meteorologists and earth scientists are continually providing a list of evidences of the past climates through;

Rocks

Rocks that are found today were formed under climatic conditions and environments that are no longer existing. A good example is the climate condition which led to the formation of the coal in Britain. Scientific investigation proves the existence of some rocks which were formed in climatic conditions which no longer exist. This is a strong implication that climate has changed and is still changing.

Fossils landscapes

Fossils landscapes that exist today have been produced by geomorphologic processes which is no longer operating. For instance, glacially eroded highlands in the North and West Britain, granite tors on Dartmoor, and wadis formed during wetter periods (fluvial) in deserts. From a climate morphological point of view, land forms on the earth's surface are shaped and reshaped by prevailing weather and climatic condition operating in a particular area. These land forms are different depending among other things on the agent involve. Therefore, land formed due to wind, is different from landforms formed due to glaciation. Therefore, presence of glacial landform in a region with no glaciers is an indication that formerly the area was under glaciation.

Changes in sea level

There are also evidences of changes in the sea level isostatically and eustatically in various areas of the world including Maldives Island. Rising of the sea level is an indicator of melting of ice resulted from high temperature. Also, there are a number of islands whose coastal lines and shores have been submerged.

Vegetation belts

Vegetation belts have shifted through some 10^{o} of latitude. A good example can be drawn from the Sahara Desert in Africa. Desert margins are progressively extending engulfing more land and changing it into bare land. This indicates progressively increase in global temperature.

Pollen analysis

Pollen analysis shows which plants were dominant at the specific area and time. Each plant species has a distinctively-shaped pollen grain. Although pollen can be transported by the action of winds or wildlife, it is assumed that grains trapped in peat form a representative sample of the vegetation that grew in the surrounding area at a given time. They show that this vegetation was a response to the

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climate conditions which prevailed at that time. Normally pollens of one plant species are completely unique from those of another plant species. In oxygen free environments deposited pollens may survive for a long period of time. Therefore, through scientific analysis, it is possible to identify the vegetation and climate type which prevailed at that time.

Dendrochronology

Dendrochronology also known as tree ring dating is a technique of obtaining a core from a tree trunk and using it to determine the age of the tree. Tree growth is rapid in spring, slower in autumn, and stops in winter in temperate latitudes. Each year's growth is shown by as single ring. However, when the year is warm and wet, the ring will be larger because the tree grows more quickly than when the year is cold and dry. Tree-rings therefore are analysed to reflect the changes in climates.

Chemical methods

Chemical methods include studying of oxygen and carbon isotopes. An isotope is one of two or more forms of an element which differ from each other in atomic weight. This means that they have the same number of protons in a nucleus with different number of neutrons. For instance, the most accurate form of dating is based on C-14, a radioactive isotope of Carbon. Carbon is taken in by plants during the carbon cycle. Carbon-14 decays radioactively at a known rate and can be compared with C-12, which does not decay and can be applied in dating process. Using C-12 and C-14 from a dead plant, scientists can determine the date of death to a standard error of ±5%, the techniques can accurately date organic matter up to 50,000 years.

Historical records

Historical records of climatic change include cave paintings of elephants in central Sahara and giraffes in Jordan. Since, elephants are not desert animals, it indicates that in past, the region (Sahara) was an another climatic region which favoured the life of animals like elephants. Another good example is that, graves for human burial in Greenland which were dug to a depth of 2 m in the 13th century, could be dug by only 1m in the 14th century, and could not be dug at all in the 15th century due to the extension of permafrost – in contrast to its retreat in the 2000's.

Recent changes in climate

Over the last century, glaciers and ice caps have been receding, snow cover has reduced and sea levels have been rising. The Earth has warmed by about 0.7°C, particularly over the last 15 years. The concentrations of greenhouse gases, such as carbon dioxide and methane in the atmosphere are greater than at any time in roughly the last 500,000 years and their concentrations have risen sharply in recent decades. The current concentration of atmospheric

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greenhouse gases is equivalent to carbon dioxide levels of around 430 parts per million compared with only 280 parts per million before the Industrial Revolution. The rate of increase in temperature is faster now than previously, even at the end of glacial periods. The Intergovernmental Panel on Climate Change (IPCC) fourth assessment report of 2007, emphasizes that "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level".

The temperature increase is widespread over the globe but more concentrated at higher northern latitudes. For the Arctic, the temperatures over the last 100 years have increased twice the rate of the global average. The oceans have warmed down to depths of at least 3 000 metres. Numerous other long-term changes in climate have been observed. For example, there have been an increase in rainfall in northern Europe, northern and central Asia, and eastern, northern and southern America between 1900 and 2005. Rainfall has declined in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia. The IPCC fourth assessment report noted that it is very likely that cold days, cold nights and frosts have become less frequent over most land areas, while hot days and hot nights have become more frequent. It is also likely that both heat-waves and heavy precipitation events have become more frequent over most land areas.

Theories of climate change

Several arguments have been put forward to explain climate change over different time scales and epochs. Most of the climatologists now accept that each of the causes of climate change described below has a role to play in explaining change in the past, whether over long or short periods of time. Climate change is attributed to natural and anthropogenic factors as follows;

Variations in solar energy

Although it was initially believed that solar energy output does not vary overtime, increasing evidence suggests that sunspot activity, which occurs in cycles, may significantly affect our climate. High annual temperatures on Earth appear to correspond to periods of maximum sunspot activity. Whereas, low annual temperature on the earth's surroundings corresponds to minimal support output phase, which is responsible for global climate change. Most of the proponents of the theory believe that solar variability drives changes in earth's climate and positive feedback occurs either by a process involving the influence of solar wind on cosmic rays which affects cloud formation, or on the ocean's thermohaline circulation (T.H.C), which affects sea surface temperatures and wind patterns.

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Astronomical relationships between the sun and the Earth

There is increasing evidence supporting Milankovitch's cycles of change in the earth's orbit, tilt and wobble, which would account for changes in the amount of solar radiation reaching the earth's surface. According to the theory, the earth's orbit changes from being less to more elliptical within a cycle of 100 000 making the Earth to appear near or far from the Sun, affecting the annual thermal output, hence climatic change.

Changes in oceanic circulation

These affect the exchange of heat between the oceans and the atmosphere. This can have both, long term effects on world climate where currents at the onset of the Quaternary ice age flow in directions opposite to those at the end of the ice age, and short term effects (El Niño). The latest theory compares the North Atlantic Drift that brings water to North West Europe. If, for example, the conveyor belt was closed possibly by a huge influx of fresh water into the sea, then the climate would become dramatically colder.

Meteorites

Meteorites is one of the considered theories in explaining the climate change. It explains a collision of one or more meteorites falling on the earth and attributed to the reduction of incoming solar radiation, a depletion of ozone layer and lowering of global temperature. Consequently, this event was associated with the extinction of a dinosaurs among other effects about 65 million years ago.

Volcanic activity

It has been accepted for some time that volcanic activity has influenced climate in the past, and continues to do so. World temperatures are lowered after every single eruption, such as the ones in Mount Krakatoa and Pinatubo. This is due to the increase in volcanic dust particles in the lower atmosphere which absorb and scatter more of incoming radiation, and offset the greenhouse effect. Precipitation also increases due to the greater number of hygroscopic nuclei (dust particles) in the atmosphere. Volcanic dust particles also act as inhabitant to the direct incoming solar radiation, therefore lowering the global temperature, hence climate change.

Plate tectonics

The movements have led to redistributions of land masses causing long-term effects on climate. These effects may result from a land mass drifting into different latitudes or uplift forming high fold mountains. Mountains can lead to colder climate as they act as barriers to atmospheric circulation. For example, the Asian Monsoon were established by the creation of the Tibetan Plateau.

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Composition of atmosphere

The concertation of the atmospheric gases can be altered in various ways. For example, the concertation of the atmospheric gases can be increased by volcanic eruptions. At present, increasing concern is being expressed at build-up of CO_2 gases in the atmosphere and the resultant green-house effect, along with the use of aerosols.

The influence of human activities on climate change

The Earth is warmed during the day by incoming solar radiation and cooled at night by outgoing radiation (infrared radiation). Normally, the incoming solar radiation is able to pass through the atmosphere, some of the outgoing radiation is trapped by trace gases. Without these natural greenhouse gases, the earth's average temperature would have been 33^0C colder than it is today, from which life of any form would have been impossible. Water vapour provide the majority of the natural greenhouse gases effect with lesser contributions from carbon dioxide, methane, nitrous oxide and ozone. During the last 150 years there has been, with exception of water vapour which remains a constant in the system, a rise in greenhouse gas concentrations. This has been due largely to the increase in world population and a corresponding growth of human activities especially agriculture and industries.

The increased concentration of these gases into the atmosphere, is increasing its ability to trap heat. Due to this, it is widely accepted that the greenhouse effect is associated with global warming (Figure 6.41). World temperature, which have risen by 0.5^oC since the middle of the last century, increased rapidly in the 1980s and it is at this time when warmest years were recorded, and prediction suggest that there could be a further rise between 1.5^0C and 4.5^0C by the year 2100. Though warming has not been uniform across the planet, the upward trend in the globally averaged temperature shows that more areas are warming than cooling. According to National Oceanic and Atmospheric Administration (NOAA) annual climate report of 2020, the combined land and ocean temperature has increased at an average rate of 0.13 degrees Fahrenheit (0.08 degrees Celsius) per decade since 1880, however, the average rate of increase since 1981 (0.18°C / 0.32°F) has been more than twice that rate.

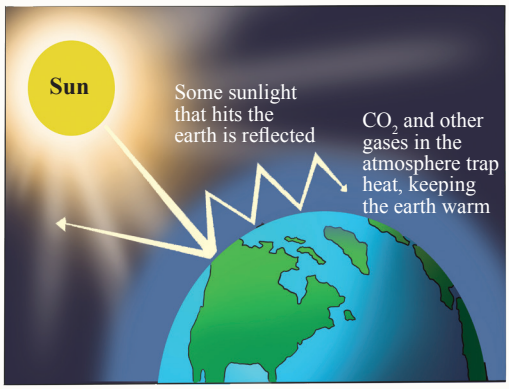


Figure 6.41: *Greenhouse effect*

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Sources of greenhouse gas

It is absolutely certain that humans have contributed large quantities of carbon dioxide by burning fossil fuels and vegetation. Similarly, the increase in methane concentrations which are currently rising at fast rates as compared to carbon dioxide can be linked to such factors as energy production, food production (from rice fields or ruminant livestock), landfills, waste treatment and vegetation burning. Recent estimates suggest that one-third of nitrous oxide emissions is caused by human actions; the increased generation rate of nitrous oxide is associated with the growing application of nitrogen fertilizers in agricultural production. Humans have also been emitting fumes and smoke from industrial processes and transport. These aerosols partly shield the planet from the sun's energy, scattering and reflecting it. However, not all aerosols behave in the same way. Aerosols from vegetation burning, 'black carbon', and the 'brown clouds' that come from urban sources may have the opposite effect. The former seems to cause cooling while the later result into warming (Table 6.5).

Table 6.6: *Major greenhouse gases*

Source gas	Rate of increase	Sources	
		Natural	Man made
Water vapour (H_2O)		Evaporation from the ocean, evapotranspiration from land	
Carbon dioxide (CO_2)	72%		Burning of fossil fuels (power houses, industry, transport) burning forests, respiration
Methane (CH_4)	10%	Decaying vegetation (peat and in swamp)	Farming (fermenting animal dung and rice-growing) sewage disposal and landfills sites.
Nitrous oxide (N_2O)	5%		Vehicle exhausts, fertiliser, nylon manufacture, power stations
Chlorofluoro carbons (CFCs)	13%		Refrigerators, aerosol sprays, solvents and foams.

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Future trend of climate change

Recent climate change models predicted a 2° to 4°C increase in global temperature over the next century and a 50 per cent chance that average global temperatures could rise by 5°C. Substantial impacts from such increase are anticipated. Such changes would transform the physical geography of the world with serious implications to where people live and how they live. The following are the notable potential impacts of climate change:

(i) There may be more severe weather events like storms, floods, hurricanes, heat-waves, and droughts as a warmer Earth means there is more energy available for atmospheric and oceanic transfers. For example, there could be a 10 per cent increase in average hurricane wind speed.

(ii) Warming may induce sudden shifts in regional weather patterns, such as the monsoons or the El Niño Southern Oscillation. This could have major consequences for water availability, crops, flooding and wildfire in tropical regions. Some climate models predict a more frequent and intense El Niño, perhaps even causing replacement of the rainforest of Brazil by savannah.

(iii) Melting glaciers will at first increase flood risk and then, once depleted, reduce water supplies. Large parts of the Indian subcontinent, China and the Andes rely on summer glacial melted water to provide water for crops and for drinking. Without this regular supply, new ways will have to be found to capture water for around one billion people.

(iv) About 40 per cent of the world's population live within 100 kilometres of the coast and two-thirds of the world's largest cities are found there. Rising sea levels from ice melt and the expansion of the water upon warming could result in hundreds of millions of more people enduring floods each year. More than a fifth of Bangladesh could be submerged by 2100.

(v) Some cold areas such as Canada, Russia and Scandinavia may enjoy an increase in agricultural productivity as a result of warming, at least in the short term, while many of the world's main food- producing regions may become too hot and dry for crops to grow for example, central and southern Europe and the Great Plains of North America. Declining crop yields, especially in Africa, could leave hundreds of millions without the ability to produce or purchase sufficient food.

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(vi) The area that is burnt by wildfires may increase warming condition substantially. It has been estimated that the area burnt by wildfire in western United States may increase by 200 to 400 per cent for every degree of warming.

(vii) Deaths from malnutrition and heat stress will increase and diseases such as malaria could become more widespread. Diseases are likely to spread from the tropics to the mid-latitudes as the climate warms and outbreaks of pests may become more extreme because natural biological controls may be lacking in these newly colonised pest areas.

(viii) Plant and animal extinction rates will increase as many species' migration will mismatch with the temperature changes. Up to 37 per cent of species may be on the road to extinction by 2050.

(ix) Ocean acidification is occurring and will increase as the oceans absorb carbon dioxide from the atmosphere. This buffers global warming but it can have major effects on marine ecosystems. For example, it reduces the ability of species such as molluscs, crustaceans, coccoliths and corals from forming the calcium carbonate needed for their structures and this would compromise the food chain.

(x) Global economic output could be reduced by 3 to 10 per cent, with the poorest countries being mostly affected.

Short-term climate change

El-Niño and La-Niña Atmospheric - Oceanic Circulations (ENSO)

El Niño Southern Oscillation (ENSO) is an inter-annual fluctuation of the atmosphere-ocean system in the equatorial Pacific ocean with three circulation phases of Warm (El Niño), Cold (La Niña) and Neutral. Although El Niño is considered the warm phase of ENSO and La Niña as a cold phase of ENSO, they are not considered opposite because they occur at different magnitudes, spatial extent, and duration. During an El Niño, usually, warm water appears in the Eastern Pacific Ocean of the coasts of Peru and Ecuador. Because the warm current usually appears around the Christmas time (December), the fishermen called it El Niño, a Spanish word (name) for "the Christ child". During La Niña, a Spanish world for "Little girl" usually cold water is present in these locations (Peru and Ecuador) causing contrasting shift in local weather patterns as well as the global climates. The name El Niño nowadays, contrary to its origin, is widely used specifically to refer to the anomalous warming of the sea surface that occurs every few years, typically concentrated in the East Central equatorial Pacific. Moreover, La Niña is contrary to its original meaning, as

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it is used to refer the adopted episode of cooler-than-normal sea surface temperature in the tropical Pacific that in many ways are opposite to El Niño. Anomalous weather patterns in La Niña seasons are generally opposite from those in El Niño. These changes in the surface water temperature are linked to the changes in the strength of the Trade Winds (Tw) blowing from East to West across the region. Neutral conditions occur when neither El Niño nor La Niña is present.

El Niños and La Niñas occur semi regularly at intervals of 2-5 years and they usually last for 9 - 12 months. The large pours of warm or cold water produced in these events change the atmospheric pressure patterns in the Tropical Pacific region and the global wind patterns far from the tropics. This leads to observable changes in temperature and rainfall patterns that vary by ENSO phase in many areas of the world. El Niño and La Niña events are associated with the wide spread changes in the climate system and can lead to significant socio-economic impacts affecting infrastructure, agriculture, health, and energy facilities. They are also associated with extreme weather events often with significant physical and financial impacts. However, they can vary greatly from year to year with the variation of the prevailing El Niño and La Niño magnitude.

Causes of El Niño and La Niña

El Niño and La Niña are the episodes that alternate in irregular inter-annual cycles called ENSO. The "Southern Oscillation" is the historical term for the atmospheric changes in the tropical Pacific that accompany both El Niño and La Niño episodes in the ocean. The name "ENSO" is a reminder that close interaction between the atmosphere and ocean is an essential part of the process. Normally, the global climate system contains many climate and weather processes, the ENSO is by far the dominant feature of Inter-annual time scale.

The cycle is the consequence of slow feedbacks in the ocean atmospheric system acting alongside the strong air-sea interaction processes in the tropics that allow the growth of small disturbances to the large scale ocean state.

Normally, the equatorial Pacific Ocean has a pool of relatively warm water in the upper part of the ocean in the West and a shallower layer or relatively cool water in the East maintained by and in balance with easterly surface winds. The well-mixed upper ocean layer lies above a thin thermocline layer with cold water below which causes the outburst of winds and, consequently, the disturbance on the balance between the upper warmer water with the lower cooler water. Through the action of Westerly wind-burst, a short-lived storm like the event in the West Pacific

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affects the balanced upper surface ocean air-mass.

The increased sea surface temperature influences the atmospheric winds which in turn influence the upper part of the ocean and thermocline such that the sea surface temperature is increased more as a positive feedback. When these conditions are favourable and continuous, they generate El Niño as a feedback. A La Niña event can arise in a similar way. Normally, El Niño and La Niña events are self-controlling, evolving and stabilizing in such a way that the equatorial surface temperature gradually returns to its normal and the event ends after several months, normally 9 to 12 months. However, most of the time, the system does not return to normal at 100% but rather it overshoots to start the opposite phase of another cycle.

Impact of El Niño and La Niña on the global climate and livelihoods

(a) Impacts on global weather and climate

El Niño and La Niña events change the sea surface temperature, which in turn causes the changes in atmospheric circulation of wind, pressure, temperature, and rainfall patterns. Through these atmospheric dynamics, the atmospheric changes extend much beyond the tropic Pacific region. At this extension, the Atlantic and Indian Oceans are also affected. This further prolongs the impacts of ENSO. Normally, the effects of ENSO vary considerably with location and extent of the event. For example, during El Niño event, the eastward shift of rainfall in West Pacific region tends to cause rainfall deficits in the Philippines, Indonesia and Australia while Central Pacific Islands experience excess rainfall. However, as explained above, each individual El Niño or La Niña event has got its different severity and timing with its different impacts on a given area. Sometimes the impacts of ENSO are modified by the state of the climate at that time. Even the sign of the anomaly, such as excess or insufficient rainfall may vary from one event to another for a particular location. By average, ENSO causes variation in extreme global precipitation at about 15%-20% of precipitation extremes while the remaining 80% is caused by other factors of climatic system.

The occurrence of both wetter and drier regions on the same latitudinal location reflects the tendency of ENSO events to displace rainfall patterns geographically and to enhance or decrease local precipitation. The effects of this is more pronounced around the Pacific and tropical regions. Along with changes in rainfall, El Niño and La Niña cycles, substantially affect other weather conditions, such as temperature, with regional and seasonal variations. However, priority is given to rainfall and tropical storms as these have more impacts on properties and people's livelihoods.

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(b) Social and economic impacts

The changes in regional temperature, rainfall and wind patterns in the tropics and extra-tropics caused by El Nino and La Nina events affect countries' economies. The direct impacts include property damage by floods or storms; failure in agriculture production due to either heavy rainfall, floods or drought during La Niña; forest damage due to fire outbreaks during La Niña dry periods; damage of infrastructure due to floods; and impact on market due to price fluctuation, especially high costs of products and goods during flooding events.

El Niño and La Niña events have very enormous impacts on people's livelihoods and social well-being. The most severe documented impacts of ENSO were those associated with a very strong El Niño event of 1997/98 and 2010/11 which followed by La Niña that extended over two years. For example, during El Niño event of 1997/98 in East Africa, Kenya experienced the damage of about 11% of its GDP. Over 90% of the calculated flood losses were associated with transport, infrastructure damage and water supply and sanitation. This was followed by two consecutive years of La Niña which caused loss of about 16% of GDP in both 1998/99 and 1999/2000 financial years. These two events were serious and affected the whole part of Eastern Africa, causing more than 11,000 deaths of people in Ethiopia, Somalia and Eritrea.

Impact of climate change

The impacts that scientists predicted in the past would result from global climate change are now occurring. The impacts include melting of ice, rise of sea level, negative impacts on ecosystems, hydrological cycle, water resources, agriculture, settlements and other economic activities. These impacts are further explained below.

Ice and snow melting

The rise of temperature has caused the melting of ice and snow in the Antarctic, Greenland, Alaska, Arctic and Siberia to an alarming speed. Melting ice and snow has at first increased flood risk and reduced water supplies. For example, large parts of the Indian subcontinent, China and the Andes rely on summer glacial melted water to provide water for crops and for drinking. Without glaciers, they will have and have already started to exprience critical water shortage.

Increased severe weather events

Due to climate change, severe weather events have intensified. Such events include storms, hurricanes, heat waves, droughts and floods. The events have increased in both severity and frequency of occurrence. A warmer Earth means there is more energy available for atmospheric and oceanic transfers. For instance, scientists predict that there could be a 10 per cent increase in average hurricane

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wind speed. Likewise, climatic change intensifies the circulation of water on, above and below the surface of the Earth. Consequently, floods and droughts have become more severe, causing huge losses to property and livelihoods in developing countries.

Disturbance on ecosystems

Rising temperatures have changed weather and vegetation patterns across the globe, has been causing unrest and in turn is forcing animal species to migrate to new, cooler areas in order to survive. The rapid nature of climate change is likely to exceed the ability of many species to migrate. Due to this it is predicted that about 37 percent of the earth's species will be headed for extinction by 2050, a good example of which being the bears of the Artic. Conservation managers will have to cope with changing biomes as the changing climate would result in changing the current conservation status quo.

Food insecurity

Drought may lead to serious shortage of food especially in the Sub-Saharan region because a large population in this region depends on rain fed agriculture for its livelihoods. Prolonged droughts and an increase in the number and severity of floods and pests have seriously compromise food security.

Disruption of settlement and economic activities

Some coastlines and river deltas of Africa which are densely populated are currently being affected by the rise in sea levels. Other coastal settlements will be subjected to increased coastal erosion. For example, recent flooding in East Africa highlighted the vulnerability of flood plain settlements, such as the Jangwani valley settlements in Dar es Salaam, and the need to develop adaptive strategies for extreme weather events management, thus mitigation. In the semi-arid and arid zones, however, many settlements were associated with inland drainage water sources, on the contrary, the increase in drought, in such areas may enhance water supply vulnerabilities. Moreover, there will be an increase in the prevalence of vector-borne diseases (such as malaria) as a result of increased temperatures and increased mobility of people from such areas to safer places. Similarly, water supply and irrigation reservoirs in seasonal river catchments might fail, leading to poor sanitation in urban areas, as well as food shortage.

Disturbing oceans and marine ecosystems

Climate change will increase ocean acidification. This is because, as the oceans absorb carbon dioxide from the atmosphere, it buffers global warming but it can have a major effect on marine

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ecosystems. Increased acidification will reduce the ability of species such as molluscs, crustaceans, coccoliths and corals from forming the calcium carbonate needed for their structures and this would have knock on effects on the food chain.

Energy insecurity

Hydroelectric power generation, for example in Mtera Dam in Tanzania, could be restricted in drought periods, which could in turn lead to a multiplicity of other impacts. As a precaution, states are advised to develop alternative sources of renewable energy.

Adaptive measures

Adaptive measures will involve methods of coastal defence (where applicable), a critical review of the energy sector, both regionally and nationally, and a rigorous adherence to city hygiene procedures. The measures will also involve the agricultural industry adapting to the changing climate in terms of cropping strategies and innovations in environment design to maximize human comfort at minimum energy expenditure. In the Savannah and arid areas, water resources management systems will be needed to optimize the use of water resources and inter-state cooperation where such resources are shared. Since the environment is a shared resource, likewise the effects of pollution resulting from emission of greenhouse gases is a transboundary problem. Thus, there is a need for all countries in the world to join together in implementing the environmental protection polices. Such polices includes those for reduction of greenhouse gases which are associated with the increased warming of the globe. This can done by localizing global polices and revising the existing polices on environmental protection.

Activity 6.6

(a) In a group of five students, visit the school library and other online sources in attempt to understand how climate change is affecting agricultural sector in Tanzania.

(b) Provide strategies to reduce/ adapt to climate change impact in the sector.

(c) Present to the class and invite for discussion and comments from fellow students.

(d) Improve and submit the work to the subject teacher for marking.

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Revision exercise 6

1. Write short notes on the following terms:
   (a) Greenhouse gases
   (b) Global warming
   (c) Ozone layer depletion
   (d) Acidic rainfall
   (e) Climate change
   (f) Atmospheric instability
   (g) Coriolis force
   (h) Heat budget
   (i) Katabatic wind
   (j) Heat budget
2. Give an account for the adaptation mechanisms of plants' survival in desert areas.
3. (a) Explain factors that determine the climate of Tanzania.
   (b) Explain the climate variations in Tanzania.
4. (a) Differentiate between temperature inversion and temperature lapse rate.
   (b) Discuss the relationship between environmental lapse rate and adiabatic lapse rate.
5. Mountains make their own climates. Justify with examples.
6. (a) Define an air mass
   (b) Discuss the origin and characteristics of tropical air masses.
7. Describe the geographical factors influencing the character and structure of a hurricane.
8. Explain factors for the occurrence of ocean currents.
9. Explain the natural and anthropogenic factors contributing to global climate change.
10. Explain the impacts of climate change on the Earth's surface.
11. Explain ways that help to sustain climate and reduce climate change impacts at local and regional level.

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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.
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.
Nitrogen fixation	A process carried out by certain algae and soil bacteria whereby atmospheric nitrogen is incorporated to form nitrogen-based organic compounds.

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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.
Pedosphere	Thin outer layer of earth's crust made up of soil. It acts as an integrator between the atmosphere, biosphere, lithosphere and hydrosphere of the Earth.
Peds	Natural unit of the soil structure that have been formed by tendency of the soil to fracture along planes of weakness.
Pervious rocks	Rocks that allow water to flow along cracks or joints.
Plucking	A form of glacial erosion in which ice freezes on to rock and pulls it away when the glacier moves on.
Regolith	The assemblage of unconsolidated rock materials that have been broken down, modified and altered by weathering; and soil materials on the earth's surface, sometimes considered to be loose earth's material above the solid bedrock.
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.
Soil horizon	Individual soil layer which has distinctive characteristics such as colour structure, texture or other properties that make it different from other layers in the soil profile.
Soil profile	Vertical section of the soil from the soil surface down through the horizons including the parent material. It consists of two parts, the solum and parent material.
Suspension	The transport of load in the body of the 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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