Higher Secondary Course

Geology

Class - XII

Government of Kerala
DEPARTMENT OF EDUCATION

State Council of Educational Research and Training (SCERT); Kerala
2015

THE NATIONAL ANTHEM

Jana-gana-mana adhinayaka jaya he
Bharatha-bhagya-vidhata,
Punjab-Sindh-Gujarat-Maratha
Dravida-Utkala-Banga
Vindhya-Himachala-Yamuna-Ganga
Uchchala-Jaladhi-taranga
Tava subha name jage,
Tava subha asisa mage,
Gahe tava jaya gatha.
Jana-gana-mangala-dayaka jaya he
Bharatha-bhagya-vidhata,
Jaya he, jaya he, jaya he,
Jaya jaya jaya jaya he!

PLEDGE

India is my country. All Indians are my brothers and sisters.

I love my country, and I am proud of its rich and varied heritage. I shall always strive to be worthy of it.

I shall give my parents, teachers and all elders respect, and treat everyone with courtesy.

To my country and my people, I pledge my devotion. In their well-being and prosperity alone lies my happiness.

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Foreword

SCERT is happy to publish the geology text book intended for the Higher Secondary students of the 12th standard this year. This and the previous textbook in Geology for the XI Standard published by SCERT form the first text books in Geology ever to be published for Higher Secondary students of the state. The text is designed to give a basic knowledge about the origin, classification and description of common types of rocks, minerals of economic importance, kinds of fossil fuels, salient events in the history of the Earth, identification of structural features associated with rock masses, causes and consequences of earthquakes, basic environmental aspects of geology and classification and essentials of disaster management associated with various types of natural disasters. The present textbook, as in the case of its predecessor, is a product of the combined effort of a team of dedicated Higher Secondary teachers in Geology , made under the guidance and supervision of experts in the respective field of the science.

I earnestly hope that the student community of Higher Secondary Schools of the state will welcome this text as a valuable and very useful companion to satisfy their entire requirement, during their course of study in Geology and the teachers also will find this text very useful for the transaction of the Geology curriculum in an effective manner.

Wishing you all success.

Dr.S.Raveendran Nair

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Contents

Chapter 01

The World of Rocks

Significant Learning Outcomes

After the completion of this chapter, the learner:

- Distinguishes between the three basic types of rock found on the Earth's crust.
- States the mode of formation of igneous rocks.
- Explains the textural and compositional differences exhibited by igneous rocks.
- Identifies common igneous rocks in hand specimens.
- Explains the formation and classification of sedimentary rocks.
- Identifies the common sedimentary rocks megascopically.
- Describes the agents and types of metamorphism.
- Identifies the common types of metamorphic rocks.
- Illustrates diagrammatically the concept of rock cycle.

Rocks have been an integral part of the history of mankind, first being used as tools for hunting and defence, and as building materials to construct shelters and monuments. If there were no rocks, we wouldn't have soil for food, no tools, no shelter, no roads and not much left. Rocks are composed of tiny fragments of one or more materials called minerals. The rocks as well as the minerals are essential to the prosperity and cultural splendour of human civilization. The branch of geology dealing with the study of rocks is called **petrology.**

Rocks are made of grains that fit together. Each grain in the rock is formed of a mineral, which is a naturally formed chemical compound. A rock is defined as a naturally occurring solid aggregate of one or more minerals or mineral-like matter (mineraloids). Such aggregates constitute the basic units of solid Earth. Rocks can be classified broadly into three groups.

1.1 Types of rocks

Geologists classify rocks according to the processes that resulted in their formation. Three basic groups of rocks they recognize are: **igneous rocks** (those crystallized or solidified from molten rock material called magma or lava), **sedimentary** rocks (those consisting of fragments derived from pre-existing rocks or of materials precipitated from solutions) and **metamorphic rocks** (those formed by the alteration of existing rocks).

1.2 Igneous rocks

Igneous, from the Latin meaning "Fire formed", is a rock type that forms from the solidification of a molten mineral solution. The earth's interior is in highly molten state because of very high temperatures inside it. The molten rock material generated at the interior of Earth is called magma. When the **magma** cools and solidifies, igneous rocks are formed.

The minerals forming an igneous rock are produced by crystallization during cooling of the magma. This transformation from disorganized atoms and ions within the hot melt to highly ordered crystal structures occurs as the temperature of the magma drops enough for the ions to begin to link together. When molten rock-forming material reaches at the Earth's surface, it is known as **lava,** when it remains within the Earth, it is referred to as **magma.** In either case, crystallization by cooling is the only mechanism by which almost all igneous rocks are formed (Fig.1.1 (a) and (b)).

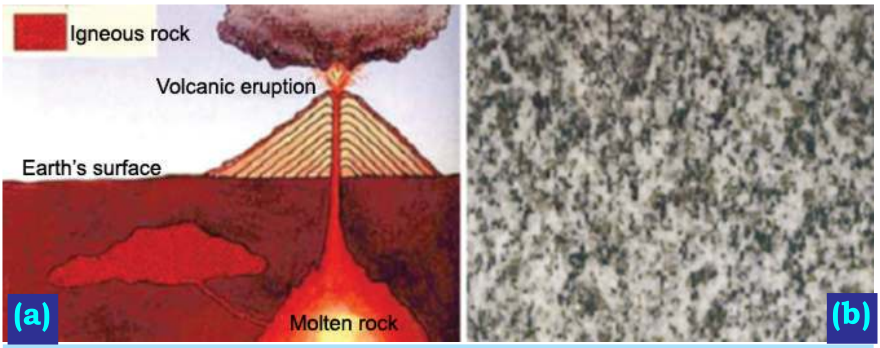


Fig.1.1: (a) Igneous activity and (b) an igneous rock

Igneous rocks represent not only the most abundant of all rock types but also the original type of rock found on Earth. Not only do igneous rocks form the cores of the continents, they also make up nearly all of the oceanic crust; and as such, study of igneous rocks allows you to understand major portions of the Earth's geosystems.

1.2.1 Classification of igneous rocks

You have learnt that igneous rocks are formed by the cooling and solidification of molten rock forming material known as magma or lava. Igneous rocks are divided into two main categories on the basis of where they form:

a) Plutonic (intrusive) rocks

b) Volcanic (extrusive) rocks.

Those igneous rocks formed deep inside the Earth's crust are called **plutonic rocks** or **intrusive rocks** and those formed at the surface are named **volcanic rocks** or **extrusive rocks.** In addition to these two basic types, a third category, known as **hypabyssal**

rocks is also recognized. A hypabyssal igneous rock is an intrusive igneous rock whose depth of formation is intermediate between that of plutonic (deep seated) and volcanic (surface) rocks.

Plutons (Intrusive igneous bodies)

Bodies of plutonic rocks are found in a great variety of shapes and sizes. Irrespective of their shapes and sizes, the term 'pluton' is often applied for any igneous intrusion formed at deep or shallow depth. Some plutons are characteristically tabular in shape while others are cylindrical and still others are irregularly ellipsoidal. A short description of some of the common types of plutons is given below:

(1) **Dyke** - a tabular wall like igneous intrusion that cuts across the planar structures of the surrounding rock. (Fig. 1.2 a)

(2) **Sill** - a tabular igneous intrusion that parallels the planar structure of the surrounding rock. (Fig 1.2 b)

Fig.1.2: a) Dyke and b) Sill

(3) **Laccolith** - A laccolith is a type of pluton that tends to have a flat floor and are domed up in their central part. Like sills, these plutons are generally **concordant**, ie, parallel to the country rock's layering.

(4) **Batholith** - These are the largest types of plutons that have more than 100 sq. km surface exposure. Like dykes, batholiths always have **discordant** (means that they cut across pre-existing country rocks) relationship with the country rocks.

The diagrammatic representation of batholith and laccolith is given below (Fig.1.3).

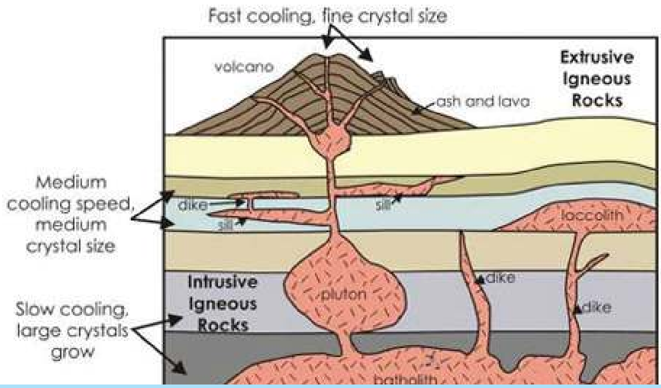


Fig.1.3:.Batholith and laccolith

1.2.2 Textures of igneous rocks

The texture of a rock describes the degree of crystallization, size, shape and arrangement of the mineral grains or crystals that make up the rock. It is the function of the relationship between the grain size and mutual relationship between the grains.

Granularity

In the case of the igneous rocks, one of their characteristic textural features is the size of the mineral grains - small or large. Igneous rocks can be subdivided into a variety of rock types based on their texture. **Coarse-grained** igneous rocks are those in which the individual crystals are large enough to be seen without the aid of a microscope. Conversely, **fine-grained** igneous rocks require microscopic study to identify individual crystals. **Medium-grained** igneous rocks with grain size intermediate between fine and coarse and are formed at shallow depth levels.

The difference in grain size is of great importance to our understanding of how igneous rock forms. Coarse-grained rocks require long periods of slow cooling in order to grow large crystals. On the other hand, fine grained rocks form by relatively rapid cooling. The rate of cooling of molten rocky matter depends on the place where the cooling takes place. Lavas, erupted at the Earth's surface, cool relatively fast to form volcanic rocks while magmas, retained deep within the Earth, cool very slowly taking thousands of years to form plutonic rocks. The difference in the locations and the rate of cooling, accounts for the basic textures exhibited by igneous rocks.

The grain shape is also controlled by the rate of cooling of the magma.

On the basis of grain size and shape (granularity), the following textures may be present in igneous rocks.

(a) **Phaneritic:** The individual mineral grains that make up a phaneritic igneous rock are sufficiently large (coarse) to be differentiated and identified with naked eyes. Example: Granite.

(b) **Aphanitic**: When the individual mineral grains in a rock are not visible to the naked eye, the resulting texture is called an aphanitic texture. Example : Basalt

Analyze the figure given below (Fig.1.4 (a) and (b)) and compare the nature of the grains present in these two types of igneous rock. Why do these two types of rocks show differences in their grain sizes?

1.4 : (a) Phaneritic texture and (b) aphanitic texture

(c) **Porphyritic:** Such textures are characterized by the presence of some larger mineral grains (visible to the naked eye), called phenocrysts (Fig.1.5) that are surrounded by smaller mineral grains (invisible to the naked eye) called the ground mass in an igneous rock. Porphyritic rocks consist of a mixture of large and fine sized mineral grains.

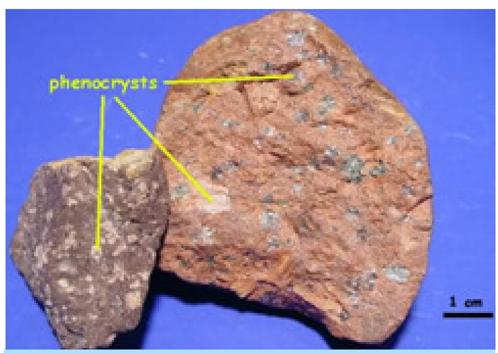


Fig.1.5: Phenocrysts in an igneous rock.

Crystallinity

Any rock composed entirely of crystallized minerals without glassy matter is described as a **crystalline rock. Crystallinity** refers to the degree of crstallization in a rock and petrologists recognize three types of basic textures on the basis of levels of crystallinity in igneous rocks, such as: (a) **holocrystalline** - rocks which are composed entirely of crystalline grains, (b) **merocrystalline (hypocrystalline)-** rocks made of partially of crystalline grains embedded in an amorphous or glassy matrix, and (c) **holohyaline** rocks composed completely of glassy material (such as obsidian, formed by chilling or super cooling, in which no crystallization is involved).

Glassy and frothy textures

Glassy texture: Glassy textures occur during some volcanic eruptions when the lava is cooled so rapidly that crystallization cannot occur. The elements and compounds are frozen in place and hence no minerals are formed, which result in a glassy texture. Simply, a glass is an amorphous (non-crystalline) substance. Example: Obsidian (Fig.1.6).

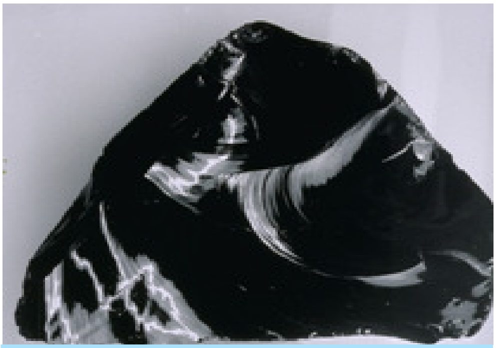


Fig.1.6:Obsidian

Frothy or vesicular texture :

It is exhibited by some volcanic rocks such as pumice, which is a light-coloured volcanic rock that is full of holes. These holes once contained volcanic gases that escaped and now are filled with air. Pumice is a very light rock that floats in water and similar one with dark colour is Scoria.

Know your progress

1. What kind of textures do you expect in plutonic rocks?
2. What differences in crystal size might you expect between two rocks, one formed at surface and the other at depth?
3. What is the basic difference between a dyke and a sill?

1.2.3 Classification based on composition

Igneous rocks are also classified (or named) on the basis of their composition (the elements and minerals present) into four categories. Most of the igneous rocks present at or near the Earth's surface are crystallized from some type of silicate magma, which means the melt was made up mostly of the two elements silicon and oxygen, combined to form "silica", or SiO_2. This is because of the relative abundances of oxygen and silicon in magmas. The continental areas are made up of close to 60 % silica, and the oceanic areas are made up of about 47 % silica. Now, let us learn this compositional variation in igneous rocks and their classification. Analyse the diagram given below (Fig.1.7) and try to classify igneous rocks based on their mineralogical composition.

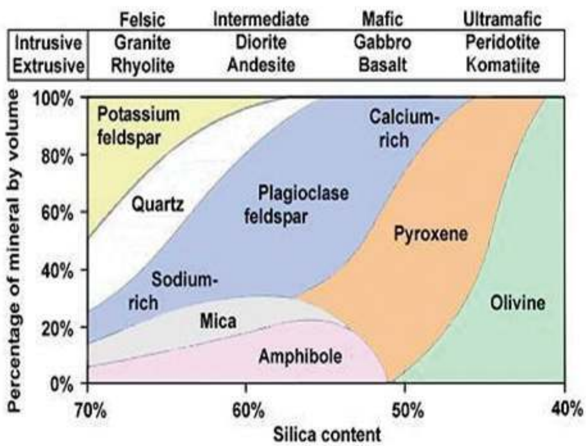


Fig.1.7: Classification of igneous rocks by composition.

(1) **Felsic igneous rocks** - Felsic rocks ("Fel" from feldspar, and "sic" from silicon) are rich in silicon and oxygen, have low melting points, lighter colour and tend to have a dominance of light coloured minerals such as quartz and feldspar. Examples: granite and rhyolite. In petrology, the term **acidic**, is also

widely used for describing igneous rocks with a range of silica (SiO_2) greater than 63 percent.

(2) **Intermediate igneous rocks-** Intermediate in composition; tends to have a mixture of light and dark minerals of almost equal amounts. The silica percentage ranges between 52 - 63% in intermediate rocks. Examples: diorite and andesite.

(3) **Mafic igneous rocks-**Mafic rocks ("Ma" from magnesium and "fic" for iron) are low in silica; rich in magnesium and iron, possess high melting points, and have relatively darker colour and density than felsic rocks. These tend to have dark minerals such as olivine, pyroxene, and amphibole. Examples: gabbro and basalt. The term '**basic**' (silica percentage ranges between 45 - 52%) is also used to describe these kind of rocks.

(4) **Ultramafic/ultrabasic igneous rocks-** Even more rich in iron and magnesium; tends to be dominated by the mineral olivine and sometimes with pyroxenes. Examples: dunite and peridotite. The silica percentage of ultrabasic rocks is less than 45%. It has no volcanic equivalent.

You have learnt that igneous rocks are classified (or named) on the basis of their composition and texture. Texturally, igneous rocks can be divided into plutonic and volcanic rocks. The two basic compositional groups recognized among the igneous rocks are felsic and mafic. Analyse the given table (Table 1.1) and make a comparison between the two kinds of considerations we have followed and present your findings in the class.

Table.1.1: Textural and compositional comparison of some felsic and mafic rocks

Textural types	Felsic (light)	Mafic (dark)
Intrusive - Coarse texture	Granite	Gabbro
Extrusive - Fine texture	Rhyolite	Basalt
Extrusive - Frothy texture	Pumice	Scoria
Extrusive - Glassy texture	Obsidian	

You can conclude that, while granite is a coarse-grained (phaneritic) plutonic igneous rock, rhyolite is a product of relatively rapidly cooled, fine-grained (aphanitic) volcanic igneous rock with a felsic composition. Again, gabbro is a plutonic, phaneritic rock while basalt is a product of relatively rapidly cooled lava and is fine-grained (aphanitic) igneous rock of mafic composition.

1.2.4 Crystallization of magma

The minerals that make up igneous rocks crystallize at different temperatures. At high temperatures, magma is completely liquid, but as the temperature drops, crystals will start to form. As magma cools, individual mineral species selectively crystallize at some unique temperature.

Certain minerals crystallize earlier and at higher temperatures than others. This important process, taking place during the crystallization of magma, is known as fractional crystallization. **Fractional crystallization** is the process by which mineral crystals formed in a cooling magma are segregated or separated from the remaining liquid with the lowering temperature.

When some of the minerals which crystallize first are likely to be heavier than the magma, they may settle to the bottom of a magma chamber and become essentially isolated from the rest of the magma. The rest of the magma will then have a different composition than the original magma.

Crystals can be removed by a variety of processes. If the crystals are denser than the liquid, they may sink. If they are less dense than the liquid they will float. When magma starts to cool, mafic minerals begin to form first. They may settle out of the magma, (because they are denser than the magma), before other minerals begin to form. Removal of crystals can thus change the composition of the liquid portion of the magma.

The naturally separated crystals give rise to rocks of differing compositions at various stages of magmatic cooling. Thus, rocks of varying composition can arise from uniform parent magma. This accounts largely for the diversity of igneous rocks found on Earth.

Bowen's crystallization reaction series

During the early part of the 1900's, the experimental work of Canadian mineralogist N.L. Bowen led to our modern understanding of the formation of igneous rocks. There is a definite sequence of crystallization - popularly known as the Bowen's reaction series (Fig.1.8). Bowen's Reaction Series is a theory concerning the crystallization process which occurs when magma cools. The eight commonly occurring rock-forming minerals (olivine, pyroxene, amphibole, orthoclase, plagioclase, muscovite, biotite, and quartz) are arranged in Bowen's reaction series in decreasing order of their temperature of formation (melting points), high temperature ones at the top and low temperature ones at the bottom. The first minerals to crystallize from a cooling magma are the ones that are the last to melt.

At first, crystals of only one or two minerals begin to grow. These early formed mineral crystals react with the residual magma to form different minerals. In the figure given below , it can be seen that olivine normally crystallizes first, followed by pyroxene, then amphibole and then biotite mica.

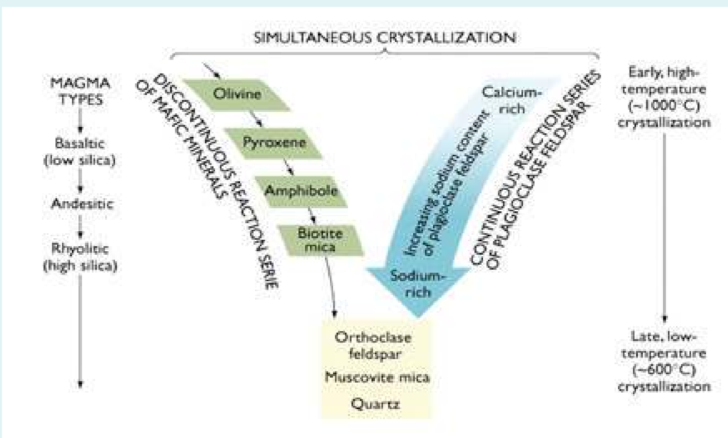


Fig.1.8:Diagram showing Bowen's reaction series.

The reaction series shows that, cooling is progressive in a magma/ lava, some minerals becoming solid at high temperatures (top of BRS) and others at lower temperature (bottom of BRS). There are two sequences of minerals in Bowen's reaction series, the discontinuous reaction series on the left and the continuous reaction series on the right. As the temperature of *magma decreases, minerals crystallize in an ordered series from olivine-pyroxene-amphibole-mica; while plagioclase feldspar crystallizes, from calcium-rich to sodium-rich form and the composition of magma changes from ultramafic to more acidic composition.*

Know your progress

1. How would you classify a coarse-grained igneous rock that contains about 50% pyroxene and 50% olivine?
2. If a granitic magma erupts on the surface of the Earth in the form of lava, what will be the extrusive rock formed?

1.2.5 Common igneous rocks

Felsic igneous rocks

Granite: Granite is a relatively light coloured, holocrystalline, usually coarse to medium-grained, phaneritic, plutonic igneous rock (Fig.1.9). Some granites exhibit porphyritic texture and these granites are called granite porphyries. Granite mainly consists of feldspar, quartz, mica, and amphibole minerals. Along with quartz, potassium feldspar (orthoclase) and sodium rich plagioclase feldspar together make up the bulk of this rock. Dark minerals, chiefly amphibole and biotite are present in small quantities. Granite is hard and tough, and widely used as a construction stone.

Fig.1.9: Granite

Rhyolite: It is a light coloured (white, light grey or various shades of red) volcanic rock, with the same compositional (mineralogical) range as that of granite, with a wholly different texture. Commonly rhyolite is fine-grained, glassy or porphyritic. Rhyolite (felsic) magma can sometimes cool so rapidly that crystallization of minerals is impossible. The resulting volcanic glassy rock is known as obsidian.

Pegmatite: Pegmatites are extremely coarse grained igneous rocks (Fig.1.10). These are formed during the final stages of crystallization of magma. The extremely coarse texture of pegmatite is attributed to both slow cooling and the low viscosity of the magmatic fluid from which they form.

Fig.1.10: Pegmatite

Pegmatites often contain exceptionally large crystals and sometimes contain minerals that are rarely found in other types of rocks. Most pegmatites have a composition that is similar to granite with abundant quartz, feldspar and mica. However, mineral compositions such as that of gabbro, diorite and any other plutonic rock are also possible.

Intermediate igneous rocks

Diorite: It is a grey to dark-grey, coarse to fine-grained, intermediate intrusive igneous rock, composed principally of plagioclase feldspar, biotite, hornblende, and/or pyroxene with little or no quartz or potassium feldspar (Fig.1.11). The dark minerals in diorites (hornblende and or biotite) can together be as abundant as the plagioclase feldspars.

Fig.1.11: Diorite

Andesite: Andesite is generally a grey to greyish black, fine grained volcanic (extrusive) igneous rock, commonly with an aphanitic to porphyritic texture (Fig.1.12). In general quartz is lacking, the chief feldspar is intermediate plagioclase, and the

Fig.1.12: Andesite

dark minerals which may be present are augite, hornblende, and biotite. Alkali feldspar may be present in minor amounts in some andesites. This rock, in general covers the same range of intermediate composition as its plutonic counterpart, diorite.

Mafic igneous rocks

Gabbro: It is a holocrystalline, phaneritic (coarse-grained), mafic intrusive igneous rock, chemically equivalent to basalt (Fig.1.13). It is often a dense, greenish or dark-coloured plutonic rock, typically containing coarse-grained mineral crystals of pyroxene and calcium-rich plagioclase. Many gabbros also contain olivine, and some possess minor amounts of hornblende. Unlike diorite and granite, gabbro contains relatively larger amounts of ferromagnesian minerals than feldspars.

Fig.1.13: Gabbro

Basalt: It is, by far the most abundant of volcanic rocks. When totally free from weathering, it is a coal black to dark grey and fine-grained to aphanitic, extrusive igneous rock (Fig.1.14). It is often porphyritic. The two principal mineral constituents of basalt are pyroxene and calcium-rich plagioclase. Many varieties contain olvine as well. Basalt with a vesicular or frothy texture is called scoria, and forms when dissolved gases are forced out of solution forming vesicles as the lava reaches the surface.

Fig.1.14: Basalt

Dolerite: Dolerite is a medium grained, intrusive igneous rock (Fig.1.15). It is a hypabyssal or medium-grained equivalent of basalt. Therefore, it is a basic rock dominated by plagioclase and pyroxene. It usually occurs as dykes and sills. The constituent minerals may be easily identified with a hand lens if not by naked eye. Dolerites may be porphyritic, containing phenocrysts of plagioclase, olivine and rarely even quartz.

Fig.1.15: Dolerite

Dunite: Dunite is a light yellowish green, phaneritic, plutonic, ultramafic rock that is composed almost entirely of coarse-grained olivine (Fig.1.16). The mineral assemblage is greater than 90% olivine, with minor amounts of other minerals such as pyroxene, chromite and magnetite.

Fig.1.16: Dunite

It is evident that, basalt and granite are two of the most common igneous rocks. These two rocks show notable differences in their texture and mineralogical composition. Complete the following table giving the characteristics of granite and basalt.

A comparison of basalt and granite		
	Basalt	Granite
Texture	Fine grained	
Dominant minerals		Quartz, Feldspar
Minor minerals present		
Place of formation		

You have learnt different textures exhibited by igneous rocks. Rocks exhibiting similar textural characteristics may contain different mineral assemblages. You will be provided with specimens of common igneous rocks available in the geology laboratory of your school in order to identify them megascopically on the basis of their texture and mineralogy. You can make use of the Table *1 of Appendix II given at the end of the text book.*

Know your progress

1. Compare and contrast granite and gabbro.
2. What is the volcanic equivalent of granite?
3. Name two intrusive igneous rocks with higher silica content than that of gabbro.

1.3 Sedimentary rocks

Much of Earth's surface, including its seafloor, is covered with sediments. Sedimentary rocks represent 7% of the Earth's crust, but they cover 70% of the Earth's surface. Most sediments are created by weathering of the rocks in the continents. Some are the remains of organisms that secreted mineral shells. Yet others consist of inorganic crystals that precipitated when dissolved chemicals in oceans and lakes combined to form new minerals.

The word sedimentary comes from the Latin word 'sedimentum', which means 'settling'. A sedimentary rock is defined as a rock formed from the consolidation of loose sediment that has accumulated in layers and consisting of mechanically formed fragments of older rocks transported from its source and deposited from water, wind or ice, or a chemical rock formed from precipitation from solution, or an organic rock consisting of the remains or secretions of plants and animals.

1.3.1 Classification of sedimentary rocks

Sedimentary rocks are classified into the following three groups on the basis of their mode of formation:

Sedimentary rocks

- **Clastic (Detrital)**
- **Chemical**
- **Organic (Biochemical)**

Clastic (Detrital) sedimentary rocks

These are formed from broken bits and pieces of pre-existing rocks. The word 'clastic' comes from the Greek word 'klastos', meaning 'broken'. Clastic sedimentary rocks are formed when existing parent rocks are weathered, fragmented, transported, and deposited in layers that compact, cement, and consolidate to form sedimentary rocks. These consist of fragments of rocks and minerals (clasts or detritus) that stuck together to form a solid mass. Running water, wind, glaciers and oceans all have the ability to erode and carry the particles. When the energy of the transporting medium is not strong enough to carry these particles, the particles are settled down - a process known as sedimentation. This type of sedimentary deposition is referred to as clastic sedimentation.

The formation of clastic sediments and the resulting sedimentary rocks involves five processes:

(1) **Weathering:** The first step is transforming pre-existing solid rocks into smaller fragments or dissolved ions through the process of physical and chemical weathering. Weathering is the general process by which rocks are broken down at Earth's surface to produce sediment particles.

(2) **Erosion:** Erosion moves the weathered products from their original location. This can take place by gravity, running water, wind, moving ice or waves.

(3) **Transportation:** Erosion overlaps with transportation. Sediments can be transported by sliding down slopes due to gravity or by being carried by running water, wind, or ocean waves. Geologists can infer the distance of travel of the

sediments and the energy of the transporting medium from a study of the sedimentary rock finally produced. Generally, the coarser fractions of sediments are left behind during transportation processes. Thus, coarser sediments are usually found closer to their source and finer grained sediments are found farther away from the source.

(4) **Deposition:** When the energy of the transporting medium becomes too low, its ability to transport the coarser sediments is also reduced. Note that it is the velocity of the transporting medium that determines the energy to transport sediments. Therefore, with a reduction in velocity, some of the sediments will stop moving and get deposited. These particles form layers of sediment on land or under the sea in sedimentary basins. The deposited materials build up sediments in layers one over the other.

(5) **Lithification (Diagenesis):**Lithification is the process that turns loose sediments, buried within sedimentary basins, into a consolidated and hard sedimentary rock. It may take thousands of years for the conversion of sediments into sedimentary rocks. Lithification includes all physical, chemical and biological processes that subsequently act on the sediments. Diagenesis is also a response to increase in temperature and pressure as sediment gets buried deeper. (As temperature increases beyond about 200^{o}C, they enter the realm of metamorphism).

The lithification processes involve, as its first stage, the process of compaction. When more and more sediments are deposited on top one over the other, the weight of the sediments on top compresses the sediments at the bottom. This is called compaction.

During compaction, the water is squeezed out from between the grains and forces the grains to come closer together, reducing the amount of pore spaces. Some of this water and other fluids flowing through the sediments and organisms may precipitate new minerals in the pore spaces between grains (intergranular spaces). These minerals act as a sort of glue that sticks or cements the grains of the sediments together. This causes cementation, which will then start to progressively bind the individual particles of the sediment together. Common cements in sedimentary rocks include fine particles of quartz, calcite, and hematite. These processes eventually make a sedimentary rock. It may take millions of years for sedimentary rocks to form. Sandstone, shale and conglomerate are some examples of clastic sedimentary rocks.

Chemically formed sedimentary rocks

Another type of sedimentary deposition occurs when material dissolved in water chemically precipitates from the water. Dissolved ions released into water during the weathering process are carried in streams or groundwater (remember the term dissolved load). Eventually these dissolved ions end up in the ocean. This explains why sea water is salty. When water evaporates or the concentration of the ions gets too high as a result of some other process, the ions recombine by chemical precipitation to form minerals that can accumulate to become chemical sediments and chemical sedimentary rocks.

Evaporites are chemical deposits formed when restricted bodies of saline water evaporate, precipitating out a range of minerals. Rock salt (composed of mineral halite, NaCl) and gypsum deposits are formed by chemical precipitation as concentration of salt increases due to water loss by evaporation.

Biochemical and organic sedimentary rocks

Biochemical and organic sedimentary rocks are those derived from decomposition of organic remains. Living organisms extract ions dissolved in water to construct their shells and bones. When the organism dies, the remains can accumulate to become sediment or sedimentary rock. This type of sedimentation is called organic or biochemical sedimentation. Accumulation of plant matter, such as that taking place at the bottom of a swamp, also comes under this category of sedimentary rock. Among the types of rock produced by this process are organic limestone, coal and coral deposits.

Know your progress

1. Why do organic and chemical sedimentary rocks belong to non-clastic rocks?
2. Which type of a sedimentary rock is limestone?
3. How does sediment turn into hard sedimentary rock?

1.3.2 Textures of clastic sedimentary rocks

The nature and type of clasts or fragments, constituting clastic sedimentary rocks and their arrangement in the rock impart characteristic textures to the rock. These include grain size, sorting and rounding.

Grain size: Grain size is used to describe the size of the individual mineral grains, rock fragments, or organic material that are cemented together to form a clastic or chemical sedimentary rock. Clastic sedimentary particles can be categorised in terms of their grain size as given below (Table 1.2).

Table 1.2: Kinds of clastic sedimentary particles

Detrital Particle	Size range	Term applied for loose sediments	Name of the consolidated sedimentary rock
Boulder	>256 mm	Gravel	Conglomerate or Breccia (depends on rounding)
Cobble	64 - 256 mm	Gravel	
Pebble	2 - 64 mm	Gravel	
Sand	1/16 - 2mm	Sand	Sandstone
Silt	1/256-1/16mm	Silt	Siltstone
Clay	<1/256 mm	Clay	Claystone, mudstone and shale

Sorting: The term sorting refers to the degree of uniformity of grain size in sedimentary rocks. Poorly sorted rocks contain a wide range of grain sizes, including fine (clay sized), medium (sand sized), and coarse (cobble and boulder sized). Well sorted rocks contain almost entirely of grains of the same size. Moderately sorted rocks may contain fine and medium grains, or medium and coarse grains.

Rounding: Rounding is the term used to describe the relative shape of the grains. Grain classifications based on rounding are based on the degree of deviations from rounded or spheroidal grain shapes. Well rounded grains are smooth with rounded edges. Moderately rounded or subrounded grains are in between those with sharp, angular edges of a poorly rounded grain and the smooth, well-rounded grains.

1.3.3 Sedimentary structures

The term, structure in sedimentary petrology, signifies the layering of sedimentary rocks and surface features on the layers formed during the sedimentation process. Here, we discuss some of the major structures found in sedimentary rocks.

Stratification and Bedding

Because sediment is deposited in low lying lands that often extend over wide areas, successive depositional events produce layers. These kind of layered features present in rocks are called bedding or stratification. Bedding is the fundamental structure of sedimentary rocks. They are developed by the deposition of sediments or grains in different environments. So they differ in colour, texture, composition, grain size, thickness, etc. within the same rock mass. Layering of extremely thin beds is called lamination and these are developed in sediments like clay or silt. The important types of bedding include cross bedding and graded bedding.

(a) Cross bedding: Cross-bedding is a type of stratification in which the layers within a bed are inclined at an angle to the upper and lower surfaces of the bed (Fig.1.17). The sets of beds are inclined in the direction that the wind or water was moving at the time of deposition. This structure is very common in beach deposits, sand dunes, and river deposited sediment.

Fig.1.17: Sedimentary rocks showing cross bedding

(b) Graded bedding: It is a kind of stratification in which the rock layer has a progressive change in particle size from top to bottom. The most common is a sequence with coarse grains at the bottom and fining upwards, which is typically caused by a declining current velocity within the depositional environment. As velocity of current decreases, first the larger or denser particles are deposited followed by smaller particles. Coarsest material settles first, medium next and then, the fine particles.

Ripple marks: These are series of parallel or subparallel ridges in sediments and are caused by the rhythmic or directional movement of wind or water (Fig.1.18). Ripples are characteristic of shallow water deposition and can also be caused by wind blowing over the surface.

Fig.1.18: A sedimentary rock showing ripple marks.

Mudcracks: These result from the drying out of wet sediment at the surface of the Earth (Fig.1.19). The cracks form due to shrinkage of the sediment as it dries.

Fig.1.19: Mud cracks in sedimentary rocks

Raindrop marks : These are small and shallow rounded pits (or tiny craters) created by falling rain drops (Fig.1.20). If present, this suggests that the sediment was exposed to the surface of the Earth just prior to burial.


Fig.1.20:A sedimentary rock showing rain drop marks

1.3.4 Common types of sedimentary rocks

Geologists name and classify sedimentary rocks based on their mineral composition and texture. Mineral composition refers to the specific minerals in the rock. For example sandstone will contain predominantly quartz, while limestone will contain mainly calcite (calcium carbonate). We will look at various clastic sedimentary rocks that result from lithification of sediments.

A. Clastic sedimentary rocks

(a) Conglomerates and breccias

Conglomerate and breccia are rocks that contain an abundance of coarse grained clasts (pebbles, cobbles, or boulders). These rocks usually contain a framework of large grains held together by a matrix of sands, silt, and clay-sized particles.

Conglomerates (Fig.1.21 a) are poorly-sorted very coarse sedimentary rocks with a wide range of rounded grain sizes ranging from sand to cobbles. In a conglomerate, the coarse grained clasts are well rounded, indicating that they spent considerable time in the transportation process and were ultimately deposited in a high energy environment capable of carrying the large clasts.

Breccia (Fig.1.21 b) is similar to a conglomerate except that it consists of angular grains, as opposed to rounded grains. In a breccia, the coarse grained very angular clasts indicate that these grains spent little time in the transportation cycle.

Fig.1.21 : a) Conglomerate and b) Breccia

(b) Sandstones

Sandstones are one of the most common types of sedimentary rocks (Fig.1.22 (a) and (b)). Sandstone is composed almost entirely of sand-sized quartz grains cemented together through lithification. Sandstones are formed in a variety of different environments including fluvial (rivers), marine, coastal (oceans and beaches), aeolian (wind blown), and glacial (ice).

Fig.1.22 : Sandstones

(c) Shale

Shale is a fine-grained, moderately to well-sorted rock formed by the compaction of well rounded silt-and clay-sized grains (Fig.1.23). Shales often contain fine laminations which helps impart fissility to

Fig.1.23:Shale

the rock. Fissility is a term used to describe layered laminations that tends to break into thin flat fragments.

B. Non-clastic sedimentary rocks

(a) Limestone : Limestones are also one of the very common sedimentary rocks. Limestone consists almost entirely of the mineral calcite ($CaCO_3$), and can form by either inorganic or biochemical processes. Limestones form under a variety of environmental conditions and for this reason several types of limestone exist. Limestone accounts for about 10% of all sedimentary rocks, and of those, limestones with marine biochemical origin are the most common. Limestones formed by chemical precipitation are usually fine grained, whereas; in case of organic limestone the grain size vary depending upon the type of organism responsible for the formation. Sometimes the fossilized remains of the organism are preserved in the rock, other times recrystallization during lithification has destroyed the remains. Fossiliferous limestone (Fig.1.24) is a type of limestone consisting of identifiable shells and shell fragments of organisms. Limestones that have been chemically modified by Mg-rich fluids flowing through the rock are converted to dolostones. $CaCO_3$ is recrystallized to a new mineral dolomite with the composition $CaMg(CO_3)_2$.

Fig.1.24: fossiliferous limestone

(b) Coral Reefs: These are limestone formations created by marine organisms. Corals are invertebrate animals which secrete a calcareous (calcite-rich) external skeleton. Accumulation of these skeletal remains results in a limestone.

(c) Chalk: It is formed from calcareous microscopic marine organisms (nanofossils). When the organisms die, their exoskeletons fall to the ocean floor creating a sedimentary layer.

(d) Coal: Coal is an organic rock made from organic carbon and is the remains of fossil plant matter. Although the chemical composition of coal changes from its organic origins, it often retains fossilized imprints of plant leaves, bark, wood, and organisms that lived during the time the organic materials were deposited.

Residual sedimentary rocks

Laterite: You have learnt in Class XI, that laterite is a residual product of weathering. It is formed when heavy tropical rainfall results in intense weathering of rock and soil after many millions of years, which can be either iron-rich, or in extreme cases, aluminium-rich in composition. The concentrations of mostly iron and aluminium oxides give it a typical red or brown colour.

The rock was first named by the Schottis physician Dr. Francis Buchanan Hamilton in 1807. He coined the term 'laterite' which means brickstone in Latin. Laterites are very soft when fresh and could be cut into bricks. When exposed to air and sun, it becomes hard. Laterite is widespread in its distribution in the midland regions of Malappuram, Kannur and Kasaragod districts.

Now identify some of the major types of sedimentary rocks that are given to you. See the description of sedimentary rocks in Table 2 of Appendix II given at the end of the textbook. Try to identify the textural features exhibited by the rocks. As for example, you are provided with a specimen of sandstone.

What does it look like? What about the size and degree of roundness of the grains?

Sandstone is often red to brown, light gray to nearly white. Sometimes it is yellow or green. It usually is composed of rounded grains that are all of the same size; and it is usually medium grained. Some sandstones show slight colour variations in layering.

What minerals make up the rock?

The mineralogy of sandstone is dominantly quartz; and it may contain feldspars, mica, magnetite, garnet, rutile, ilmenite etc.

What type of rock is it?

It is sedimentary rock.

Based on the texture and mineralogy of the given rock specimen, you can identify the type and name of the rock.

Know your progress

1. Mention the types of sedimentary rocks described below.
   (a) Rocks whose range of particle size varies from 2 mm (a pebble) to more than 256 mm (a boulder).
   (b) A rock composed of sand sized (1/16 mm to 2 mm) particles of quartz.
   (c) A non-clastic rock made up of the mineral calcite.
   (d) Rocks whose range of particle size is less than 1/256 mm (clay).
2. What do you infer from the following?
   (a) Long distance transport= well-rounded and well-sorted grains.
   (b) Short distance transport = poorly sorted angular grains.
3. What information can be obtained about the depositional processes when you find the following features in sediment or sedimentary rocks? (a) cross-beds, (b) graded bedding (c) rain drop marks.

1.4 Metamorphic rocks

Metamorphic rocks are the third type of rock we will look at. Metamorphic rocks are formed by the transformation of pre-existing rocks in response to changing environmental conditions, such as variations in temperature, pressure, and the addition or subtraction of chemical components. Metamorphic rocks can be derived from any type of pre-existing rocks that have been altered or modified as a consequence of changes of their physical environment. The transformative process leading to the formation of metamorphic rocks is called metamorphism.

The word "metamorphism" is derived from the Greek terms *meta* meaning change and *morph* meaning form; so *metamorphism* means change of form. Metamorphism is defined as 'the mineralogical and structural adjustment of solid rocks to physical and chemical conditions that have been imposed at depths (below the near surface zones of weathering and diagenesis) and which differ from conditions under which the pre-existing rocks originated. Some common examples of metamorphic rocks are gneiss, slate, marble, schist, and quartzite.

Rocks are subjected to higher temperatures and pressures as they are buried deeper in the Earth's crust by crustal movements. Earth movements can cause rocks to be deeply buried or squeezed. As a result, the rocks are heated up and put under great pressure. Melting does not occur but the minerals they contain are changed chemically, forming metamorphic rocks.

The upper limit of metamorphism occurs at the pressure and temperature where melting of the rock begins. Once melting begins the process changes to an igneous process - which is beyond the realm of metamorphism. The reactions taking place during metamorphism occur in the solid state, facilitated by the presence of a fluid phase lining the grain boundaries of the minerals. In this respect metamorphism differs from the formation of primary igneous rocks.

Metamorphism changes the mineralogy, texture or both, of the original rock. The processes often produce new mineral assemblages that are stable under the changed conditions of temperature and pressure. The original rock or the pre-existing rock is generally termed **protolith**. The protolith undergoing metamorphism may be a sedimentary rock, an igneous rock or another older metamorphic rock.

1.4.1 Agents/factors of metamorphism

Three factors that contribute, in varying proportions, to the transformation of a protolith to a metamorphic rock are: (1) heat,

(2) pressure and (3) chemically active fluids (mostly water with dissolved ions).

(i) Heat factor: Heat contributes to the metamorphic process in two ways. First, the atoms may combine differently at different temperatures. This means that a mineral stable at one temperature might become unstable at a higher (or lower) temperature and be converted to a different mineral with a more stable atomic structure stable at that temperature. Second, heat makes practically all chemical reactions go faster, meaning that mineral transformations become much easier at higher temperature.

There are several sources of heat that contribute to the process of metamorphism. These include: (1) Geothermal gradient (temperature increases with depth at a rate of 20 - 30° C per km in the crust, i.e., the deeper you go the hotter it gets, (2) Heat generated by radioactive decay and (3) Heat supplied by the intrusions of hot magma.

(ii) Pressure factor: Pressure is the force acting on rocks from different directions. There are two types of pressure affecting rocks: (1) **Lithostatic pressure** ('lithos' means rock and 'static' means unchanged) or confined/uniform (equal intensity from all directions by rocks) pressure which is similar to the hydrostatic pressure acting vertically down and is caused by the weight of overlying rock mass and (2) **Directed pressure** resulted from tectonic forces and these are acting in some preferred directions. If the stress is not equal from all directions, then the stress is called a differential stress. If differential stress is present during metamorphism, it can have a profound effect on the texture of the rock. Rounded grains can become flattened in the direction of maximum stress. Minerals that crystallize or grow in the differential stress field can have a preferred orientation. The effect of pressure is to reorient minerals with linear or platy structure resulting in a preferred orientation of elongated grains as they form. A texture of this sort in a metamorphic rock is called **foliation** and the rocks having this feature are said to be foliated.

Thus minerals with elongated crystals, such as amphiboles, and platy minerals such as mica tend to align themselves parallel to each other when under pressure. This can happen only under directed pressure as confining pressure does not accomplish it. The diagram shown here (Fig.1.25) illustrates the effect.

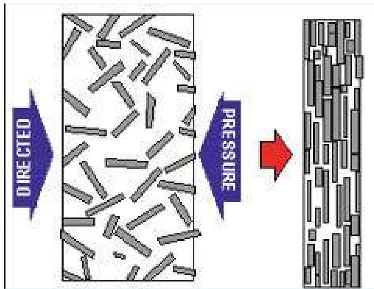


Fig.1.25: Diagram showing effect of pressure during metamorphism

As already noted foliation is generally caused by a preferred orientation of platy or elongated minerals. You can infer from the diagram that, platy or elongated crystals of minerals, such as mica and chlorite, become rotated such that their long axes are perpendicular to the orientation of shortening.

(iii) Fluid factor: Fluids serve only to speed up other metamorphic processes. Chemical reactions require water, and most of these proceed much faster as the amount of water increases in the metamorphic environment. Dissolved ions in the fluid also make those mineral transformations that require chemical changes in the minerals to occur, whether by supplying needed ions or flushing away the excess or unwanted ones from the region of metamorphism.

1.4.2 Recrystallization and grade of metamorphism

The processes that take place during metamorphism mainly include recrystallization (reorganization of the crystals) of pre-existing minerals. For example, the small calcite crystals in a sedimentary rock (e.g. limestone and chalk) undergoing metamorphism recrystallize into larger crystals and give rise to a metamorphic rock known as marble. During the metamorphism of sandstone, recrystallization of the original sand grains (i.e, the mineral quartz) results in the formation of a very compact metamorphic rock called quartzite consisting of larger quartz crystals with interlocking texture. Both increased temperature and increased pressure contribute to recrystallization. You should note that recrystallization of mineral grains during metamorphism involves both changes in size as well as the shapes of the grains making up the protolith. Moreover, during recrystallization, while the mineralogical identity of the grains of the rock undergoing metamorphism remains unchanged, the original texture of the protolith undergoes significant changes.

Grade of metamorphism

The grade of metamorphism describes the relative temperature and pressure conditions under which metamorphic rocks form. High-grade metamorphism takes place at temperatures greater than 320°C and relatively higher pressure. Low-grade metamorphism takes place at temperatures between about 200 to 320°C, and at relatively lower ranges of pressure.

Metamorphic grade is an informal term designating the amount or degree of metamorphism suffered by the parent rock. The higher the pressure and temperature in which the rock is formed, the higher will be the grade of the rock formed.

1.4.3 Types of metamorphism

Metamorphism can take place in several different environments where special conditions exist in terms of pressure, temperature, stress and chemical environments. The metamorphic processes, that change pre-existing rocks into new types of rocks, can be treated under the following basic types:

(1) Contact metamorphism: This type of metamorphism occurs adjacent to igneous intrusions, owing to the heat associated with the igneous intrusion. As plutons cool, the heat they lose is absorbed by the country rock around them. This heat can be sometimes sufficient to cause metamorphism of the intruded rocks. Because it occurs at the contact with the igneous body, this type of metamorphism is called contact metamorphism.

The heat from an intrusion tends to be most intense immediately beside the intrusion and to become less noticeable farther away. This means that the highest temperature minerals produced in the metamorphosed country rock will be immediately around the pluton. Somewhat lower temperature minerals will be found farther from the pluton, and at some distance away from the contact, the heat will be insufficient to cause any changes in the country rocks which remains unaltered by the intrusive event (Fig.1.26). The region of the country rocks altered by contact metamorphism is called a contact metamorphic aureole.

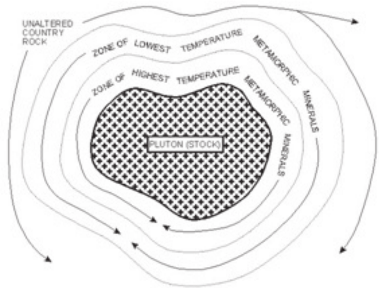


Fig. 1.26: Zones of contact metamorphism

The grade of metamorphism decreases in all directions away from the contact of intrusion and the country rocks. Because the temperature contrast between the surrounding rock and the intruded magma is larger at shallow levels in the crust, where pressure is low, contact metamorphism is often described as a high temperature-low pressure metamorphism. The resulting metamorphic rock produced in contact metamorphism is often a fine-grained rock lacking any foliation called *hornfels*. Since the primary agent in this type of metamorphism is heat and not pressure, the term thermal metamorphism is also given to the process.

(2) Burial metamorphism

Uniform pressure increases with depth due to the weight of the overlying rocks. When sedimentary rocks are buried to depths of several hundred meters, temperatures greater than 300°C may develop in the absence of differential stress. The lithostatic pressure and geothermal heat at these depths cause recrystallization and alteration of the rock's minerals. This kind of metamorphism caused by lithostatic pressure and geothermal heat is termed burial metamorphism and this grades into regional metamorphism as temperature and pressure increase.

(3) Dynamic metamorphism

When directed pressure or directed stress is the dominant agent of metamorphism, it is termed dynamic metamorphism. Mineralogical changes occurring on a fault plane provide an obvious example. Along major fault zones of the Earth, blocks of the crust are forced to slip past each other in opposite directions. This localizes intense pressures on the rocks adjacent to the faults, but the temperatures are typically not high. This allows for a type of high-pressure/low-temperature metamorphism called dynamic metamorphism. Often this type of metamorphism involves a change in texture of the rock with little or no change in mineral composition. The resulting texture is that of finely pulverized rock powder called *mylonite.*

(4) Regional metamorphism

Regional metamorphism occurs over large areas where increased pressure and temperature have caused recrystallization over extensive regions in mountain belts. Thus, regionally metamorphosed rocks occur in the cores of fold/thrust mountain belts or in eroded mountain ranges. Most regional metamorphism is accompanied by deformation under non-lithostatic or differential stress conditions. Thus, regional metamorphism usually results in forming metamorphic rocks that are strongly foliated, such as slates, schists, and gniesses. The differential stress usually results from tectonic forces that produce compressional stresses in the rocks, such as when two continental masses collide. Compressive stresses result in folding of rock and thickening of the crust, which tend to push rocks to deeper levels where they are subjected to higher temperatures and pressures.

(5) Metasomatism

Metasomatism is the drastic change in the bulk chemical composition of a rock that often occurs during the processes of metamorphism. It is due to the introduction of chemicals from other surrounding rocks. Water may transport these chemicals rapidly over great distances. Because of the role played by water, metamorphic rocks generally contain many elements absent in the original rock, and lack some that originally were present.

Still, the introduction of new chemicals is not necessary for recrystallization to occur.

1.4.4 Types of metamorphic rocks

Because of the great variety of protolithic rock types and the variation in the kinds and degrees of metamorphism, many types of metamorphic rocks have been recognized.

As you have noted earlier, the layering within metamorphic rocks is called foliation (derived from the Latin word 'folia', meaning "leaves"), and it occurs when a rock is being shortened along one axis during recrystallization. Textures of metamorphic rocks are separated into foliated and non-foliated categories. Most metamorphic textures involve foliation.

Foliated rocks are metamorphic rocks that have parallel bands of mineral grains. Non-foliated rocks are types of metamorphic rock that do not exhibit any kind of preferred orientation or banding of grains. The major types of foliated rocks are slate, schist, gneiss, and phyllite. Important nonfoliated rocks are quartzite, marble, hornfels, greenstone, and granulite. Some of the important characteristic features of common foliated and non-foliated rocks are given below.

(1) Slate

Slate is a foliated metamorphic rock, originating from shale. A rock that has a slaty cleavage as its foliation is generally termed as slate. Slaty cleavage is produced by the parallel alignment of minute flakes of platy minerals, such as mica, chlorite, and talc.

Slate is a very fine-grained metamorphic rock (usually developed from clay-rich sedimentary rocks, such as a mudstone or shale) that cleaves, or splits, readily into thin slabs and thus exhibiting perfect planar layering (Fig. 1.27). The principal minerals in slate are mica (in small, irregular scales), chlorite (in flakes), and quartz (in lens-shaped grains).

Fig. 1.27:Slate

Slate is useful for making roof tiles because its layers can be split into separate flat sheets. As the intensity of metamorphism increases the average crystal size increases, and mineral segregation develops; the rock then may be termed a phyllite.

(2) Phyllite

Phyllite is a fine-grained metamorphic rock formed by the reconstitution of fine-grained, sedimentary rocks such as shales (Fig. 1.28). It has a marked fissility (a tendency to split into sheets or slabs) due to the parallel alignment of platy minerals; it may have a shine on its surfaces due to the occurrence of tiny flakes of micas.


Fig. 1.28: Phyllite

Phyllite is formed by relatively low-grade metamorphic conditions. Phyllite has physical characteristics intermediate between those of slate and schist. Its grain size is larger than that of slate but smaller than that of schist.

(3) Schist

If a rock has a shistose foliation, it is termed schist (Fig 1.29). The foliation of schist differs from that of slate mainly in the size of the crystals. In schists, metamorphic minerals are easily seen by eye or hand lens and the mineral grains have a highly orientated fabric. The mineral grains produce an obvious planar structure because of their overlapping subparallel arrangement. Schist is typically composed of platy minerals (e.g., amphiboles and micas) with a parallel to subparallel geometric orientation that gives the rock a tendency to split along planes.


Fig. 1.29: Schist

Schists result from a higher grade of regional metamorphism than the type that produces slates. Schists are usually classified on the basis of their mineralogy, with varietal names that indicate the characteristic mineral present. Talc schist contains abundant talc; it has a greasy feel, a well-developed schistosity, and a grayish-green colour. Mica schist often contains muscovite mica rather than biotite, although both minerals are common. It represents a somewhat higher grade of metamorphism than talc schist and is more coarse-grained; individual flakes of mica can be seen.

Schists that are rich in the amphibole (hornblende) and are often derived by metamorphism of common igneous rocks of the basalt-gabbro type are called amphibolites.

(4) Gneiss

Gneiss is a coarse-grained, granular metamorphic rock in which foliation results from alternating layers of light (felsic) and dark (mafic) minerals called gneissic banding (Fig. 1.30). The composition of most of the gneisses are similar to that of granite. Gneiss is produced by intense metamorphism, at high temperature and pressure.

Fig. 1.30:Gneiss

It is convenient to think of gneiss as a rock with parallel, somewhat irregular banding which has little tendency to split along planes. In contrast, schist typically is composed of platy minerals with a parallel to sub parallel geometric orientation that gives the rock a tendency to split along planes.

(5) Marble

These are rocks composed mostly of calcite, and less commonly of dolomite (Fig. 1.31). They result from metamorphism of limestones. The main result of metamorphism is an increase in grain size. Because of the rather equidimensional habit of calcite and dolomite crystals, they appear as massive rather than schistose, unless they contain other minerals such as mica. Some foliation may be present if the marble contains micas.

Fig. 1.31:Marble

(6) Quartzite

Sandstones that have been converted into a solid quartz rock are called quartzites (Fig. 1.32). Since quartz is stable over a wide range of pressures and temperatures, metamorphism of sandstones and cherts will result only in the recrystallization of quartz forming a hard rock with interlocking crystals of quartz.


Fig. 1.32:Quartzite

Unlike sandstones, quartzites are free from pores and have a smooth fracture. When struck, they break through, not around, the sand grains, producing a smooth surface instead of a rough and granular one.

High-grade metamorphism produces a distinctly granular rock called **granulite** and it is not foliated because the mineral grains forming its principal constituents, do not form platy crystals. Granulites lacks minerals such as micas and amphiboles but may contain pyroxenes, garnet, kyanite, sillimanite, quartz and feldspars. Hornfels is a type of metamorphic rock that shows no foliation with a smaller grain size and if the grain size is large and individual minerals can be easily distinguished with a hand lens, it is a granulite.

(7) Charnockite

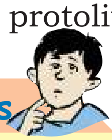
Charnockite is a hypersthene granite (composed of hypersthene, feldspar and quartz) with a granulitic texture (Fig 1.33). Some charnockites contain a brownish-green hornblende, often rather rich in titanium. The rocks of the characteristic group are the predominant type in Kerala.

Charnockites with variable chemical composition, was first described from the state of Tamil Nadu and is named after Job Charnock, the founder of Kolkatta city. Charnockite occurs all over the world, most often in deeply eroded Precambrian basement rock complexes.

The charnockite series originally was assumed to have developed by the fractional crystallization of a silicate magma (molten material). Subsequent studies have shown, however, that many, if not all, of the rocks are metamorphic, formed by recrystallization at high pressures and moderately high temperatures.

Fig 1.33:Charnockite

Now try to identify the common types of metamorphic rocks available in the geology laboratory of your school. See the description of metamorphic rocks given in Table 3 of Appendix II given at the end of this textbook. Compare the textures exhibited by the foliated rocks (Slate, Schist and gneiss) with that of the non-foliated rocks (marble, quartzite and charnockite). Make a profile of the dominant minerals present in each type of these metamorphic rocks. Mention the types of metamorphism that might have resulted in the formation of the metamorphic rocks from their respective protoliths.



Know your progress

1. Every metamorphic rock has a protolith (parent rock). Give a possible protolith for each of the following metamorphic rocks.

   Slate, Marble, Quartzite, Schist
2. How is foliation created during metamorphism?
3. Can you establish any relation between the grade of metamorphism and the degree of foliation?

1.5 The rock cycle

You have learnt that there are three main types of rocks. Make sure that you can describe how each type of rock forms, and give examples of each type of rock. The Earth's rocks do not stay the same forever. They are continually changing because of processes such as weathering and large Earth movements. Over the course of time, rocks can transform from one type into another, as described by the geological model called the rock cycle (Fig.1.35). The rocks are gradually recycled over millions of years. The rock cycle shows how the Earth's rocks are changed again and again.

Igneous rocks can be weathered and broken down to form sediments (sand, clay). Sediments are lithified to form sedimentary rocks. Sedimentary rocks can be deeply buried and subjected to heat and pressure that converts them to metamorphic rocks. Metamorphic rocks may be heated to temperatures so great that they melt. The molten rock crystallizes to form igneous rocks. This completes the simplified cycle.

Many routes through the rock cycle are possible. The process depends on temperature, pressure, time, and changes in environmental conditions in the Earth's crust and at its surface. The rock cycle represents the processes of continuous changes that connect the three major groups of rocks.

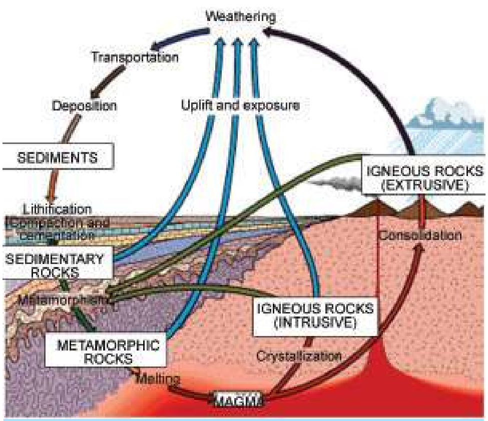


Fig.1.34: Rock cycle

Using the rock cycle shown in Fig.1.34, trace the path from magma to a granite intrusion to metamorphic gneiss to sandstone. (Be sure to include the role of tectonics and the specific processes that create the rocks). Diagrammatically represent the ideas in your *activity log.*

Let us conclude

Knowledge of rocks is fundamental to the study of Earth sciences and the dynamics of the Earth systems. Combined with the effects of tectonics, weathering and vegetation, rocks define the natural landscapes we see around us.

Igneous rocks contain randomly arranged interlocking crystals. The size of the crystals depends on how quickly or slowly the molten magma solidified. Most sedimentary rocks consist of grains that weathered from a parent rock and were transported by water, wind, or ice before being deposited. The texture of a sedimentary rock can provide a lot of information about the types of environments that the sediments were weathered in, transported by, and deposited in prior to their lithification into sedimentary rocks.

Metamorphic rocks can originate not only from igneous and sedimentary rocks but also other types of metamorphic rocks. Metamorphic rock is formed under extreme pressure combined with heat over time. Foliated rocks are types of metamorphic rocks that have parallel bands of mineral grain. Non-foliated rocks are types of metamorphic rocks that have no arrangement or bands of mineral grains. The rock cycle describes the processes through which rocks of one category may be altered to form rocks of another category.

Let us assess

1. Which one of the following is a sedimentary rock?
   a. shale
   b. slate
   c. granite
   d. charnockite
2. Which of the following is the order of formation of sedimentary rocks?
   a. sedimentation - cementation - compaction
   b. compaction - sedimentation - cementation
   c. sedimentation - compaction - cementation

3. What does the presence of tiny crystals in a piece of igneous rock tell you about it?
   a. The molten rock cooled very quickly.
   b. The molten rock cooled very slowly.
   c. The molten rock cooled deep underground.
   d. The rock is plutonic in origin.
4. Which statement about metamorphic rocks is correct?
   a. They are formed when rocks are heated until they melt.
   b. They are only formed from heated sedimentary rocks.
   c. They are formed from all types of rock.
   d. They are formed at the surface of the Earth.
5. Of the three groups of rocks, which form at Earth's surface and which in the interior of the crust?
6. Why are intrusive igneous rocks coarsely crystalline and extrusive igneous rocks finely crystalline?
7. How do clastic sedimentary rocks differ from non clastic sedimentary rocks?
8. Compare and contrast sandstone and quartzite.
9. Distinguish between slate and gneiss.
10. Give the texture and mineralogy of Granites and Basalts.
11. Mention the igneous, sedimentary and metamorphic rocks that contain predominantly quartz.
12. Describe the cyclic geologic process by which an igneous rock is transformed into a metamorphic rock and then into sedimentary rock.

Chapter 02

Economic Mineral Deposits

Significant Learning Outcomes

After the completion of this chapter, the learner:

- Delineates the conditions to treat mineral deposits as ores.
- Describes the formation of mineral deposits associated with magmatic concentrations.
- Explains the ways of formation of hydrothermal mineral deposits.
- States the processes that produce sedimentary deposits.
- Distinguishes between residual and placer mineral deposits.
- Identifies metamorphism as a mode of mineral formation.
- Discusses the formation of mineral deposits associated with contact metasomatism.
- Identifies major metallic and non-metallic mineral specimens based on their salient physical properties.
- Mentions the uses of some major industrial minerals.

The well being of human society and the rate of scientific, technologic and economic development depend to a great extent on the availability of mineral materials. Minerals are necessary and unavoidable for such basic needs of modern times as farming, production of fertilizers, harvesting, transportation, manufacturing of vehicles, etc. To cite an example, it takes 38 elements, all of them derived from minerals, such as copper, zinc, lead, mercury, tin, gold, tellurium, silver and so on, to build a computer.

Economic geology *is a branch of geology, concerned with Earth materials that can be used for economic or industrial purposes.* Humanity's requirement for mineral raw materials, caused by increasing global population and living standards, has resulted in economic geology becoming a subject of great importance in modern times.

2.1 Minerals and ores

As you have learnt in the previous chapter, rocks are aggregates of one or more minerals. Minerals in turn, are chemical compounds with definite arrangement of their atoms. For example, quartz (SiO_2) is made up of oxygen and silicon atoms. Only a few minerals occur in nature in elemental form. Mostly two or more elements are bound together in combinations to form minerals.

The eight most abundant elements in the Earth's crust are oxygen, silicon, aluminum, iron, calcium, sodium, potassium and magnesium. Among the 8 most abundant elements in the Earth's crust oxygen tops the list in terms of abundance followed by silicon. Add these two elements together, and you get silicates. The majority of rocks scattered across the landscape of our terrestrial planet are silicate minerals, such as quartz and feldspar.

What constitutes an ore?

We depend on minerals as sources of metals, like Iron (Fe), Copper (Cu), Gold (Au), Silver (Ag), Zinc (Zn), Nickel (Ni), Aluminum (Al), etc., and non-metals such as gypsum, mica, clay, and talc. An ore can be considered as a type of rock that contains sufficient minerals with important elements including metals that can be economically extracted from the rock. We can define an **ore** as a body of material from which one or more valuable metals can be extracted economically. For example, the metal aluminium can be extracted commercially from the mineral bauxite.

A metal may have more than one ore mineral as its natural source. For example, iron is obtained from magnetite, hematite (Fig.2:1 a & b) and a few other iron bearing minerals.

Fig.2.1 (a): Iron ore mineral-Hematite (b): Magnetite

An individual ore deposit may yield several different metals. In other words, several different ore minerals may be contained in the same mineral deposit. An ore that yields a single metal is described as a **simple ore** while an ore that yields several metals is termed a **complex ore.** Some of the common associations of metals in ores are gold and silver; silver and lead; lead and zinc; lead, zinc and copper; copper, gold and molybdenum; titanium and iron and so on.

Metals and their ore minerals

Many different kinds of ore minerals are identified in nature. The following table (Table: 2.1), gives a list of common metallic elements and their principal ores.

Table 2-1: Some common metals and their chief ore minerals

Metal	Ore	Composition
Iron	Hematite	Fe_2O_3
	Magnetite	$FeO.Fe_2O_3$
	Limonite	$Fe_2O_3.H_2O$
Copper	Chalcopyrite	$CuFeS_2$
	Native Copper	Cu
Manganese	Pyrolusite	MnO_2
	Psilomelane	$Mn_2O_3.x\ H_2O$
Aluminium	Bauxite	$Al_2O_3.2H_2O$
Chromium	Chromite	$FeO.Cr_2O_3$
Lead	Galena	PbS
Zinc	Sphalerite	ZnS
Gold	Native Gold	Au
Titanium	Ilmenite	$FeTiO_3$
	Rutile	TiO_2
Uranium	Uraninite	Mainly UO_2 often contians variable amounts of U_30_8
	Pitchblende	Uranium oxides
Thorium	Monazite	Phosphate of thorium and Rare Earths

A few ore minerals occur in nature as **native elements** (any element found uncombined in a non-gaseous state in nature) of which gold and platinum are best known examples. However, most of the ore minerals are compounds of metals with oxygen, sulphur, silicon, or other elements. Thus the metals may be present as native elements, oxides, sulfides, silicates, or other compounds.

The term *ore* is commonly accompanied by the name of the metal, for example, iron ore or silver ore. The ores are extracted through mining; these are then refined (often via smelting) to extract the valuable metallic or other element(s).

Gangue

Mineral deposits are seldom made up entirely of valuable metallic or nonmetallic minerals. Minerals of little value or no value usually occur associated with the ore minerals. The worthless non-metallic minerals, which occur in close association with ore minerals, are called **gangue**. The most common gangue minerals include quartz, feldspars, calcite and dolomite.

The ore is often a mixture of ore minerals and gangue. Some gangue minerals may not be worthless and some of these can be used as byproducts. For example calcite and limestone, common gangue, can be used as a fertilizer or flux and pyrite for making sulphuric acid.

Grade of an ore

The term **grade** of an ore is commonly used to denote the concentration of metal content in a potentially mineable ore deposit. It is generally expressed in percentage of the metal. The concentration of the useful metal in an ore determines the grade of the ore- the higher the concentration, the higher the grade.

Know your progress

1. Why do we say that all mineral deposits are not ore deposits?
2. Can you give examples of the following?
   - i) An ore mineral of copper.
   - ii) Metals having more than one ore mineral.
   - iii) A common gangue mineral.

2.2 Formation of mineral deposits

Mineral deposits can be considered as natural aggregate of a useful mineral in an unusually high concentration. Mineral resources fall into two groups: nonmetallic resources and metallic resources. A nonmetallic resource is any useful rock or mineral that does not have metallic properties, such as gypsum, limestone and rock salt. In a broader sense, the term mineral deposits include, in addition to metalliferous minerals, any other useful minerals or rocks.

Mineral deposits tend to be concentrated in nature in small localized rock masses that form as a result of special geologic processes. Some mineral deposits are intimately related to the rocks in which they occur. A mineral deposit formed contemporaneously (formed at the same time) with the enclosing rock is termed a **syngenetic deposit** and those that were formed later than the rocks in which they occur are called **epigenetic deposits.** Let us classify the different mineral deposits formed in association with various geologic processes into different categories as discussed below.

2.2.1 Magmatic deposits

Mineral deposits that originate often by the concentration of valuable minerals during the cooling and crystallization of magma are called magmatic deposits. Magmatic deposits are so named because they are genetically linked with the evolution of magmas emplaced into the Earth's crust.

(a) Magmatic segregation

When minerals cool and crystallize out of the magma, fractional crystallization occurs. You have learnt in the previous chapter that, fractional crystallization separates minerals according to their crystallization temperature. Recall that cooling magma does not solidify all at once. Instead, higher-temperature minerals crystallize first, and lower-temperature minerals form later as the temperature drops.

In some instances, ore minerals crystallize with other early-formed minerals and consequently accumulate in layers near the bottom of the igneous mass. As minerals crystallize from magma, heavy minerals may sink or settle to the bottom of the magma chamber. Magmatic segregation is a term referring to *any process by which one or more minerals become locally concentrated (segregated) during the cooling and crystallization of magma.*

Magmatic segregation deposits occur within the igneous rocks from which they were derived. The heavier metal-rich liquids sink and concentrate at the base of the intrusive body, while lighter silicate liquid and crystals tend to raise. Heavy minerals such as chromite, olivine, and ilmenite contain high concentrations of chromium, titanium, platinum, nickel, and iron. These elements thus attain higher concentrations in the layers (Fig.2:2) that form at the bottom of the magma chamber.

Fig.2.2: Segregation of chromite in layered ultramafic rock

The chromite deposits in ultramafic rocks of Sukinda (Odisha) are of segregation origin.

(b) Magmatic disseminations

When magma solidifies by simple crystallization, sometimes, the economically valuable minerals will be distributed throughout the resulting rock. This type of mineral deposit in which the minerals occur as small particles scattered throughout the country rock without any local concentration are called magmatic disseminated deposits (Fig.2.3).

Fig.2.3 : Dissemination deposits

An excellent example of mineral deposit formed by the process of dissemination is diamond in the Kimberlite rocks of South Africa. Diamond deposits of Panna (Madhya Pradesh), Wajrakarur (Andhra Pradesh) are also found disseminated in the enclosing rocks.

(c) Pegmatite deposits

Certain magmas, such as those which form granites, contain water in them. During fractional crystallization water and elements that do not enter the minerals separated from the magma by crystallization will end up as the last residue of the original magma. Such magmatic residues will be rich in silica, water and in elements like Lithium, Tantalum, Niobium, Boron, Beryllium, Gold, and Uranium. This residue is often injected into fractures surrounding an igneous intrusion and crystallizes there as a rock called pegmatite.

Fig. 2.4: Topaz in pegmatite rock

As pegmatite deposits are formed by slow cooling from a low viscosity fluid composed largely of water, extremely coarse sized mineral crystals are found in pegmatites (Fig. 2.4). A large number of rare minerals and metals are found in pegmatites.

Know your progress

1. What do you know about the formation of segregated chromite deposits?
2. Why are diamond deposits in Kimberlite rocks termed as disseminated deposits?
3. How are pegmatite deposits enriched with uncommon elements?

2.2.2 Hydrothermal ore deposits

Hydrothermal deposits are formed through the process of concentration of ore minerals or other valuable minerals from hot aqueous (water-rich) fluids *known as* ***hydrothermal solutions*** flowing through fractures and pore spaces in rocks. Such hot water can dissolve valuable substances of the rocks into which they come into contact and carry them away. As the hot water moves into cooler areas of the crust, the dissolved substances are precipitated from these water solutions.

Hydrothermal fluids might be a part of the magma undergoing crystallization. It is also believed that the water and metals released during regional metamorphism can give rise to hydrothermal mineral deposits. The elements released from the minerals would migrate to low-pressure zones, such as fissured areas and concentrate into mineral deposits. Surface water or seawater trickling down to great depth and come into contact with a hot igneous body or water heated up by geothermal gradient may also become a hydrothermal solution.

A wide variety of ore-forming processes are associated with such fluids and these can be found in igneous, sedimentary, and metamorphic environments. Vein deposits are the simplest type of hydrothermal deposits that are found.

Vein deposits

Veins or lodes are tabular or sheet-like bodies that form by filling of pre-existing fissures in country rocks or replacing the country rock along a fissure. Vein deposits are formed when a hydrothermal solution flows through an open fissure and deposits its dissolved load. When hydrothermal fluids are injected into open fractures, they cool rapidly and precipitate mainly quartz, but also a variety of sulfide minerals, and sometimes gold, and silver within the veins of quartz (Fig.2.5).

Fig. 2.5: Examples of vein type mineral deposits

Know your progress

1. Where did the metal in hydrothermal fluids come from?
2. Why do vein deposits belong to epigenetic mineral deposits?

2.2.3 Sedimentary deposits

Sedimentary process can also produce economic mineral deposits. Although some clastic sedimentary processes can form mineral deposits, the term sedimentary mineral deposit is generally restricted to chemical sedimentation.

(a) Chemical sedimentary deposits

Several valuable minerals are concentrated by chemical precipitation from lake or sea water, where minerals containing valuable substances are precipitated directly out of water. Chemical precipitation in layers is the most common origin for ores of iron and manganese. Most of the world's iron and manganese are derived from sedimentary deposits. These deposits are believed to have precipitated on the floor of the shallow oceanic basins in a highly oxidising environment. Manganese in solution will, on meeting an oxidizing environment, quickly precipitate the mineral such as pyrolusite, (MnO_2). Iron ores of this type is commonly termed as the **banded iron formation (BIF).** In BIF, iron rich layers (generally hematite, magnetite, or siderite) alternate with silicate or carbonate layers (Fig.2.6).


Fig.2.6: Banded iron formations

Since banded iron ores are all Precambrian in age, their origin might be connected to an ancient atmosphere, or ocean chemically different from that of today. The primitive atmosphere is believed to have lacked free oxygen, and under those conditions, iron from weathering of continental rocks would have been soluble in the oceans. As they are very ancient, most of these deposits have been intensely deformed and metamorphosed.

In some parts of the deep sea floor, precipitation of manganese oxides from sea water led to the formation of **manganese nodules.** These are lumpy accumulations or nodular deposits composed mostly of manganese minerals. They also contain lesser but potentially valuable amounts of copper, nickel, cobalt, platinum and other metals.

(b) Evaporite deposits

The process of evaporation brings about deposition of many valuable minerals dissolved in water. Evaporation of lake water or sea water results in the loss of water and thus concentrates dissolved substances in the remaining water.

An **evaporite** is the sediment that forms through the evaporation of saline water. Most evaporites are derived from bodies of sea-water, but under special conditions, inland lakes may also give rise to evaporite deposits, particularly in regions of low rainfall and high temperature. The most common evaporites are halite and gypsum deposits.

(c) Bio-chemical sedimentary deposits

Organisms also extract the dissolved ions from sea water to make their solid shells. Some organisms construct their shells out of calcium and carbonate ions, which then merge to make the mineral calcite. When the organisms die, the solid material in their shells turns into sedimentary deposits. You have learnt in Chapter I that, rocks formed from the calcite skeletons of organisms are classed as bio-chemical limestone.

Limeshell deposits formed by the accumulation of skeletal remains of organisms that grow in the brackish waters of river mouths and lagoons of Kerala are of bio-chemical origin. Resources of lime deposits that occur in Vembanad lake and adjacent areas comprising parts of Alappuzha, Ernakulam and Kottayam districts are lime shell accumulations.

2.2.4 Residual deposits and placer deposits

At the Earth's surface, where rocks and minerals exposed to the agents of weathering, minerals formed by other processes are often altered with the subsequent formation of new minerals. Soluble constituents of the rocks are removed in solution. Insoluble materials of the original rock may remain as residual deposits. Hence the weathering crust is gradually enriched with valuable components. A **residual deposit** is an accumulation of valuable minerals, formed by the natural removal of undesired constituents of rocks.

Bauxite, the ore of aluminium and clay deposits are formed as a result of residual concentration. Under tropical conditions of high rainfall and temperature, most weathering products are soluble. The insoluble residues remaining in them are hydroxide minerals of iron and aluminum. Most laterites are such intimate mixtures of iron and aluminium minerals. Most of the world's aluminium is mined from lateritic bauxite ($Al_2O_3.nH_2O$) deposits.

Many lateritic types of bauxite are pisolitic (Figure 2.7). The section given in the inset within figure shows the concentric banding of pisolitic structure. The word pisolitic comes from the Greek meaning pea-sized rock particles.

Fig.2.7: Pisolitic bauxite

Bauxite occurs in close association with laterite in Kasaragod (Nileswaram) district of Kerala. Residual deposits of clay minerals are extensive in occurrence, over the entire state. China clay (Kaolinite) deposits found paticularly in Thiruvananthapuram, Kundara (Kollam), Pazhayangadi(Kannur), Nileswaram and Manjeshwaram (Kasaragod) are typical examples.

Placer deposits

When mineral grains of different densities are moved by flowing water, the less dense grains will be most rapidly moved, and a separation of high density and low-density grains can be effected by the action of gravity. Mineral deposits formed as a result of gravity separation based on density are called **placer deposits.**

Minerals which have high specific gravity are chemically resistant and durable. While being in transport, streams can effectively concentrate such resistant and dense minerals in places along the stream channel. Separation and concentration of heavy minerals may be accomplished by streams, waves and currents, air, or by soil and hill creep.

Concentration of grains of economic minerals in stream sediments results in the formation of alluvial placers. The most important economic placer deposits are those formed by stream action. (The name is from the Spanish word 'placer', meaning "alluvial sand"). Waves and currents of a coastal environment can sort and concentrate valuable minerals along beaches forming beach placer deposits.

Placer deposits are thus, the result of mechanical concentration whereby heavy, chemically resistant, tough minerals are separated by gravity from light friable minerals. Gold, monazite, magnetite, ilmenite, are examples of minerals that have been mined from the sands and gravels of placer deposits. Less commonly diamond, platinum and gem stones occur as placers.

The beach placer deposits along the shores of Chavara, Kollam district of Kerala, typically contain rich concentration of heavy minerals such as ilmenite, rutile, zircon, garnet and monazite.

The coastal tract between Alappuzha and Cherthala contain deposits of white silica sand (Glass sand) in the form of placers. Alluvial placer gold deposits are found on the beds of Chaliyar and Punnapuzha rivers draining Nilambur valley, Malappuram district.

Know your progress

1. How does stream action lead to the formation of placer mineral deposits?
2. How were rock salts and gypsum deposits formed?
3. Why do we treat banded iron formations as chemical sedimentary deposits?

2.2.5 Metamorphic deposits

The mineralogical changes caused by the heat and pressure of metamorphism also can produce economic mineral deposits. You have already learned that metamorphism occurs deep in the Earth as a result of changes in temperature, pressure and chemical environment.

Metamophism at elevated temperature and pressure acts to change the former minerals into new minerals that are stable under the new conditions. Thus clay formed under the conditions of weathering, when buried deeply by later rocks, may be converted to mica schist or garnet. Similarly talc is formed by the alteration of the magnesian minerals of the dolomitic limestone and ultrabasic igneous rocks.

Deposits of magnetite, titaniferous iron and various sulphides may form in metamorphic rocks, as well as deposits of nonmetallic minerals, such as kyanite, corundum, talc, graphite, garnet and asbestos. Several building stones, including marble and slate are also products of metamorphism.

2.2.6 Contact metasomatic deposits

As you have already learnt, magmas often contain a considerable amount of fluids rich in mineral constituents. In many cases, great quantities of these materials are introduced from magma into the invaded rocks. These fluids may produce wide-spread changes *near the contacts of intrusive with the surrounding rocks.* The invaded constituents replace many of the minerals of the invaded rocks along the contact, in whole or part. When appreciable material is contributed by the magma during an intrusion into the country rocks, and form mineral deposits, the resulting deposits are termed **contact metasomatic deposits.**

Some of the iron and copper ore deposits are formed by contact metasomatic process. Many garnet and graphite deposits are classed as contact metasomatic deposits.

You have learnt that mineral deposits are generally classified based on their genesis as magmatic, hydrothermal, sedimentary, residual and placer deposits, metamorphic and contact metasomatic deposits. Now complete the given table on different ways of formation of mineral deposits and their examples. A few hints are given herewith.

Examples for various types of mineral deposits	
Types of ore deposits	**Examples**
Magmatic segregation	Chromium and iron ores
Pegmatite deposits	Lithium and rare metal deposits
Hydrothermal veins	
Chemical precipitation	
Evaporite deposits	
Residual deposits	Bauxite
Placer deposits	
Metamorphic mineral deposits	

2.3 Metallic and non-metallic minerals

Mineral deposits can be divided into two major groups: metallic and nonmetallic minerals. Ore minerals were metal bearing minerals and the term ore minerals is generally restricted to those that may be used to obtain one or more metals. Majority of the ore minerals are characterized by a metallic luster and hence spoken of as metallic minerals.

2.3.1 Metallic minerals

Various metals are extracted from the ores of this group and are utilized for various purposes. Iron and steel are used in a huge variety of products, from cast-iron frying pans to locomotives. Copper is used in electric cables and wires and for making alloys (brass, bronze), cooking utensils, coins and ornaments.

Aluminium is consumed in the manufacture of cans, bottles, electric cables, automobiles, air planes, building, and many other products. Manganese is vital in steel and metallurgical industries. Lead is used in batteries and ceramics. Zinc is necessary for galvanizing and for the manufacture of brass and other alloys. Chromium is essential for making stainless and heat-resistant steel.

Titanium as strong as steel, but weighing half as much, is used in aircrafts, jet engines, space, missile and other applications. The rare and valuable metal, gold is used in jewelry, decoration, electronics, dentistry and the space program.

Not only separate metals, but also their melts and compounds are used in industries. For example, manganese compounds are utilized in medical industry and agriculture.

2.3.2 Non-metallic minerals

Generally the minerals belong to non-metallic group lacks the metallic lustre that are characteristic of metallic minerals. They are mined for their commercial value and used in their natural state or after beneficiation either as raw materials or as additives in a wide range of industrial applications. Typical examples of industrial minerals/rocks are limestone, kaolin (china clay), baryte, gypsum, graphite and magnesite.

Limestone is composed of the mineral calcite, which is the principal raw material in cement industry. Portland cement is made by heating a mixture of crushed limestone and clay. Concrete is a mixture of cement, sand and gravel. Reinforced with steel, it is used to build roads, bridges and buildings.

Several important minerals such as gypsum, halite or rock salt, are recovered from evaporite deposits. Clay is not a single mineral, but a group of hydrous silicates that is commonly formed as a product of chemical weathering. The diversity of clay minerals leads to a variety of applications, from the manufacturing of ceramics to the processing of ores in metallurgical industries.

Baryte is used in oil drilling, to make the 'drilling mud', which lubricates the drill bit. Mica, asbestos, baryte, magnesite, graphite, precious and semi precious stones, construction materials such as sands and gravels, etc. are all of large economic importance. Analyze the given table (Table 2.2) on some of the non-metallic minerals used in different industrial applications. Conduct a discussion in your class on the importance of mineral deposits in your daily life. Summarize the findings in your *activity log.*

Table.2.2: Industrial uses of some major minerals

Industrial mineral	Uses
Mica	In electrical and electronic industries as insulators; as a filler in rubber goods and paints; as lubricants.
Gypsum	For plastering of walls; making plaster of paris; for the production of fertilizers; as a retardant in cement manufacture to control the setting time.
Asbestos	For making asbestos sheets, electrical and thermal insulators, fire proofing materials and special type of cements.
Magnesite	For making refractory materials; production of salts of magnesium; for the extraction of magnesium metal.
Baryte	Used as a drilling mud to prevent "blow-outs" of oil and gas wells; as fillers in paint, paper and plastics; for making glass utensils and medical applications.
Graphite	Used in the manufacture of heat and chemical resistant containers; for making lubricants and pencils.
Clay	As a raw material in ceramic industry; for manufacturing electrical insulation materials, floor and wall tiles, bricks, refractory products and sanitary articles; filler in paper, rubber, insecticides, cement, paint, leather, soap, toothpaste, textiles, fertilizers, deodorant powder and medicines.

2.3.3 Construction materials

Building industries require stones such as granite, limestone, marble, slate, sandstone, and many other rocks. Stones refer to rock used in blocks to construct building. Stone is removed from open pits called *quarries.*

Millions of tons of dimension and facing stones such as marble, sandstone and granite were used for making monuments and building facings in different parts of the globe. The utilization of polished rocks is employed in decorative purposes like flooring, sinks, table tops, interior wall paneling, name plates, etc. Besides being used as dimension stones, rocks are also needed in broken or crushed forms for the construction of concrete aggregate, road/ railway ballasts, etc.

2.4 Mineral based industries in the state

The most important mineral resource of Kerala, in terms of economic significance and size, is the extensive beach placer deposits of ilmenie-rutile-zircon-monazite-sillimanite-garnet, occurring in the coastal stretch of Kollam district.

Heavy mineral sands (placers) and residual china clay deposits constitute significant portion of mineral production in the State. Crystalline limestone is found at Walayar (Palakkad district). Though, Kerala state is deficient in high-grade limestone deposits, resources of limeshell occurring in the backwaters/estuaries, river mouths and lagoons along the coastal tract are wide spread. Now complete the table given below, on the mineral raw materials and associated industries that are functioning in our state.

Some mineral based industries in the state		
Name of industry	**Location in the state**	**Minerals used/ Extracted**
Indian Rare Earths Ltd.	Chavara, Kollam	Monazite, Ilmenite Rutile
Malabar Cements Ltd.	Walayar, Palakkad	Limestone (crystalline)
Travancore cements Ltd.	Kottayam	Limeshells
Kundara Ceramics Ltd.	Kundara, Kollam	Clays
Kerala Clays and Ceramic Products Ltd.	Pazhayangadi, Kannur	Clays
Excel Glass Industry	Alappuzha	Quartz sand

2.5 Identification of minerals

As you have learned in Class XI, minerals exhibit certain diagnostic properties called physical properties, which can be tested and observed, thereby leading to the identification of the mineral.

One of the keys for identifying minerals is observing a combination of physical properties displayed by the mineral. A description of these properties of some important ore minerals and industrial minerals is given in Table-1 & 2 of Appendix-III, at the end of the book. You have to go through the description of minerals shown in the table.

You will be provided with specimens of metallic and non-metallic minerals that are available in the Geology laboratory of your school. You have to identify the given mineral specimens, on the basis of their characteristic diagnostic properties. All the observations you have made related with the identification of the ore and industrial mineral specimens shall be entered in your *practical log book.*

Know your progress

1. What is the significance of beach placer deposits of Chavara in Kollam district of Kerala?
2. How can you distinguish galena from graphite?
3. List out some minerals and their applications in your daily life.

Let us conclude

Mineral deposits have supplied useful and valuable materials for human consumption long before they became objects of scientific curiosity or commercial exploitation. Most mineral deposits are natural concentrations or enrichment of original materials produced by different geological processes. This concentration is usually accomplished by various processes such as preferential crystallization from magmas, dissolution of the element by hot water (hydrothermal ore deposits) surface weathering and leaching, or gravity separation of minerals during erosion and so on. All mineral resources are nonrenewable and we use them up at a much faster rate than natural processes create them.

All precious and industrial metals, such as gold, silver copper, lead, zinc, tin, tungsten, nickel, chromium and others occur only in relatively lesser amounts. Some metallic minerals that are exploited in the industrial field are now present in limited quantities and in areas and may be depleted in just a few years' time, making recycling compulsory or finding suitable substitutes.

Let us assess

1. Ore deposits crystallized directly from magma are termed as -------- deposits.

   (Magmatic, Pegmatite, Metasomatic, Placer)
2. Bauxite is an example for ------------ deposits.

   (Placer, magmatic, metamorphic, residual)
3. Which of the following is a sedimentary deposit?

   (Disseminated diamond deposits, Veins, Banded iron formations, Pegmatites)
4. Define an ore. Give any two examples for ore minerals.
5. What is an evaporite? Give an example of a common evaporite mineral.
6. How are hydrothermal deposits formed?
7. Describe any two types of magmatic deposits.
8. Mention any two mineral deposits formed by metamorphic process.
9. What is meant by contact metasomatic deposits?
10. Distinguish between residual and placer deposits.
11. Mention any three industries that are functioning in our state and the minerals they use as raw materials.
12. List out any three industrial uses of clay.

Chapter 03

Fossil Fuels

Significant Learning Outcomes

After the completion of this chapter, the learner:

- Recognises the significance of fossil fuels as a non-renewable source of energy.
- Describes the origin and types of coal.
- Explains the processes involved in the formation of petroleum and natural gas.
- Makes an appraisal of the distribution of fossil fuels in India.
- Evaluates the environmental issues associated with the consumption of fossil fuels.

The Earth has provided mankind with number of energy resources, which man has been continuously utilizing since civilization came into existence. Every facet of human action, be it food production, transportation, health care, or other such activities, is dependent on one or the other form of energy.

The energy sources can be classified into renewable and non-renewable sources. The renewable energy resources include hydro-power, solar power, wind energy, geothermal energy, bio-fuels, biomass, ocean-wave energy, biogas, etc. On the other side, the non-renewable energy resources include the large and significant group called the *fossil fuels.* Fossil fuels are also one of the conventional energy sources.

We can simply conceive fossil fuels as fuels formed from fossils-remains of ancient plants and animals.These include coal, petroleum, natural gas, oil shale and tar sand. In this chapter we will be discussing about the different types of fossil fuels, their origin and distribution.

3.1 Coal

The term coal is generally applied to sedimentary formations of high carbonaceous character that are derived from vegetable matter. Coal, is a solid, usually brown or black, carbon-rich material that most often occurs in stratified sedimentary deposits. Coal is found in beds called *seams*, usually ranging in thickness from 0.5 to 3m, although some seams reach upto 30 m.

Coal is a major source of energy in the production of electrical power using steam generation. It is also used in the production of coke for metallurgical processes and as a chemical feedstock from which numerous synthetic compounds (e.g., dyes, oils, waxes, pharmaceuticals, and pesticides) can be derived.

3.1.1 Properties of Coal

Coal is composed chiefly of carbon with varying proportions of hydrogen, oxygen, nitrogen, and impurities such as sulphur, silt, clay etc. The *calorific value* is the amount of heat produced by the burning of a standard unit of coal. Ash comes from the included silt, clay, silica or other substances.

Moisture is an important property of coal, as all coals are mined wet. Volatile matter include the components of coal, except for moisture, which are liberated at high temperature in the absence of air. This is usually a mixture of short and long chain hydrocarbons, aromatic hydrocarbons and some sulfur.

The **fixed carbon** content of the coal is the carbon found in the material which is left after volatile materials are driven off. This differs from the ultimate carbon content of the coal because some carbon is lost in hydrocarbons with the volatiles. The *fuel ratio* is the ratio of fixed carbon to volatile matter.

3.1.2 Origin of coal

Coal is formed from the breakdown of buried vegetation. Rapid plant growth and deposition in water with low oxygen content are needed for the conversion of organic material into coal. How do the remains of plants transform into coal?

A swampy setting, in which plant growth is lush and where there is water to cover fallen trees, dead leaves, and other debris, is especially favourable to the initial stages of coal formation. The process requires anaerobic conditions, in which oxygen is absent or nearly so, since reaction with oxygen destroys the organic matter. The following steps are needed for the formation of coal.

(1) Accumulation of plant materials (source material) in suitable environment.

(2) Transformation of source material into coal.

Accumulation of plant materials

Most of the vegetation came from the primeval forests and swamps that flourished many millions of years ago. In the swamps thick forest grew and died in the water. Thick sediments or mud was washed in over the thick layers of dead trees. As millions of years went by the layers of buried forest were changed to coal.

There are two hypotheses regarding the accumulation of source material.

(i) *Growth in place or In-situ theory:*

The popular theory held by many geologists is that the plants which compose the coal were accumulated in large freshwater swamps or peat bogs during many thousands of years. According to this hypothesis, coal has resulted from the decay of vegetation matter *in situ*. The plant material from which coal deposits formed are grown at the same place they are found.

(ii) *Drift theory:*

The second theory which claims transportation of vegetable debris is called the drift theory. It suggests that coal deposits are thought to have formed by the drifted vegetable matter getting buried in a deltaic estuarine environment. The strata are believed to be accumulated from plants which had been rapidly transported and deposited under flood conditions.

Transformation of source material into coal

Plant matter is composed mainly of carbon, hydrogen, and oxygen and contains large amounts of water. During burial, rising pressure expels the water from the vegetable matter and chemical reactions release most of the hydrogen and oxygen, and the proportion of carbon increases.

Large quantities of coal formed worldwide during the Carboniferous Period, between 360 and 285 million years ago, and later in Cretaceous and Paleocene times, when warm, humid swamps covered broad areas of lowlying land. The perennially wet, tropical climate at that time was particularly conductive to coal formation. Leaves, stems, spores, tree trunks, branches, plant roots, resins, charred wood from swamp fires, other organic material, and mineral (inorganic) matter were deposited within the swampy basins.

Thick deposits of partially decomposed vegetal debris *(peat)* accumulated under the cover of stagnant water in these basins. Burial by sediments compresses the plant material, gradually driving out any water or other volatile compounds. Continued burial and the influence of the Earth's thermal gradient subjected the peat to pressure and heat. Eventually, the heat and various chemical and physical changes transformed the peat into other forms of coal.

The process of conversion of peat to coal is known as ***coalification.*** The general sequence of coalification is from peat to lignite, lignite to sub-bituminous to bituminous and to anthracite. All of these, more or less represent altered remains of land vegetation transformed by slow chemical changes (mainly the elimination of oxygen and hydrogen from the original woody tissue), into a material containing higher percentage of carbon.

As the plants die, they accumulate to first become peat. Compaction of the peat due to burial drives off volatile components like water and methane, producing a black- coloured organic-rich coal called lignite. Further compaction and heating results in a more carbon-rich coal called bituminous coal. If the rock becomes metamorphosed, a high grade coal called anthracite is produced.

A very high volume reduction occurs in the transformation of peat to coal. The coal changes from brown to black as the amount of carbon in it increases. The figure given below (Fig. 3.1) shows the graphical representation of the process of coal formation under the influence of pressure, temperature and time.

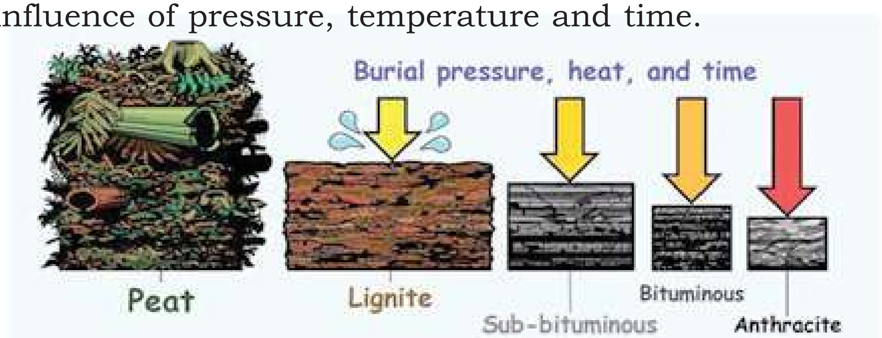


Fig. 3.1: Coalification process

It is the processes of coalification that determine the rank of coal. The rank of coal is defined by its position in the coalification series, i.e., peat-anthracite series, the peat being the lowest ranked coal followed by lignite, bituminous coal and anthracite.

3.1.3 Types or ranks of coal

Analyse the given table (Table 3.1) showing the composition of different varieties of coal. You will get an idea on variation in the amounts of carbon, oxygen, hydrogen, nitrogen, water and volatile matter during the alteration of wood into different varieties of coal.

Table 3.1: Composition of different types of coal

Type of coal	Carbon (%)	Oxygen (%)	Hydrogen (%)	Nitrogen (%)	Water (%)	Volatiles (%)
Wood	49.65	43.20	6.23	0.92	90-95	variable
Peat	55.44	35.56	6.28	1.72	35-95	40
Lignite	72.95	20.50	5.24	1.31	20	30-40
Bituminous coal	84.24	8.69	5.55	1.52	6-20	12-26
Anthracite	93.50	2.72	2.81	0.97	6	3-12

Note down the percentage of variation in the amounts of carbon. Lignite, the least altered variety of coal has large amounts of gaseous elements while anthracite, the most altered variety contains highest amount of carbon. The fuel ratio, the main factor in determining the rank of coal is high in anthracite and low in lignite. On the basis of the amount of fixed carbon content, coal can be broadly classified into the following varieties.

(a) Peat: Peat is regarded as the first stage in the evolution of coal from wood. It results from the accumulation of vegetable matter such as mosses and other bog plants. It consists of relatively less altered vegetable matter making the vegetable structure easily visible to even naked eye (Fig.3.2). When dry, peat can be burned as a fuel.

Fig.3.2 : Peat

(b) Lignite: The next type of coal ranked higher to peat is lignite. This consists of vegetable matter decomposed more than that in peat. This is commonly known as brown coal (Fig.3.3). It has an earthy appearance with brown streak. Lignites contain carbon below 70% and oxygen above 20%. Moisture content and volatile matter is less than that of peat.


Fig.3.3: Lignite

In India, lignite deposits occur in the Tertiary sediments in the southern and western parts of peninsular shield particularly in Tamil Nadu, Union territory of Pondicherry, Kerala, Gujarat, Rajasthan, West Bengal and Jammu and Kashmir. The Neyveli lignites that occur in the Cuddalore sandstones of Tamil Nadu are the most important lignite deposits of India. In Kerala lignite deposits occur at Madayi, Kayyur and Nileswaram.

(c) Bituminous Coal: It is also known as the coking coal or soft coal and is a hard brittle substance with no or very little vegetable matter (Fig 3.4). It is black in colour and has waxy appearance. Its carbon content is 80%. Bituminous coals are mostly of Palaeozoic age. These are harder than lignite and are coherent and banded.


Fig.3.4: Bituminous coal

Bituminous coals vary considerably in character, but they all burn with a smoky flame, and during combustion soften and swell similar to the fusion of pitch or bitumen. Bituminous coals form the major percentage of world's coal resources. Bituminous coals have a bright, pitchy lustre and there are different varieties based on their manner of burning. Accordingly bituminous coal is divided into two: Coking coal and non coking coal.

Coke is the name given to an agglomerated product or **cake,** obtained by heating powdered coal in a closed crucible i.e, in the absence of air. Bituminous coal is also called caking coal because it tends to cake together through exudation when burning. Coal suitable for coking must be bituminous and contain only a small proportion of sulphur and ash.

Jharia coal field of Jharkhand has been recognized as the store house of the best coking coal in the country. The coals of coking quality are also located in a number of coal fields in India, including the Bokaro coal field of Hazaribagh (Jharkand) and Raniganj coal field of West Bengal.

Coals that are high in moisture and volatiles are of non-coking type. The coals in Talchir coalfield (Orissa) and Singarani coal field (Khammam district, Andhra Pradesh) are examples of non-coking types.

(d) Anthracite: Anthracite is the highest rank of coal and hardest of all coals. They are black or brownish in colour and posses a brilliant or sub-metallic lustre (Fig.3.5). Anthracites break with a conchoidal or uneven fracture and have a black streak and do not soil the fingers. They have high carbon, low moisture and volatiles and their calorific value is high.

Fig.3.5: Anthracite

Anthracite burns with little flame and virtually no smoke. This explains its importance as a fuel in 'smokeless zones' and during its combustion gives out much heat.

Get a lump of peat and the same size of anthracite coal. Find out yourself which of them is easier to set on fire. Compare the differences in the amount of heat energy liberated from both the varieties of coal. Record your findings in your *activity log.*

Know your progress

1. Which type of coal has high calorific value?
2. Can you arrange the different types of coal according to their decreasing order of smoke emission?
3. How does the transformation of organic matter into coal take place?

3.2 Petroleum and natural gas

It is not known exactly when humankind first used petroleum. It is known, however, that ancient people worshipped sacred fires that were fuelled by natural gas seeping to the surface through pores and cracks. Asphalt, the very viscous form of petroleum, was used to waterproof boats and heat homes as early as 6,000 BC. Asphalt was also used as an embalming agent for mummies and in the construction of the Egyptian pyramids around 3,000 BC.

The oil we are concerned with here is derived from rocks within the Earth. It is called petroleum, a name taken from the Latin words meaning "rock oil" (Latin *petra* meanning rock and *oleum* meaning oil). Petroleum (or crude oil) is a complex, naturally occurring liquid mixture containing mostly of hydrocarbons, and some compounds of oxygen, nitrogen and sulphur. Petroleum is often referred to as the ***"black gold."*** The importance of petroleum to humankind took a giant leap in the late 1800's when it replaced coal as the primary fuel for the machines of the industrial revolution. After World War II, the huge oil reserves in the Middle East became available at a very low cost, and they rapidly revolutionized the way we live. Today, petroleum still remains our primary source of energy.

3.2.1 Chemical properties of petroleum and natural gas

Petroleum is a compound made up predominantly of atoms of hydrogen and carbon; thus the name **hydrocarbons.** Hydrocarbons can combine in various ways to form many different compounds. They can form solids, such as the asphalt that is used to pave roads; liquids such as conventional liquid petroleum, and gases such as natural gas. Natural gas is a mixture of hydrocarbons that are in a gaseous state at normal temperature and pressure.

Oil and gas, however, contain mostly two elements: **hydrogen** and **carbon**. How those elements are arranged determines the form of the **hydrocarbon**. For example, natural gas contains the simplest hydrocarbon, methane, while crude oils can be made up of more complex *liquid* and *solid* hydrocarbons. Natural gas consists mostly of methane, but also contains ethane, propane, butane and pentane, which are the simplest and lightest hydrocarbons.

3.2.2 Products of petroleum

The naturally occurring oil, in its 'crude' state is usually black or dark brown, but it can also be yellowish or even greenish. The term **crude oil** refers to oil in its "crude" or unrefined state, that is to say oil as it comes out of the ground which may be a mixture of various components, must be transported to a refinery to be separated into constituents such as petrol (gasoline), aviation fuel, fuel oil, etc. before it can be used by the consumer (Fig 3.6).

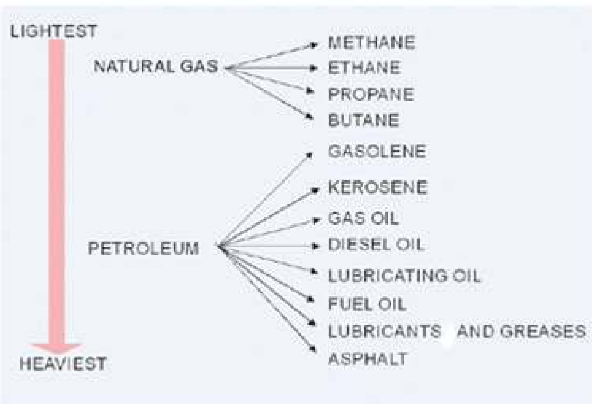


Fig 3.6: Petroleum and some of its components

Besides petrol and jet fuels, many other products such as diesel, heating oil, lubricants and asphalt also come from oil. The heavier the crude, the harder and more expensive it is to refine for use in products. At the refinery, crude oil is separated into "fractions" (its component parts) through **distillation**. Some of these fractions, through simple treating, are converted to final petroleum products at the refinery. Other refined products require further processing at chemical plants and factories showing up as final consumer products.

There are thousands of petroleum products in use today. Some of the more familiar ones are: solvent for paints, insecticides, medicines, synthetic fibres, enamel, detergents, weed killers and fertilizers, plastics, synthetic rubber, photographic film, candles, waxed paper, polish, ointments and creams, roofing, protective paints and so on.

Natural gas is a vapour, but it can be pressurized and cooled to become a liquid (LNG stands for liquid natural gas) for easier transportation. The vapour is colourless and odourless, but gas companies add a chemical to make it smell bad so leaks can be more easily detected. Natural gas is used to generate electricity; it is also used in the manufacture of plastics, fertilizers, fabrics and other products.

3.2.3 Formation of petroleum and natural gas

The oil and gas deposits started forming about 350 to 290 million years ago during the Carboniferous Period, which gets its name from the basic element present in oil and gas: carbon.

Oil and natural gas occur simultaneously and are originated from organic matter in marine sediments. It is believed that oil is formed from the soft bodies of microscopic organisms such as diatoms and single celled algae living in the sea. As these organisms died, billions of their bodies settled on the sea bed and accumulated in the marine mud.

Over geological time, this organic matter, mixed with mud, got buried under heavy layers of sediments. As burial continues, the organic matter begins to change. Pressure increases with the weight of overlying sediments. Temperature also increases with depth in the Earth. The gradual decay by the effect of heat and pressure resulted in the formation of hundreds of organic compounds. Heat from within the Earth cooked the mud's organic remains into a soup of hydrocarbons, the main element of petroleum and natural gas.

The high levels of heat and pressure caused the organic matter to chemically alter, first into a waxy material known as *kerogen* which is found in *oil shales*, and then with more heat into liquid and gaseous hydrocarbons.

The nature of hydrocarbons changes with temperature, pressure and time factors. In the early stages of formation of petroleum, the deposits consist mainly of larger hydrocarbon, which have nearly solid consistency of asphalt. As the petroleum matures, successively *lighter* hydrocarbons are produced. In the final stages of breakdown of organic molecules, simple, light, *gaseous* hydrocarbons-natural gas is formed.

3.2.4 Migration of oil and formation of oil pools

Because petroleum is a fluid, it is able to migrate through the Earth as it forms. Once the solid organic matter gets converted into liquid and gaseous hydrocarbons, they migrate out of the rocks in which they formed. The rock where the organic matter is converted into oil by burial and post depositional changes is called the **source rock.** The sedimentary rock in which oil originally forms is the source rock. The rock in which oil occurs at present is the 'reservoir rock' or oil pool.

Oil pools are valuable underground accumulations of oil. Petroleum reservoirs aren't underground pools as is commonly believed. They are actually rocks soaked in oil and gas, just as water is held in a sponge.

The movement of petroleum from the source rocks to a reservoir rock is termed **migration of petroleum.** The migration is controlled by the physical and physico-chemical conditions of the sedimentary strata through which the oil is moving.

In order to be collected into an economically valuable deposit, migration of oil or gas is necessary. Petroleum migrates slowly to a nearby layer of permeable rock -usually sandstone or limestone- where it can flow readily. Because petroleum is less dense than water or rock, it then rises through the permeable rock until it is trapped within the rock or escapes onto the Earth. The migration of petroleum continues as long as it does not encounter structural configurations where the reservoir strata form traps.

Factors controlling migration of oil

One of the main driving forces for migration of petroleum is sediment compaction due to overburden load. This is achieved by the reduction of pore spaces due to the expulsion of pore waters. During sediment compaction most of the pore water is expelled. With further burial, very little pore water remains for additional expulsion. As the muddy sediments compacted, the oil droplets and gas may have been squeezed out of the mud and moved into more porous and permeable sandy layers.

Another set of physical and physico-chemical conditions which exercise major control over the ability of petroleum to move through rocks are porosity and permeability. Porosity is the volume of void spaces as percentage of a given total volume of rock. Permeability characterizes the ability of fluids (water, oil and gas) to pass through porous rocks. Significantly higher porosities, permeabilities and pore sizes allow for the formation of oil droplets and small continuous oil stringers, i.e., a network of interconnected oil-filled pores.

Movement of oil occurs as a discrete oil phase controlled by the interplay of driving and counteracting resisting forces. The main driving force is buoyancy which is due to the density contrast between petroleum hydrocarbons and water. These density contrasts result in oil/water buoyancy gradients. Being lighter than oil, moving water can easily float and carry oil along with it.

The movement of petroleum through porous rocks is also influenced by capillary forces. The resisting force of capillary pressures counteracts the driving force of buoyancy. Capillary pressure is the pressure which oil or gas has to overcome in order to displace the water from the pores of the rock it is trying to penetrate. The capillary pressure of a rock increases with decreasing pore size. The petroleum compounds generated from kerogen have a very limited primary pore volume available for accumulation in fine-grained source rocks like shale and mudstones. They are forcefully transported through capillaries between the clay minerals and narrow pores towards contact with the nearest strata of higher porosity.

The specific conditions required for the formation of oil pools are:

(1) ***Source Rock:*** It is the rock where the organic matter is converted into oil by burial and post depositional changes.

(2) ***Reservoir Rock:*** It is a sufficiently porous and permeable rock to store and transmit the petroleum.

(3) ***Oil Trap:*** A cap rock or a set of conditions which hold the oil in the reservoir rock or prevent its migration.

Oil traps

The reservoir rocks often contained water, which then pushed the lighter oil and gas upward until they encounter an impermeable rock layer, such as mudstone or salt rock, which becomes a 'seal' or 'cap rock'. Obviously, in order to stay in the ground, the fluids- oil and associated gas, must be trapped, so that they cannot flow to the surface of the Earth.

An **oil trap** is a non-porous rock formation that holds the oil pool in place. The hydrocarbons (oil and gas) trapped and get accumulated in reservoir rocks such as the porous sandstone or limestone. Many oil traps form where impermeable cap rock prevents the petroleum from rising further. Oil or gas then accumulates in the trap as a petroleum reservoir.

Types of Traps

The Earth's tremendous forces can change the original form of the reservoir rocks, moving them up, down or sideways, and *folding* the layers into arches or troughs. These shifts can determine the type of trap in which the petroleum resides. A *fault* is a structural feature, where rock blocks have been displaced after fracturing. You will learn about in detail, the structural features such as folds and faults in the next chapter.

Folds and faults create several types of oil traps. A "fold" trap is formed when rock layers are pushed upward into an arch or "anticline (Fig.3.7)." The hydrocarbons move into the uppermost porous layer of the arch until they hit the impervious rock seal.

The contact between the oil-saturated and the water saturated pore spaces is always sharp and, in most cases, horizontal. This boundary is referred to as the oil/water-contact. A free gas phase will separate from the oil. Since gas has the highest buoyancy, it accumulates in the apex of the structure as a gas cap. The gas-oil contact is equally sharp and horizontal.

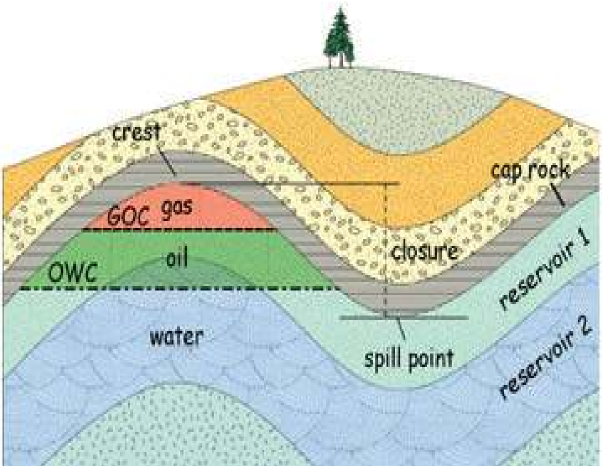


Fig. 3.7: Accumulation of oil and gas in anticlinal trap (GOC: Gas-oil contact; OWC: Oil-water contact)

Where oil and water occur together in folded rock beds, oil droplets being less dense than water, rise toward the top of the fold. There the oil may be trapped by impermeable layers overlying the reservoir rock. As shown in the above figure, oil traps consist of hydrocarbon fluids held in porous rock covered by a cap rock. The impervious rock covering the reservoir rocks is called a **cap rock.**

The natural gas being less dense than oil also collects at the top of the oil. The fluids and gases caught in the geological "traps" separate into three layers: water at the bottom, oil in the middle and natural gas on top.

In a "fault" trap, the reservoir rock is sealed off along a fault or fracture when Earth movements shift the impermeable rock layer over the reservoir rock (Fig. 3.8).

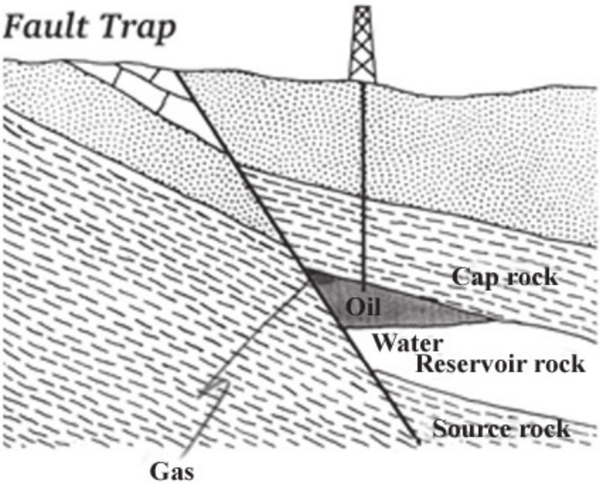


Fig. 3.8: Fault traps

Another kind of trap occurs when salt or some other non-porous material is pushed up by pressure from within the Earth to create a 'dome' (Fig.3.9). A salt dome results when a bed of rock salt is under pressure; the salt extends upward plastically through a sedimentary sequence, disrupting the sediments and creating open spaces that trap petroleum. The salt dome breaks through the layers and when it meets the reservoir rock it blocks the path of the hydrocarbons, which then accumulate around the salt pillar.

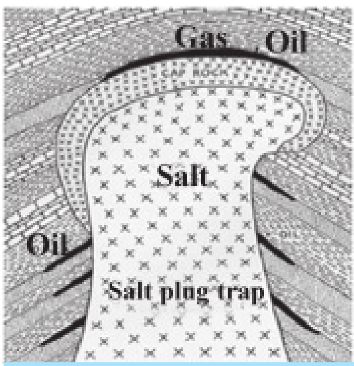


Fig.3.9: Salt plug trap

In fact, petroleum traps in nature are often a combination of different varieties of formations. In order for a trap to hold petroleum in place, it must be sealed by an impermeable cap rock. Cap rocks of most petroleum fields are fine-grained, clay-rich sediments like shales or mudstones. Due to their low permeabilities and very small-diameter pores, capillary entry pressures are so high that they cannot be overcome by the buoyancy of a high oil or gas column. The most ideal and best sealing cap rocks are, however, evaporite strata like anhydrite or rock salt. Such good-quality cap rocks hold many of the large petroleum accumulations in the Middle East petroleum deposit.

The combination of the above mentioned circumstances creates underground accumulations of oil (oil pools). ***Oil fields*** are regions underlain by one or more oil pools. Most oil and gas fields are buried anywhere from one to five kilometers under the Earth's surface, with the record well at nearly ten kilometre. Reservoirs under the ocean can be covered by as much as three kilometers of water on top. Oil and gas are generally trapped together, but sometimes they separate and form fields containing predominately one or the other. If a reservoir lies deeper than five kilometers, the liquid petroleum can become "overcooked," leaving only the natural gas.

3.2.5 Oil seepage

The cap rocks sometimes do not form perfect seals and petroleum escapes to the Earth's surface as natural seepage, which can be spotted by oily residue on the surface soil and rocks. Underwater seeps can bubble up to the surface and leave an oily shine.

The leakage of oil and gas from subsurface strata to the surface of the Earth occurs and has occurred continuously at many places both on land and on the ocean floor. Petroleum seeps occur where permeable pathways in the form of fractures or faults lead to the surface of the Earth either from mature source rocks or from leaking accumulations. Oil seeps include springs with oil bearing waters, tar pits and asphalt lakes. Like oil, gas seeps out at many places on the Earth's surface.

3.2.6 Distribution of petroleum

Petroleum is not distributed evenly around the world. More than half of the world's proven oil reserves are located in the Middle East (including Iran but not North Africa); that is to say, the Middle East contains more oil than the rest of the world combined. Following the Middle East are Canada and the United States, Latin America, Africa, and the region occupied by the former Soviet Union.

Most of India's crude oil reserves are located in the western coast (Mumbai High) and in the northeastern parts of the country. The important oil fields of India are Mumbai High of Maharashtra and Digboi of Assam, the former is an offshore oil field and the latter is an on-shore oil field. The onshore fields in Assam, Andhra Pradesh, and Gujarat states are also major producers of natural gas. The Krishna-Godavari Basin spread across more than 50,000 square kilometers in the Krishna River and Godavari River basins in Andhra Pradesh is known for the biggest natural gas deposits in India.

Now you have to collect information on the distribution of oil and natural gas in the country as well as their commercial production. Make a comparison between our commercial need and domestic supply of these conventional energy resources. Summarise your findings and make a presentation in the form of a *slide show* in the class.

3.3 Oil shale

Some shales and other sedimentary rocks contain a waxy, solid organic substance called kerogen. Kerogen is organic material that has not yet been converted to oil. Kerogen bearing rock is called oil shale. The rock, while always sedimentary, need not be a shale, and the hydrocarbon in it may not be oil. As already mentioned, the potential fuel in an oil shale is the waxy solid, kerogene, formed from the remains of plants, algae and bacteria.

The rock must be crushed and heated to distill out the fuel. If oil shale is mined and heated in the presence of water, the kerogen converts to petroleum.

3.4 Tar sand

Tar sands are sedimentary rocks containing a very thick, semisolid, tar like petroleum. These are tar (asphalt) cemented sand or sandstone deposits. Tar sands may represent very immature petroleum deposits. The breakdown of the larger molecules of hydrocarbons has not progressed to the production of the liquid and gaseous hydrocarbons. The tar is too thick to flow out of the rock and so the rock must be mined, crushed, and heated to extract petroleum, which can then be refined into various fuels.

Know your progress

1. What is the significance of trap rocks in the formation of an oil pool?
2. What are the major components of crude oil?
3. Why does oil migrate through porous and permeable rocks?

3.5 Significance of fossil fuels

Fossil fuels are non-renewable sources of energy. What this means is that, these natural sources are finite; there will come a time when we have used them up. The use of coal as a fuel predates recorded history. Coal was used to run furnaces for the melting of metal ore. Commercial exploitation of petroleum began in the 19^{th} century and its use is on the upward trend. Natural gas is a very valuable resource especially in the domestic sector.

Fossil fuels are consumed by man to a great extent, without which all developmental activities will be on a standstill. These fuels can be employed in internal combustion engines and in power stations. All forms of transportation including road ways, railways and aircraft required fossil fuels.

The uncontrolled utilization of these non-renewable natural resources has had its impact on mankind. The burning of fossil fuels releases large quantities of carbon dioxide (CO_2) into the atmosphere.

According to the Intergovernmental Panel on Climate Change (IPCC), there is substantial evidence that higher concentrations of CO_2 and other greenhouse gases have increased the mean temperature of the Earth since 1950. Because no known natural mechanism can explain such a rapid increase in CO_2, the inescapable conclusion is that burning of fossil fuels must be a primary reason for the observed increase in CO_2.

The CO_2 molecules allow the shorter-wavelength rays from the Sun to enter the atmosphere and strike the Earth's surface, but they do not allow much of the long-wave radiation reradiated from the surface to escape into space. The re-radiated energy, thus does not pass through the air envelop to outer space but is absorbed by the carbon dioxide and water vapour in the atmosphere; and adds to the heat that is already present. The CO_2 acts like a glass of a green house, and on a global scale, tends to warm up the lower atmosphere. Whereas the greenhouse effect is a naturally occurring process, its enhancement due to increased release of greenhouse gases (CO_2 and other gases, such as methane and ozone) is called global warming.

Alternative energy sources for the future are thus needed, both to supply essential energy and to repair the damage already done to our environment. We need to develop substitutes and renewable energy sources for the future in order to preserve nature and natural resources. The concept of sustainable development is very significant as far as the fossil fuel resources are concerned. The topic is discussed in more detail in the Chapter VI (Geology and Environment).

Let us conclude

Fossil fuels are formed by natural processes of anaerobic decomposition of buried dead organisms. The three major fossil fuels are coal, petroleum and natural gas. All represent the partially decayed and decomposed remains of living organisms. Most of the energy we use today comes from fossil fuels. But fossil fuels have a disadvantage in that they are non-renewable on a human time scale, and cause other potentially harmful effects on the environment. Known oil and natural gas supplies are likely to be exhausted within a few decades. Getting these resources out of the ground and ultimately to the consumer can create environmental problems anywhere along the line.

Let us assess

1. Fill in the blanks.

   (i) Fuels formed from remains of organisms are called --------.

   (ii) ------- is a combustible black or brown organic sedimentary rock.

   (iii) The process of conversion of peat into coal is known as ----------.

2. Complete the given table on the types of coal.

Type of coal	**Characteristics**
Peat	
Lignite	
Bituminous coal	
Anthracite	

3. Name the following

   (i) Ratio of fixed carbon to volatile matter in a coal.

   (ii) The highest grade of coal.

   (iii) Asphalt cemented sand deposits.

   (iv) Coal that burns with less amount of smoke.

4. Why do people depend on petroleum and natural gas for their energy requirements?

5. Mention any two coal fields of India.

6. What are the features that trap the migration of oil?

7. Define the following terms

   (i) Source rock

   (ii) Kerogen

   (ii) Migration of oil

8. Describe briefly the process of coalification.

Chapter

04 Geological Structures

Significant Learning Outcomes

After the completion of this chapter, the learner:

- Explains the meaning of linear and planar features exhibited by rocks.
- Measures the attitude of beds in terms of dip and strike.
- Demonstrates the basic concepts of rock deformation which results in secondary structures in rock masses.
- Recognizes important large scale structures such as folds, faults, joints and unconformities.
- Illustrates basic types of folds, faults, joints and unconformities.

Rocks of the Earth's crust are continuously bent, broken, uplifted or depressed in response to forces acting deep beneath the surface. A structural feature is a feature produced by deformation or displacement of rocks such as a fold or fault. For such features the more commonly used term 'structure' used as a specific noun has been long in use. The term structure is given for the general disposition, attitude, arrangement or relative positions of the rock masses of a region or area. The branch of geology that deals with the form, arrangement and internal structure of the rocks, is known as structural geology. Geologic structures are important in shaping the various landscapes of the Earth's surface. This chapter discusses the forces that cause structures and the kinds of structures exhibited by rocks.

4.1 Geometrical elements in rock structures

Rocks are the building blocks of Earth. You can observe different kinds of rocks that vary in size, shape, colour and in other features. Have you ever observed a rocky land bare of vegetation? An exposure of bedrock on the Earth's surface is referred to as **outcrop**. Have you noticed any kind of structural features displayed on rock outcrops? How can you communicate information about the orientation of geologic structures you have noticed?

The term *attitude* is applied for orientation of a geometric element in space. You will learn about the general method of expressing attitude of rock bodies and geological surfaces in the subsequent section of this chapter. In order to understand the position of a structure in space, some geometrical elements such as points, lines, planes or combinations of these are generally used in geology.

4.1.1 Linear and planar structures

Structural features are either **linear** or **planar** in nature. The arrangement of any geological feature in a linear fashion gives rise to a **linear structure**. Some minerals such as kyanite and amphibole, grow such that they are very long in one direction relative to the other two directions. If the long axes of the crystals are aligned in a rock, they create a mineral lineation. Parallel arrangement of elongated minerals in a lava flow (flow lines) is another example. These structures resemble a line rather than a plane.

Planar structure in rocks can occur as a result of the arrangement of mineral grains of different sizes, colour, composition, and so on in *layers*. Parallel orientation of plate-like minerals (clays and micas in a slate), or segregation of light and dark minerals into contrasting layers, imparting a banded appearance (in gneiss), constitute a foliation. We call these structures planar because they resemble the geometric shape known as a plane.

Pebbles in a metamorphosed conglomerate can have a lineation (when stretched in one direction only as shown in the figure 4.1 below),but they can also have a foliation when simply flattened. Planar surfaces are also produced by structural deformation of rocks (such as joints, faults and folds or by other means). You will learn about these in detail.

Fig. 4.1: Stretched pebbles in metamorphosed conglomerate showing lineation

In nature, any intersection of two planar features will produce a linear feature. Analyze the given figures (Fig. 4.2 a and b) and note down the formation of a line when two horizontal surfaces meet.

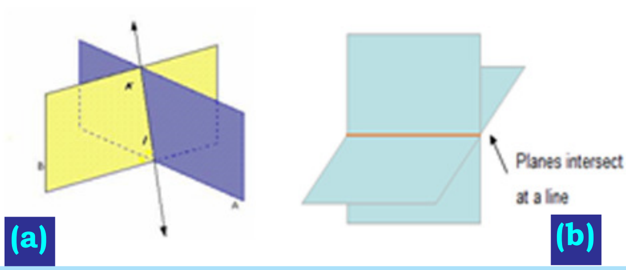


Fig. 4.2 a & b: Intersection of two planar features producing a linear feature

4.1.2 Attitude

The term *attitude* denotes the position of a structural surface relative to the horizontal. The term is also applied for the orientation of a planar or linear feature in three-dimensional space. To describe the orientation of a geologic structure, geologists consider the structure as a simple geometric shape, and then specify the angles that the shape makes with respect to a horizontal plane, a vertical plane and a geographic direction. The attitude of any structural surface (e.g. a tilted succession of strata), is expressed quantitatively by **strike** and **dip** measurements. A planar structure's orientation can be specified by its strike and dip, while in the case of linear features, their attitude is described in terms of **trend** and **plunge** of the feature.

Strike and Dip

At an outcrop, the strike and dip describe the orientations of bedding planes, fault planes, joints, and other planar features in the rock. Consider an inclined structural feature (such as a portion of a roof shown in Fig. 4.3).

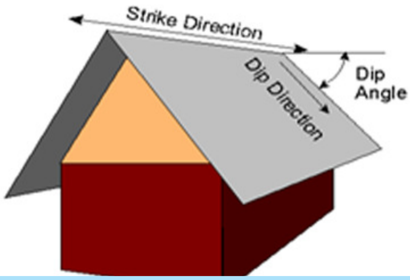


Fig. 4.3: Portion of a roof depicting the concept of strike and dip

Note that, strike is the direction of the line formed between the intersections of a horizontal plane with any inclined plane. The term **strike** is used to denote the *direction* or *trend* that a structural surface (e.g. a bedding or fault plane), makes as it intersects an imaginary horizontal plane (Fig. 4.4).

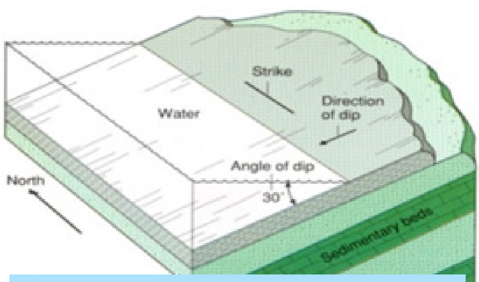


Fig. 4.4: Strike and dip of sedimentary strata

The strike (or **strike line**) is formed by the intersection of two planar surfaces among which, one is always a horizontal surface (shown as the surface of water in the figure given above) and the other is a planar surface of different attitude. The strike in this case is described in terms of direction such as North. Note that a geological feature may strike in any geographic direction, viz., east, west, north or south, or in any conceivable direction in between.

Carefully study the above figure 4.4 and try to understand the concept of strike. The water provides a necessary reference to a horizontal plane. The trend of the waterline along the bedding plane is the direction of strike. The angle between the bedding plane and the water surface is the angle of dip.

Dip

We can also measure the inclination of a non-horizontal surface. The term **dip** denotes the angle that a structural surface makes with the horizontal, measured in a vertical plane that is perpendicular to (or normal to) the strike of the structure. Therefore, the value of the angle of inclination or dip of a structural surface may range between 0° to 90°. The inclination of a linear feature (which is one dimensional) is expressed by the term **plunge**. Dip of any geological feature is always expressed in terms of its angle and its direction. A geological or structural feature may dip in any geographic direction. Suppose, a bed has an inclination of 30° with the horizontal plane towards west, as shown in the Fig. 4.4, then its dip is expressed as '30° west'. Here the angle '30°' is the dip amount and 'west' indicates the direction of dip.

True dip and apparent dip

Now let us learn a little more about the term dip. We have learned that the 'dip' is the angle between an inclined surface and an imaginary horizontal plane *measured in a vertical plane normal to the strike of the surface.* The inclination of a structural feature (such as a bed) will be the maximum in a direction perpendicular to the strike and the inclination measured is termed **true dip** (Fig.4.5). The inclination of any surface will gradually decrease on either side of the true dip direction. This is because the directions are not exactly perpendicular to the strike line. Inclination of bed (or any structural feature) measured along a direction other than the true dip direction is termed **apparent dip.** Note that the values of apparent dip for any inclined surface are always less than that of true dip of that surface and in the direction of the strike the apparent dip value will be zero.

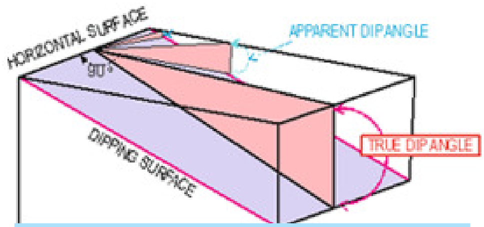


Fig. 4.5: True dip and apparent dip

Measurement of Strike and Dip

In the field, the attitude of geological features (strike and dip) is measured using a clinometer compass or with a little more sophisticated instrument called Brunton Compass. **Clinometer Compass** (Fig. 4.6) is an instrument used in geological mapping. The compass enables one to determine dip and strike of rock beds or other geological features.


Fig. 4.6: Clinometer compass

Geologists frequently use another instrument called **Brunton Compass** to measure strike and dip. The various parts of the standard Brunton compass are shown in Figure 4.7. When using the compass to determine the attitude of a plane the edge of the compass is placed against the inclined surface and then the bulls-eye bubble is centered. In this configuration the compass lies in a horizontal plane and its edge is parallel to the line produced by the intersection of the imaginary

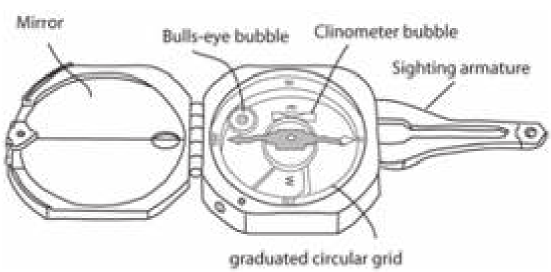
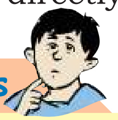


Fig. 4.7: Brunton Compass

horizontal plane and the inclined surface or layer. The sighting armature points in the direction that this line is oriented, and this direction is read directly off the compass.



Know your progress

1. How is the strike direction related with the true dip direction?
2. When we measure attitudes of planar features, how can we determine the direction and amount of dip?
3. Would you consider foliation as a planar feature? Why?

4.2 Rock deformation

A block of rock changes location when it moves from one location to another. It changes orientation when it tilts or rotates around an axis. It changes shape when its dimensions change. Rock beds no longer have the same shape and position that they had when first formed.

To learn about rock deformation, an understanding of the concept of **stress** and **strain** is essential. *The force exerted on a material object is termed stress and the term strain denotes the change in shape or volume of a body as a result of stress imposed on it.*

All of Earth's rocks are under some type of stress, but in many situations the stress is equal in all directions (confining stress) and the rocks are not deformed. However, the magnitude of stress is not always the same in all directions and rocks experience differential stress. Differential stress means that the push or pull in one direction differs in magnitude from the push or pull in another direction. As a result, the rocks yield to the unequal stress and deform by changing shape or position. Strains are changes in the volumes or shapes of rocks resulting from stress.

4.2.1 Types of stress

There are several types of stress that deform rocks. The figure 4.8, given below shows the different types of stresses that are acting on a rock body.

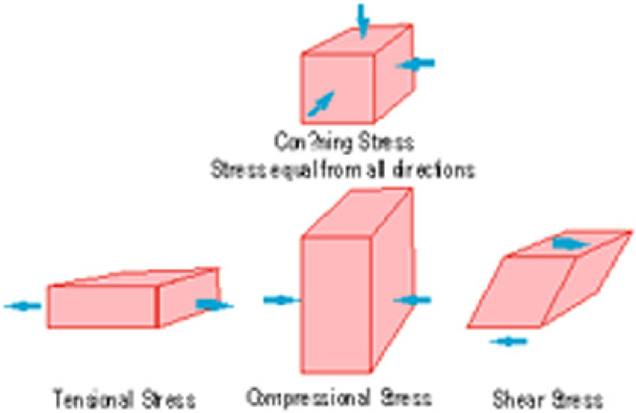


Fig. 4.8: Different types of stresses

Tension is the stress on rocks that are being pulled apart. If you stretch a rubber band you are applying tension to it. **Compression** pushes rocks together, which is the opposite of tension. **Shear stress** pushes rocks horizontally past each other in two opposite directions.

Strain refers to the change in shape that deformation brings. If a layer of rock becomes longer, it has undergone *stretching,* but if the layer becomes shorter, it has undergone *shortening.* Tensional stress results in a stretching or extensional strain while, compressive stress results in rocks being deformed by a shortening strain. If a change in shape involves the movement of one part of a rock body past another, the result is *shear strain.* Shear stresses result in a shear strain parallel to the direction of the stress.

Strain is a complex phenomenon, which passes through different stages in a same body under the application of stress. With increasing stresses, the rock body passes through *three successive stages of deformation.* For a better understanding of the behavior of rocks in response to stress, we have to identify these three stages of deformation.

4.2.2 Stages of deformation

Stresses are forces that deform rocks. The figure 4.9 given below represents the different stages of deformation.

a) Elastic Deformation: This is a type of deformation in which *temporary* changes in shape or size of the rock occurs. The *deformed object resumes its original shape and size when the deforming force is removed.* Here the strain is reversible. It is like squeezing of a piece of rubber, pulling of elastic materials, etc.

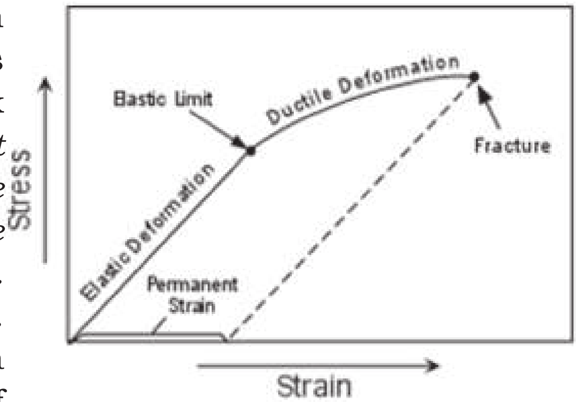


Fig. 4.9: Different stages of deformation

b) Ductile Deformation or plastic deformation: With increasing intensity of deformation, a material crosses the **elastic limit** and enters a stage called ductile or plastic deformation. In this stage *permanent* change in shape or volume of the material occurs without any rupture (fracturing). A material (including rocks) does not recover original shape when the deforming force is released. So the strain is irreversible. An example of ductile deformation is the permanent bending of a metal rod or bending of rock layers resulting in the formation of folds. (Folds, which we will learn later are the best examples of ductile or plastic deformation of rock layers).

c) Fracture or Rupture: As the applied force is increased further a material (including rocks) undergoes no further change and it suddenly breaks. It is also an irreversible strain as in the case of the ductile deformation. Fracturing of rocks is a common feature observable on surface rocks. Faults and joints are best examples representing this stage of rock deformation in nature. Depending on their relative behavior under stress, we can classify materials into two classes: (a)Brittle materials and (b) Ductile materials.

- **Brittle materials:** Materials which pass suddenly to the stage of fracture without the intermediate ductile deformation. E.g., glass and several minerals such as quartz, feldspar etc;

- Ductile materials: Materials having a small region of elastic response and a large region of ductile behavior before they fracture. E.g., clay and metals (such as copper, gold and silver) plastic materials etc.

Some rocks are naturally brittle and some rocks are naturally ductile. A rock that is brittle in shallow depths can be ductile at greater depths.

Know your progress

1. Compare tensional stress with compressional stress.
2. Rocks change their shape or volume in response to differential stresses. How do the brittle materials differ from ductile materials?
3. How does the process of rock deformation result in the development of structural features?

4.3 Structural features in rocks

You have learnt that stress is the push, pull or shear that acts on a material. The resulting change in shape in response to the application of stress is called strain. The process by which rocks stretch, bend or break in response to strain is referred to as deformation. Rock deformation produces geologic structures. Geologists classify the rock structures under any of the following two types:

(i) Primary structures: Structures which develop during the formation of a rock are called primary structures. Bedding or stratification in sedimentary rocks and flowlines (linear arrangement of elongated minerals) in igneous rocks are examples of primary structures.

(ii) Secondary structures: Structures which develop after the formation of rocks are termed as secondary structures. They are actually the modifications of the original shape and arrangement leading to the formation of new structures. Folds, faults, joints and unconformities are typical examples of secondary structures.

Let us learn some important structural features exhibited by rocks in the following section of the chapter

4.3.1 Bedding (Stratification)

The term **bed** is a subdivision of a stratified sequence of rocks, internally composed of relatively homogeneous material exhibiting some degree of lithological unity, and separated from the rocks above and below by visually or physically more or less well-defined boundary planes. The term is used primarily for a sedimentary unit, but has been applied to a metamorphic derivative of a sedimentary bed, to a layer of pyroclasts (e.g. ash bed), to an individual lava flow in a sequence, and to a structurally defined layer in an igneous intrusion. The thinnest or smallest recognizable unit layer in a sedimentary succession is called a **lamina.** Beds may vary widely in thickness and may occur in horizontal, vertical or inclined positions. **Bedding** is defined as the arrangemen t of a sedimen tary rock in beds or layers of varying thickness and character (Fig. 4.10).

Fig. 4.10: Bedding or stratification

The term **stratum** (pl. strata) is applied for a tabular or sheet-like mass or a single or distinct layer of homogeneous or gradational sedimentary material of any thickness, visually separable from other layers above and below with respect to grain size, colour, composition and so on. Thus the term 'stratum' is a synonym of the term 'bed'. The formation, accumulation or deposition of Earth materials in layers is termed **stratification** in geology. In other words, it is the arrangement or deposition of sedimentary rocks in the form of strata.

4.3.2 Folds

Folds are one of the most common geological structures that are found in rocks of the Earth's crust. A **fold** can be defined as a curve or bend of a planar surface, such as rock strata, bedding plane, etc. A fold is usually a product of plastic or ductile deformation. These curved planar structures are formed due to compressive forces

Fig. 4.11: Folds in rocks

Folds occur in all scales varying from few millimeters to kilometers in size. They are common structural features of mountainous region. The process of development of folds in a rock is called **folding.** It is a very slow process.

Parts of a fold

Some geometrical features and associated terms related with folds are given below (Fig. 4.12).

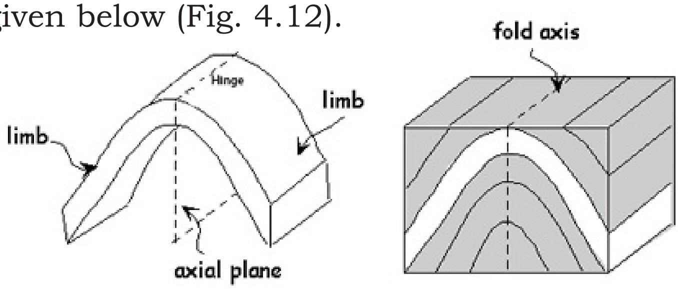


Fig. 4.12: Parts of a fold

Axial plane: The axial plane of a fold is the plane or surface that divides the fold as symmetrical as possible. Depending on the attitude of the fold, the axial plane may be vertical, horizontal, or inclined at any intermediate angle. Attitude of an axial plane is also defined by its dip and strike. In nature, the axial planes of folds need not be always a planar surface (i.e., it may be curvi-planar, i.e., a curved plane about one or more axes).

Fold axis: An axis of a fold is an imaginary line formed by the intersection of the axial plane with any folded layer or one of the strata of which the fold is composed. Although in the simpler types of folds the axis is horizontal or gently inclined, it may be steeply inclined or even vertical. When the axis is not horizontal, the angle of inclination of the axis, as measured from its departure from the horizontal, is called its **plunge.**

Limbs or Flanks: The portions of the fold between adjacent axes form the flanks, limbs, or slopes of a fold. A fold has two limbs. The limbs may have inclined vertical or horizontal orientations. Fold limbs may dip in the same direction or in opposite directions. The attitude of a fold limb is also expressed in terms of its dip and strike.

Hinge and hinge line: In a cross section of a fold, the point of maximum curvature or bending of a folded surface is called the **hinge** of the fold. The hinge of any fold is a linear feature. **Hinge line** is an imaginary line connecting the hinges of the folded surface. Hinge lines of folds can be inclined, vertical or horizontal, depending on the attitude of the folded surface.

Types of folds

Folds can be classified in a number of ways.

Anticline and Syncline: An anticline is a convex upward fold with a core of older rocks (Fig. 4.13 a and b). A syncline is a convex downward fold, with a core of younger rocks (Fig. 4.14 a and b).

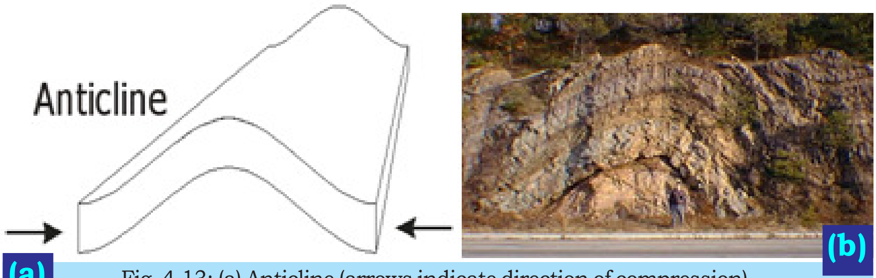


Fig. 4.13: (a) Anticline (arrows indicate direction of compression),
(b) A natural anticline

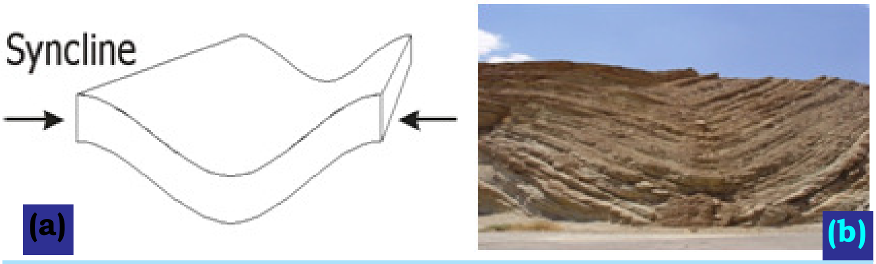


Fig. 4.14: (a) Syncline (arrows indicate direction of compression),
(b) A natural syncline

Limbs of an anticline dip away from the crest of the fold while those of a syncline dip towards the crest of the fold (Fig. 4.15).

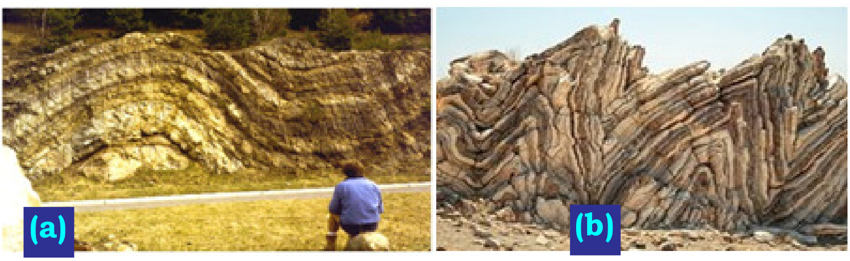


Fig. 4.15: Exposures of fold showing both anticline and syncline

Geologically older rocks occupy the inner portions of the anticlines whereas in a syncline younger rocks occupy the core of the fold. Both anticlines and synclines are produced by compressional stress.

Symmetrical, Asymmetrical and Overturned folds: A symmetrical fold is one in which the axial plane is vertical. An asymmetrical fold is one in which the axial plane is inclined. An overturned fold is one in which limbs dip in the same direction. This implies that the axial plane is inclined to such an extent that the strata on one limb are tilted beyond the perpendicular or overturned (Fig. 4.16).

Fig. 4.16: (a) Symmetrical fold, (b) Asymmetrical fold, (c) Overturned fold

Recumbent fold: Arecumbent fold has an essentially horizontal or sub-horizontal axial plane (Fig. 4.17).

Fig. 4.17 (a) and (b): Recumbent folds

Isoclinal fold: 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 an isoclinal fold (Fig. 4.18).

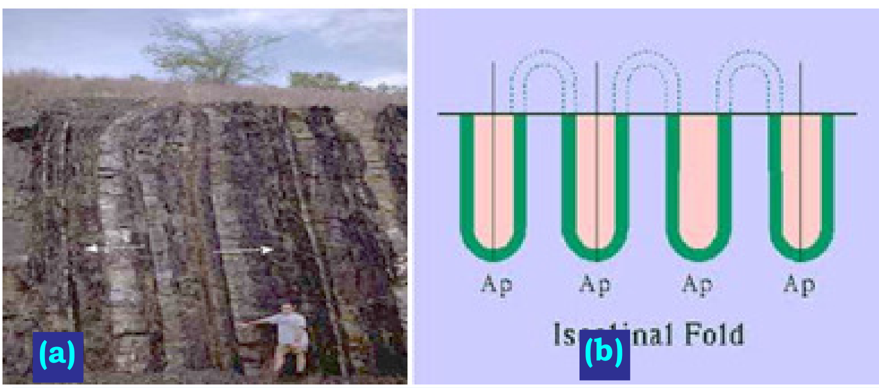


Fig. 4.18 (a) and (b): Isoclinal folds

Symmetrical, asymmetrical, overturned and recumbent folds develop with increasing intensity of deformation of beds (Fig. 4.19).

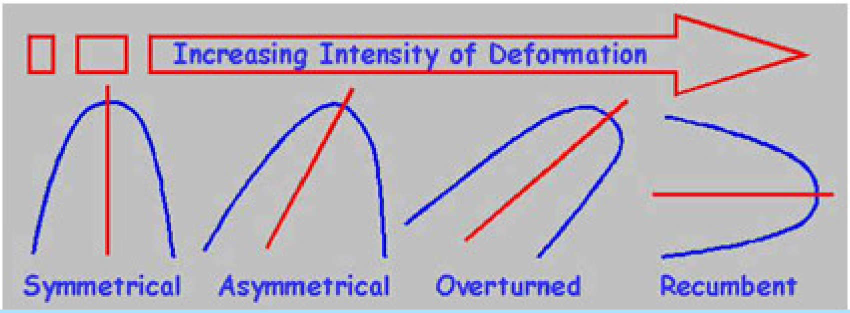


Fig. 4.19: Development of different types of fold with increasing intensity of deformation

Domes and basins

Many folds are distinctly linear; that is, their extent parallel to the axis is many times their width. Some folds, however, are not linear but are more or less circular in plan. Domes are upward arched circular folds. When domes are eroded, the oldest rocks are in the centre of the dome structure (Fig. 4.20).

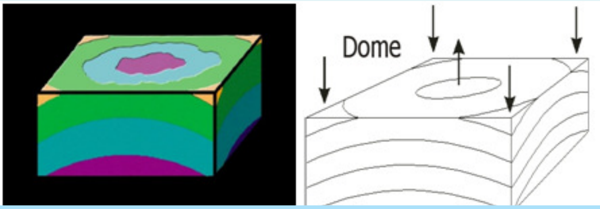


Fig. 4.20: Dome

Domes resemble anticlines, but the beds dip uniformly in all directions away from the center of the structure. Domes are caused by compression and uplift. Basins resemble synclines, but the beds dip uniformly in all directions toward the center of the structure (Fig.4.21). Basins are caused by compression and down warping. Basins are circular features that arch downward. When basins are eroded, the youngest rocks are in the centre of the basin structure.

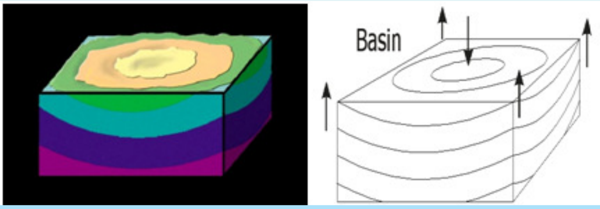


Fig. 4.21: Basin

Identification and analyzing of folds have great importance in geology. Folds are the major locations which control the formation of minerals and metals of high economic value. Mineral deposits may be indicated at or near the surface by anticlines. Folds form potential traps for petroleum and natural gas. Synclinal folds form storage for large quantity of water and also provide artesian condition. Identification of folds are very significant in the construction of dams, tunnels, etc.,

4.3.3 Faults

During brittle deformation, rocks break or fracture. A **fault** is a surface or zone of rock fracture along which there has been displacement, from a few centimetres to a few kilometres in scale. In other words, those fractures along which relative movement of blocks has taken place are called **faults** (Fig. 4.22). The process of development of fracture and relative displacement in rocks is known as faulting.

Fig. 4.22: Examples of faults

Parts of a fault

Fault plane: The term **fault surface** is applied for the surface along which displacement has occurred and **fault plane** is applied for a fault surface that is more or less planar. It may be smooth or rough and have inclined, vertical or horizontal positions.

Wall: The rock mass on a particular side of a fault (*e.g.hanging wall and footwall).*

Footwall and hanging wall: In faults which have inclined fault plane, the term footwall refers to the underlying side of a fault while hanging wall refers to the overlying side of a fault. Normally, in cross sections of faults, one block is seen resting over the other block and this block is known as the **hanging wall** and the underlying block is known as the **foot wall.** The Fig. 4.23 shows the side view of a fault with a mine tunnel dug through the fault and a miner standing. The wall on which the miner places his feet came to be called the "footwall", and the wall on which he hangs his lamp thus termed the "hanging wall".

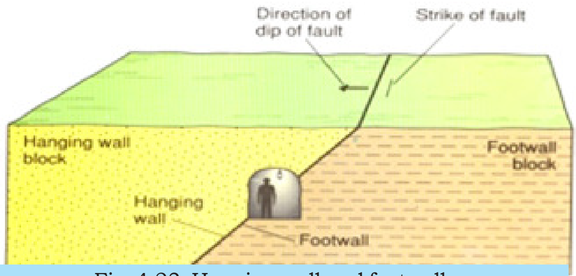


Fig. 4.23: Hanging wall and footwall

Fault zones

When the fault plane is not a smooth surface and contains small fractures, it is termed a ***fault zone*** *or* ***shear zone.*** *It is expressed as a zone of numerous small fractures or of fault breccias or fault gouge. (Fault breccia is a rock composed of angular fragments resulting from crushing, shattering or shearing of rocks during movement on a fault, from friction between the walls of a fault. Fault gouge is a soft, uncemented, pulverized, clayey or clay-like material, filling or partly filling a fault zone)*

Common types of faults

Faults are fractures (cracks) in rocks along which movement has occurred. Displacement of blocks may take place in any direction, parallel, inclined and rotational. Faults are classified according to the direction towards which the blocks of rocks moved along the fault plane into the following types: normal faults, reverse faults, thrust faults, and strike-slip faults.

Normal Faults: A fault in which the hanging wall appears to have moved downward relative to the footwall is called a normal fault. Fig. 4.24 represents a block of rock mass before and after faulting that resulted in a normal fault. The fault plane is the surface on which movement occurs and the footwall of the fault (where your feet would be if you stood on the fault plane) appears to have remained stationary while the hanging wall appears to have moved down relative to the footwall.

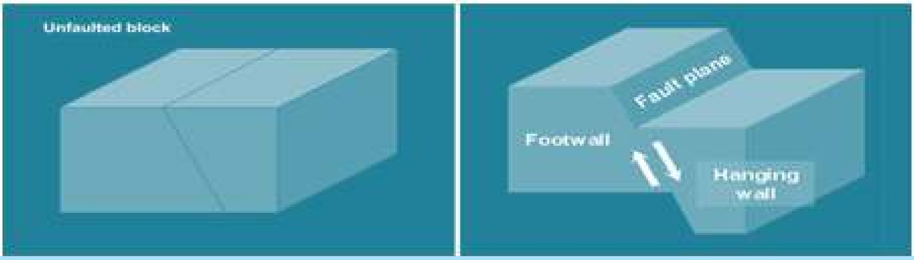


Fig. 4.24: Normal fault showing the relative downward movement of hanging wall

Normal faults are caused by tensional stress, or stress that pulls rocks apart. In the diagram (Fig.4. 25) given below, the right side of the fault is the hanging wall which has moved down relative to the left side.

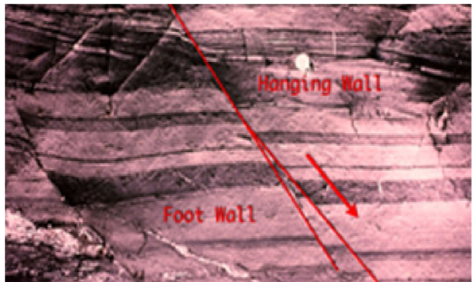


Fig.4.25: A normal fault

Reverse Faults: A fault in which the hanging wall appears to have moved upward relative to the footwall is called a reverse fault. Reverse faults are caused by compressional stress, or stress that pushes rocks together. The reverse fault shown in Fig. 4.26 below is in a gray limestone. In this fault, the hanging wall block has moved up relative to the shale rocks of the footwall.

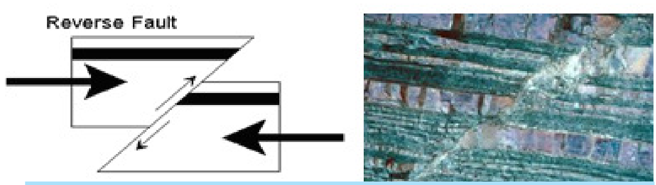


Fig. 4.26: Compression and reverse faulting

Thrust Faults

If the angle of the fault plane of a reverse fault is low (<30°), the fault is called a thrust fault (Fig. 4.27).

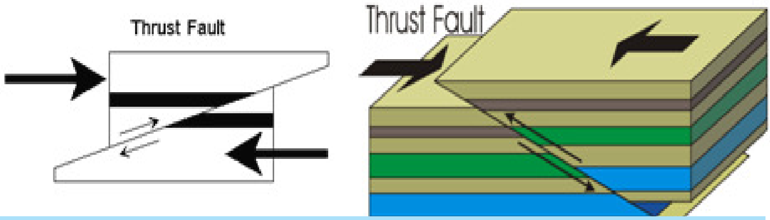


Fig. 4.27: Thrust fault

A thrust fault is a special type of reverse fault because it has a low angle. Thrust faults are also the result of extreme compressional stress.

Strike-slip Fault: A fault in which the actual movement of the blocks is parallel to the strike of the fault is called a strike slip fault. These result from shearing (Fig. 4.28).

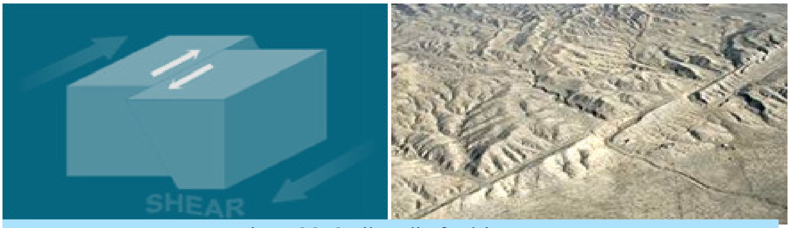


Fig. 4.28: Strike-slip faulting

Horst and Graben: Horsts are upthrown blocks bounded on either side by non-parallel normal faults and grabens are downthrown blocks bounded on either side by non-parallel normal faults (Fig. 4.29).

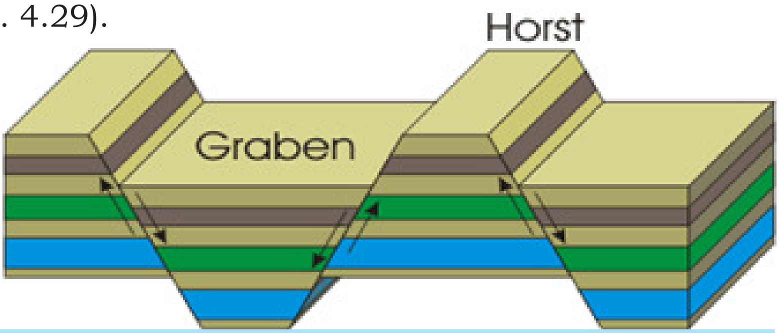


Fig. 4.29: Horst and Graben

Sometimes blocks forming horsts may be very high (2000 to 4000 meters) and extensive and then they constitute **block mountains.**

Faults are important for groundwater storage and movement, they create surfaces along which fluids such as oil or water can travel. Faults also cause hazards such as rock slides and earthquakes. Faults provide potential surfaces along which rocks can slide. If faults move suddenly, they generate earthquakes.

You have learnt some basic types of fold and fault. Now, draw cross sections of each of the following geologic structures in your *activity log.*

(i) Anticline, syncline, isoclinal and overturned folds.

(ii) Normal and reverse faults.

Mention the kind of overall stress field viz., compression, tension or shear that produced the different types of folds and faults. Show the direction of motion of both the hanging and footwall blocks using arrows.

Know your progress

1. Identify the folds mentioned below.
   (a) Folds in which each half of the fold dips toward the trough of the fold.
   (b) Folds in which each half of the fold dips away from the crest.
   (c) Low angle reverse faults.
2. When a rock has undergone plastic deformation, either it can bend or break with displacement of masses. What is the name for:
   (a) Rock structure resulting from bending of rock?
   (b) Rock structure due to breaking with displacement?
3. How does faulting result in the formation of horst and graben?

4.3.4 Joints

Joints are fracture surfaces or planar discontinuities in rocks involving no relative displacement of the adjacent blocks. These are perhaps the most common structural features exhibited by rocks (Fig. 4.30). Joints can form from compressional, tensional and shear stresses. The length of joints varies considerably and can range in size from microscopic to kilometers in length. Joints may have any orientation or attitude, some joints are vertical, others are horizontal, and many are inclined at various angles. The strike and dip of joints are measured in the same way as that for bedding.

Fig. 4.30: Joints in rocks

Joints develop during the exhumation or exposure of rocks following erosion of the overburden. The joints also result from contraction and expansion due to cooling and decompression respectively. Multiple sets of joints that intersect at angles ranging from 45° to 90° are very common. They divide rock bodies into large, roughly rectangular blocks. A joint set is a group of two or more joint surfaces trending in the same direction with almost the same dip. Each set probably formed at a different time and under a different stress orientation. Long planar cracks that occur almost regularly throughout a rock body can be considered as **systematic joints.**

Types of Joints

Joints occur in almost all types of rocks, whether it is igneous rocks, sedimentary rocks or metamorphic rocks. Columnar joints and sheet joints are two common types of regular or systematic joints that are very prominent worldwide.

Columnar joints: Columnar joints or prismatic joints divide the rock mass into polygonal blocks, each block bounded by three to eight sides. Five and six sided blocks are common. The resulting columnar structure consists of long hexagonal blocks (Fig. 4.31) closely packed together. The columns may extend to varying depths ranging from a few centimeters to many meters.

Fig. 4.31: Hexagonal pattern of outcrop in columnar joints

These joints are typical of volcanic igneous rocks like basalts. The polygonal cracks are thought to be directly developed during cooling related to the tensile forces (accompanied by con traction) of the hot molten material (lava or magma). You may have seen polygonal cracks developed in the dry paddy field by contraction of mud during extreme summer season (Fig. 4.32).

Fig. 4.32: Polygonal cracks developed in dry paddy fields during extreme summer season

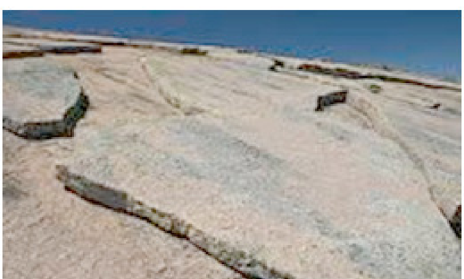


Fig. 4.33: Sheet joint in granite

Sheet joints: These joints are generally seen in granites and other related igneous rocks as well as in some sedimentary rocks. They develop in sets and are more or less parallel to the surface of the ground. A horizontal set of joints often divides the rock mass in such a way that it gives the appearance of a layered sedimentary structure (Fig. 4.33).

Joints are important because they create open spaces in rock in which water, oil, or natural gas can move or be stored. Joints also provide potential surfaces along which rocks can slide. Quarry operations, especially those involved in obtaining blocks of certain dimensions and sizes are obviously greatly influenced by the joints. Best examples are the breaking of granites, sandstones, slates, etc. in their respective quarries. In civil engineering projects such as construction of tunnels, highways, dams, reservoirs or multi-structures and high-rise buildings, the orientation and concentration of joints are very significant.

4.3.5 Unconformities

The term *'unconformable'* is employed in geology to denote younger strata or beds that do not 'conform' in stratigraphic position (i.e., not succeeding the underlying rocks in immediate order of age). An **unconformity** is a surface of erosion or non-deposition occurring within a sequence of rocks and that separates younger strata from older rocks.

From the perspective of historical geology,unconformities are substantial breaks or gaps in geologic record (generally termed hiatus). The formation of an unconformity may be attributed to three main processes like erosion, deposition and tectonic activity. Unconformities result from a change that caused deposition to cease for a considerable span of time, and it normally implies uplift and erosion with loss of some of the previously formed rock record in the locality. Therefore, unconformities mark an interruption in the continuity of a depositional sequence of sedimentary rocks or a break between an eroded igneous or metamorphic rock and younger sedimentary strata. Most unconformities are typically buried erosional surfaces.

Since unconformities indicate a gap or interval of time in the geological history of the area during which the normal process of deposition was interrupted, these represent a break in the geologic record (a period of non deposition or erosion) which may in some cases extend hundreds of millions of years or more. An unconformity is therefore, a plane of discontinuity that separates two rocks, which differ notably in their ages. It is a structural feature in the sense that the rock formations lying above and below it generally represent different conditions under which they have been formed.

Types of unconformities

The main types of unconformities are (1) Angular unconformity, (2) Parallel unconformity or Disconformity and (3) Non-conformity.

Angular Unconformity: An angular unconformity is a contact that separates a younger, gently dipping or horizontal rock unit or set of units and an older, set of underlying rocks that are tilted or deformed layered rocks. It is a type of unconformity in which the beds below the unconformity dip at a different angle than the beds above it. In angular unconformities, both the underlying and overlying rocks are of sedimentary origin, but the attitude of rocks above and below the plane of discontinuity notably differ from each other. Now analyse the figures (Fig. 4.34) given below and note the different stages involved in the formation of an angular unconformity.

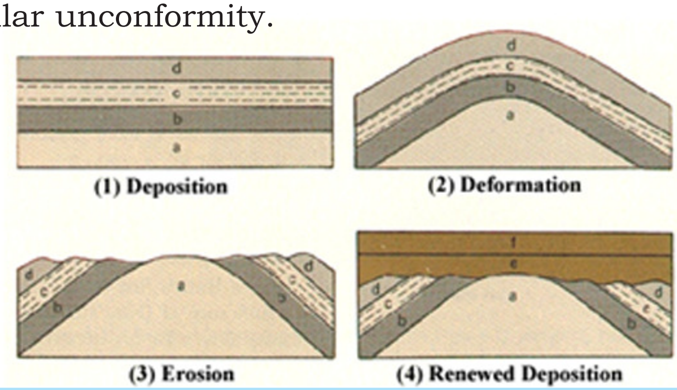


Fig. 4.34: Stages of formation of an angular unconformity

Stages of formation of an angular unconformity involve: First: a set of rocks was deposited; Second: these rocks were uplifted and tilted or folded (deformation); Third: erosion removes the uplifted portion of the sedimentary layers and the rocks were eroded down to a level surface; Fourth: subsidence and deposition of new sediments occurs on top the eroded surface (previous land surface) and a younger set of rocks was laid down on top. You can infer that angular unconformities are those where an older package of sediments has been tilted, truncated by erosion, and then a younger package of sediments was deposited on this eroded surface.

Disconformity or Parallel unconformity: Disconformities are also erosion surfaces occurring between two sets of sedimentary layers. But in these types of unconformities the lower set of sedimentary layers was not tilted prior to deposition of the upper set of sedimentary layers. Disconformities are also known as 'parallel unconformities', because of the fact that the beds above and below the surface of unconformity or plane of discontinuity are parallel. In the Fig.4.35, the disconformity is indicated by an irregular black line between the 3rd and 4th rock units from the bottom set of sedimentary layers.

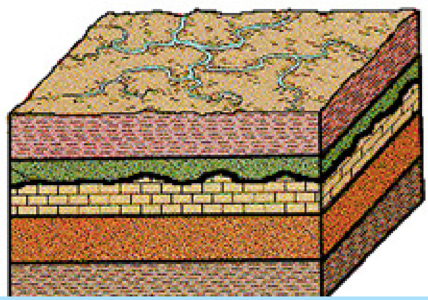


Fig. 4.35: Disconformity

The sequence of events leading to the formation of a disconformity is as follows: (1) subsidence and sediment deposition; (2) uplift and erosion; (3) renewed subsidence and deposition.

Because the beds below and above a disconformity are parallel, the disconformities are more difficult to recognize in the sedimentary record. Since disconformities are hard to recognize in a layered sedimentary rock sequence, they are often discovered when the fossils contained in the upper and lower rock units are carefully studied. A gap in the fossil record indicates a gap in the depositional record, and the length of time the disconformity represents can be estimated.

Non-conformity: Nonconformity is the contact that separates a younger sedimentary rock unit from an older igneous intrusive rock or metamorphic rock unit. The term is commonly applied to structures in which the older formation, made up essentially of plutonic rocks, is overlain by younger sedimentary rocks or lava flows. In the cross section of a locality shown here (Fig. 4.36), there is a body of rock that is not sedimentary, upon which sedimentary strata are laid down. This kind of junction between two different major rock types is a 'nonconformity'.

Fig. 4.36: Nonconformity

A nonconformity suggests that a period of long term uplift, weathering, and erosion occurred to expose the older, deeper rock at the surface before it was finally buried by the younger rocks above it. The erosional surface formed over the underlying rock is represented by a nonconformity, over which younger layers of sediments were deposited.

Unconformities are very important in dating of orogenic and epeirogenic movements. They are also useful to students of stratigraphy, sedimentation and historical geology.

Knowyour progress

1. What is the difference between a joint and a fault?
2. What are the importance of joints in the field of civil engineering?
3. How are unconformities developed? Why do you consider an unconformity as a structural feature?

Let us conclude

When the crust of the Earth is subjected to deformational stress, it buckles and breaks and the rocks become permanently deformed. In some places, originally formed horizontal strata become tilted or folded, and in others the rock units are fractured and often offset along faults. The large-scale shape, geometry, and deformation of rock bodies are part of what we call their structures. Identification and analyzing of geological structures have great importance in the field of geotectonic, groundwater prospecting, in the search of mineral deposits and in petroleum exploration.

Let us assess

1. Fill in the blanks.
   - (i) In ______ fault, the hanging wall appears to have moved down relative to the footwall.
   - (ii) If two faults dip away from each other, the middle block moves up. Mountains formed in this manner are called ______ mountains.
   - (iii) Folds consist of two sides. Each side of the fold is called a ______ .
   - (iv) ______ are long columns of joints with polygonal cross sections formed as lava cools and contracts into an igneous rock.
2. A clinometer compass is used to measure ______ .
   - a) Strike and dip direction only.
   - b) Strike direction only.
   - c) Dip direction and amount of dip only.
   - d) Strike direction, dip direction and dip amount.

3. Define the following terms.
    (a) Strain
    (b) Joints
    (c) Bedding
4. What is meant by attitude of rock beds?
5. When a rock has undergone non-recoverable strain, what types of deformations take place?
6. Which type of fold has the limbs that dip towards each other with younger strata at the centre of the fold?
7. Describe the three major types of stress.
8. What is the difference between elastic and plastic deformation?
9. Distiguish between an angular unconformity and a disconformity.
10. Draw a block diagram showing a horst and a graben.

Chapter 05

History of the Earth

Significant Learning Outcomes

After the completion of this chapter, the learner:

- Explains the necessary conditions for preservation of fossils in rock strata.
- Summarizes the different modes of fossilization.
- Describes the significance of fossils in stratigraphy.
- Understands the concept of geologic time and its usefulness in understanding the history of the Earth.
- Establishes the difference between the determination of relative age and absolute age of geological events.
- States the principles of stratigraphy that are employed to determine relative age of rocks.

Geology is not only the study of the Earth as we see it today, but it also includes the study of the history of the Earth. The Earth has evolved (changed) throughout its history, and will continue to evolve. The branch of geology that deals with the study of the history of the Earth, particularly the changes that affected the Earth and as it has evolved to its present condition, including its life forms in time and space, is known as **Historical Geology.**

5.1 Stratigraphy and Palaentology

Stratigraphy is a branch of geology, concerned with the description of rock successions and their interpretation in terms of Geological Time Scale. It provides a basis for historical geology. The principles and methods used in stratigraphy also find their applications in petroleum geology and archaeology. Stratigraphy deals primarily with sedimentary rocks, and also deals with layered igneous rocks (e.g., a succession of lava flows) or metamorphic rocks derived from pre-existing sedimentary rocks.

Three basic objectives of stratigraphic studies are: (1) the subdivision of a sequence of rock strata into mappable units, (2) determining the time relationships that are involved, and (3) correlating units of a sequence or the entire sequence with rock strata elsewhere.

The need to classify and organize rock layers according to their age led to the geologic discipline of stratigraphy. Stratigraphers can summarize information about the sequence of strata at a location by drawing a **stratigraphic column.** Stratigraphic columns everywhere are divided completely on the basis of lithology into mappable units, known as 'formations'. The thickness of formations may range from less than a meter to several thousand meters. A stratigraphic column shows the succession of formations in a region.

The process of determining the relationship between strata at one location and strata at another is called **correlation.** You will learn about stratigraphic correlation later in this chapter. By correlating strata at many locations, one could trace individual formations of strata over fairly broad regions and create geologic maps. The portrayal of the history of the Earth can be made by correlating rocks from locality to locality at numerous places around the world. If fossils are present in the rocks, they can be used to correlate rock layers across large distances.

The branch of historical geology dealing with the study of fossils is **Palaeontology.** Evidence of most of the life-forms of the past are found as fossils, which are the remains or traces of an organism from the geologic past that has been preserved in some sedimentary rocks. Stratigraphy deals with the lithologic composition, fossil content, classification, succession, age relationships and several other aspects of stratified (layered) rocks. One of the major objectives of the study of layers of rocks (strata) is the interpretation of the geologic history of the localities, regions and Earth as a whole.

5.2 Fossils

Sedimentary rocks are, by far, the most common rocks at the Earth's surface. They are formed mostly from particles of older rocks that have been broken apart, carried and deposited by water, ice and wind. The particles of gravel, sand, silt and clay, which are collectively called *sediment;* settle in layers at the bottoms of rivers, lakes and oceans. As the sediments accumulate, they most often bury shells, bones, leaves, pollen, and other bits and pieces of living things. With the passage of time, the layers of sediments are compacted by the weight of overlying sediments and cemented together to become sedimentary rocks and the buried plant and animal remains become preserved as fossils in the resulting rocks:

Fossils are the remains or traces of ancient life. *A fossil is a life form or evidence of a life form preserved in an ancient rock. Life form* means that fossils can contain all or part of any plant or animal that has existed during some part of the Earth's history. *Evidence of life* means that fossils can be traces of plant or animal activity, such as tracks, trails, burrows, or coprolites (fossil excrement). By the term *ancient* means that, the fossils must be in rocks older than 10,000 years. Fossils are thus remains or evidences of animals and plants (Fig. 5.1a and b) that lived during the geological past and are found buried in sedimentary rocks.

Fig. 5.1 (a) : Fossil of a dinosaur skeleton (b): Fossilized plant leaves

5.2.1 Conditions for preservation of fossils

Most organisms that lived in the past left no record of their existence. Fossil preservation is a rare occurrence. The process of forming a fossil is described as **fossilization.** All organisms do not have an equal chance of being preserved as fossils. First of all, the organism must live in a suitable environment. Generally, marine and transitional (shoreline) environments are more favourable for fossilization than the continental environments, because the rate of sediment deposition tends to be higher in the former environments. The conditions favouring fossilization of an organism are many and the possibility of finding a fossil depends on several factors. See the figure (Fig.5.2) given below, and discuss with your peer learners the conditions that favour fossilization.

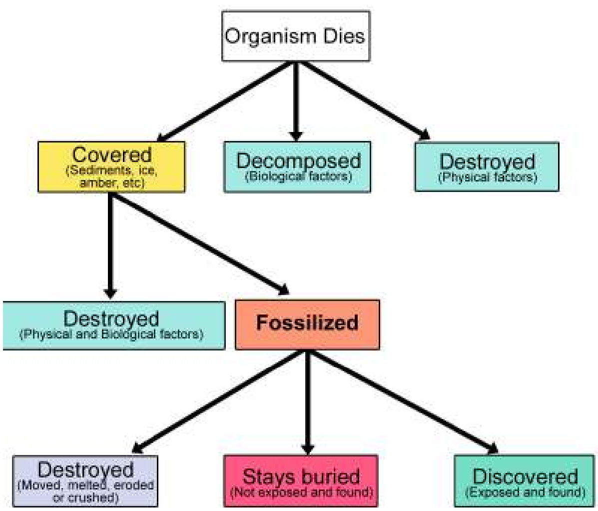


Fig.5. 2: Conditions of fossilization

To become preserved as a fossil, an organism must have preservable hard parts. Hard parts (bones, shells, teeth, and wood) have a much better chance of being preserved than do soft parts (muscle, skin, internal organs). Moreover, the organism must be rapidly buried by sediment. Burial protects the organism from decay. The remains of organisms could be destroyed by the processes of burrowing by other animals, dissolution, metamorphism, or erosion. Therefore, to become a fossil, the organism must also escape physical, chemical, and biological destruction after burial.

In short, the organism must be buried quickly to prevent decay and then must remain undisturbed throughout thousands of years needed for fossilization. Because of these requirements, only a very small number of plants and animals are preserved as fossils.

Fossils are found in sedimentary rocks, like sandstone, shale, limestone and coal. Igneous rocks are formed from molten rock erupting from deep within the Earth and most metamorphic rocks which are formed by tremendous heat and pressure. Therefore, fossils are not usually found in either igneous or metamorphic rocks.

5.2.2 Modes of fossilization

When you think of a fossil, you will imagin a bone or shell of an organism. In fact, there are many different kinds of fossils, based on the specific way in which the organism was fossilized. These include the following.

(i) Preservation of unaltered hard parts

The bones and teeth of vertebrate organisms may survive in rocks in unaltered condition. Similarly, the shells of invertebrates and single-celled organisms may also be preserved in rocks.

(ii) Chemical alteration of hard parts

The hard parts of many fossil organisms have been chemically altered by the addition, removal, or rearrangement of chemical constituents. Alteration of hard parts of organisms is generally accomplished by *permineralization, replacement and carbonization.*

Porous shells and bones are commonly altered by mineral matter deposited in them by percolating water. Fossils altered in this way are called permineralized fossils. **Permineralization** is the filling of pores (tiny holes) in bone or shell by the deposition of minerals from circulating solution. The added mineral matter makes the permineralized fossil much heavier than the original material.

The chemical composition of some fossils is found to be quite different from that of the original hard parts of the organism they represent. Simultaneous solution of the original material and *replacement* by a new substance may result in the preservation of original structures in such fossils. **Replacement** is the molecule-by-molecule (or atom by atom) substitution of another mineral (of different composition) for the original material. The fine details of wood are generally preserved faithfully in petrified wood (Fig. 5.3) by replacement process. Minerals which commonly replace hard parts of organisms are silica, calcium carbonate and pyrite.

Fig.5.3: Petrified wood

Carbonization is a process that preserves soft tissues of plants or animals as a thin carbon film, usually in fine-grained sediments (shales). The volatile elements (such as hydrogen and oxygen) of the organisms are distilled, leaving a residue of carbon to preserve the form of the original material. Fine details of plant fossils, such as ferns, soft-bodied animals like jellyfish or worms may be preserved in shale as carbonaceous films by carbonization process.

(iii) Imprints of hard parts in sediment

Many fossils are simply imprints with no shell material present at all. Hard parts are commonly destroyed by decay or dissolution after burial, but may leave a record of their former presence in the surrounding sediment.

Impressions or **moulds** are the imprints of an organism (or part of an organism) in the sediment. A mould is formed when the fossil surrounded by hardened sediment dissolves and leaves a cavity in the shape of the original fossil. A shell buried in sandstone may be leached or dissolved by groundwater, leaving a mould of the shell in the surrounding sandstone. There are two types of moulds:

(a) External moulds are imprints of the outside of a shell in the rock. External moulds are produced when water percolating through the compacted sediments in which the shell is buried may dissolve away and leave a mould of the exterior of the shell in the sediment. If the original shell was convex, the external mould will be concave.

(b) Internal moulds are imprints of the inside of the shell in the rock. Internal moulds are produced when a shell is filled with sediment which becomes cemented, and then the shell is dissolved away.

A **cast** may be produced if a mould is filled with sediment or mineral matter (which then hardens). A cast is a replica of the original. Casts are relatively uncommon. (A rubber mould of a fossil can be filled with modelling clay to produce a replica or artificial cast of the original object.)

(iv) Preservation of unaltered soft parts

In rare circumstances, the soft parts of an animal may be preserved. Soft parts of organisms such as insects (Fig.5.4), or small frogs may be preserved if the organism becomes trapped in pine resin (later altering to amber). Larger animals may become trapped in oily, tar-like asphalt or in peat bogs.

Fig. 5.4: A fossilized insect preserved in prehistoric resin

(v) Trace fossils or Ichnofossils

Trace fossils are markings in the sediment made by the activities of organisms. These traces of organisms preserved in the rocks are called *ichnofossils.* They result from the movement of organisms across the sediment surface, or the tunneling of organisms into the sediment, or the ingestion and excretion of sedimentary materials. Trace fossils include trails, burrows, borings, foot prints and tracks (Fig. 5.5).

In many cases, tracks of animals are the only record of their existence. For example, in many places, dinosaur tracks are much more abundant than dinosaur bones. During its lifetime, a single dinosaur makes millions of tracks, but leaves only one skeleton, which may or may not be preserved.

Fg. 5.5: (a) Footprint of a dinosaur, (b) Fossil tracks made by an animal (probably a slug).

The fossils found in rocks throughout the world represent only a few of the numerous plants and animals that have existed since life began. Although a fossil record of all the living things that have ever existed is unavailable, scientists use the fossil record they do have to help them reconstruct the geologic history of the Earth.

Know your progress

1. Why do we say that fossil preservation is a rare occurrence?
2. A coral is originally made of calcite. After the coral dies, the calcite is replaced by pyrite. What type of preservation is this?

5.2.3 Significance of fossils in stratigraphy

Recall the term 'strata' (singular: stratum) which refers to the layers of sedimentary rocks. Stratigraphic columns everywhere are divided completely on the basis of lithology into mappable units, known as 'formations'. Such units are known as **lithostratigraphic units.** The thickness of formations may range from less than a meter to several thousand meters. Geologic formations are typically named for the geographic area in which they were first described (e.g., Quilon Limestone Formation, Warkalli Sandstone Formation, etc.). A brief outline of the significance of fossils in stratigraphy is given below.

Establishing Geologic Time

It is a very important point to note that, stratigraphy basically deals with two concepts, namely (1) time and (2) the rock record. The term **geologic time** refers to the period of time covering the formation and development of the Earth, from about 4.6 billion years ago to today. The time is continuous and has no breaks and the units making up the time scale of the Earth's history are called geological time units. These time units are also known as **geochronologic units.** The largest defined unit of time is the **supereon,** composed of **eons.** Eons are divided into **eras,** which are in turn divided into **periods, epochs** and **ages.**

The Geologic Time Scale is based on the appearances and disappearances of fossil species throughout the stratigraphic record. Each of the eras ends with a mass extinction of species. You can see in the table given below (Table.5.1) that, period boundaries in Geologic Time Scale coincide with smaller extinction events, followed by appearances of new species.

Table 5.1: Fossil species and corresponding periods of the Earth's history

Ages of organisms	Eras/Periods
Age of Man	Quaternary
Age of Mammals	Cenozoic
Age of Reptiles	Mesozoic
Age of Coal	Carboniferous
Age of Amphibians	Carboniferous and Permian
Age of Fishes	Silurian and Devonian
Age of marine invertibrates	Cambrian and Ordovician

The geologic time scale divides up the history of the Earth based on life-forms that have existed during specific times since the formation of the planet.

Identification of Chronostratigraphic Units

A succession of sedimentary rock layers formed during a specific time intervals are called **chronostratigraphic units (or time-rock units).** The terms eonothem, erathem, system, series, and stage are used to refer to the layers of rock that correspond to the largest to the smallest time units of geologic time of the Earth's history. For example, the Jurassic System in chronostratigraphy corresponds to the Jurassic Period in geochronology.

Where do the names of the periods in the Geologic Time Scale come from? They refer either to localities where a fairly complete stratigraphic column representing that time interval was identified. For example, rocks named Juras (for the Juras Mountains) in France and Switzerland were traced northward and found to overlie a group of rocks in Germany named Trias. The Trias rocks in turn, were found to underlie rocks named Cretaceous in England.

The location where a particular rock layer was discovered is called a "type locality". Most of the "type localities" of the geologic time column are located in Europe because this is where the science of stratigraphic correlation started.

Correlation of rock sequences

Rocks at different locations on Earth give different "snapshots" of the geologic time column. At a particular location, the stratified rocks never fully represent the entire geologic rock column due to extensive erosion or non-deposition. Moreover, the thickness of a particular rock layer (representing a particular time period) will vary from one location to another or even disappear altogether. The process that stratigraphers use to understand these relationships between strata at different localities is known as "correlation". The age of rocks could be determined and detached sequences can be correlated on the basis of their contained fossils.

Correlation is the process of determining the age relationship between geographically widely separated rock units. Rocks of the same age contain the same, or very similar, fossil species, even when the rock units extend over a large area or the exposures are not continuous. *There is a distinct, observable succession of fossils from older to younger rocks that did not repeat itself.* The kinds of fossils found in rocks of different ages differ because the kinds of animals and plants found on Earth have changed through time (evolution). Therefore, *when we find the same kinds of fossils in rocks in different places, we know the rocks are of the same age.* Similarity of fossil assemblages can be used for worldwide correlation of rocks.

Fossils can be used to recognize the approximate age of a unit and its place in the stratigraphic column. They can also be used for establishing age equivalence of strata and to correlate them from place to place.

5.3 Geologic records

Many features of the rocks serve as records of past events in Earth's history. During the very long period of geologic time, several natural events occurred on Earth. These include meteorite impacts, volcanic eruptions and lava flows, mountain building, quakes, erosion and sedimentation, slow movement of continents (plate tectonics), formation and destruction of ocean basins (plate tectonics), invasion and spreading of vast ice fields (glaciations), climatic changes, evolution and extinction of countless forms of life, etc. Evidence of all of these events is preserved in the geologic record in some form or other. In fact, rock strata are a *stony book* presenting the history of the Earth.

Geologists can extract from the rocks a fairly consistent record of events in the Earth's history- a record of time. Geologic time is continuous; it has no gaps. However, the rock record of a locality or a region, unlike time will not be continuous because it often consists of several breaks. This is because the areas of sedimentation and erosion do not geographically remain stationary on the surface of the Earth.

Stratigraphic sections are invariably incomplete in local and regional successions because formation of sedimentary rocks is not uniform everywhere on the surface of the Earth. Erosion will be going on in some places in a particular span of time while deposition of sediment is occurring in other places. Moreover, a locality or region undergoing erosion today may become a locality or region of deposition or sedimentation after a very long period of time. No rock record will be forming in a locality or region when it undergoes erosion.

When sediment is not being deposited, or when erosion is removing previously deposited sediment, there will not be a continuous record of sedimentation preserved in the rock record in that locality. This is indicated by an 'unconformity'. Recall the concepts you have learnt in the previous chapter, that an interval of non-deposition or erosion in a sequence of strata is called an unconformity. Unconformities are significant in that they are indicators of missing time in the rock record.

5.4 Dating of geologic events

In order to study the records of rocks and interpret the history of a locality, region or Earth as a whole, we must place the rock records in correct chronologic order. **Dating** is the science of determining the age of geological structures, rocks, and fossils, and placing them in the context of geological time. There are two methods of doing this: (1) Relative dating and, (2) Absolute dating (Numerical dating).

5.4.1 Relative dating

This involves placing rocks and events in their proper sequence (i.e., with respect to time) of formation. Relative dating tells scientists if a rock layer (or an event) is "older" or "younger" than another. Relative age does not tell how old something is; all we know is the sequence of events. Thus the relative time scale doesn't give you numerical ages. Relative dating allows you chronologic ordering of events in Earth history as recorded in rocks.

Relative dating can be carried out by identifying fossils of creatures that lived only at certain times (marker fossils), and by looking at the physical relationships of rocks to other rocks of a known age.

Long before absolute dating of rocks was developed in the 20th century, geologists had to rely on relative age dating, which places geologic events in their order of occurrence. Nowadays absolute time has been established, to determine the age of the rocks.

5.4.2 Absolute dating (Numerical dating)

Absolute dating involves specifying the actual number of years that have passed since an event occurred. In numeric dating, we can assign a number more precisely in years to the amount of time that has passed. Thus we can say how old something is.

(For example, when we say Homo sapiens appeared about 2.3 million years ago, we quantify the date of the event in years).

Absolute dating is achieved by measuring how much of a rock's radioactive elements have changed since the rock was formed, using the process of radiometric dating. Radioactive materials serve as geologic clocks. Geologists date rocks using the technique of radiometric dating. By combining radiometric age information with paleontological information, it has been possible to attach absolute numbers to the geological time scale, and also to determine the absolute ages of most rocks.

Radioactive dating

Naturally occurring radioactive materials are unstable and break down into other materials at known rates. This is known as ***radioactive decay****. Radioactive parent elements decay to stable daughter elements. Many radioactive elements can be used as* geologic clocks. *Each radioactive element decays at its own nearly constant rate. Once this rate is known, geologists can estimate the length of time over which decay has been occurring by measuring the amount of radioactive parent element and the amount of stable daughter elements. The following table (Table 5.2), lists radioactive parent isotopes, their stable daughter products and their half lives.*

Table 5.2:Half lives of various radio isotopes

Unstable Radioactive parent	Stable daughter	Half Life
Rubidium 87	Strontium 87	48.8 billion years
Thorium 232	Lead 208	14 billion years
Uranium 238	Lead 206	4.47 billion years
Potassium 40	Argon 40	1.25 billion years
Uranium 235	Lead 207	704 million years
Carbon 14	Nitrogen 14	5730 years

In the above table, note that the number is the mass number (the total number of protons plus neutrons). Note that the mass number may vary for an element, because of a differing number of neutrons in its atom. Elements with various numbers of neutrons are called isotopes of that element. Each radioactive isotope has its own unique half-life. A half-life is the time it takes for half of the parent radioactive element to decay to a daughter product. Radioactive decay occurs at a constant exponential or geometric rate. The rate of decay is proportional to the number of parent atoms present.

Know your progress

1. How can you substantiate that the Geologic Time Scale signifies the appearance and disappearance of certain fossil species in rock records?
2. What is the difference between absolute age and relative age which we speak of a geological event?

5.5 Fundamental principles of Historical Geology

Students understanding of Earth's immensely long history is enhanced by looking at the relative sequence of events, rather than specific dates and time periods. Relative dating is established by studying the layers of rocks, and the rocks and fossils they contain.

Using relative dating principles, it is possible to reconstruct the sequence of geologic events that have occurred at a site. In the reconstruction of the history of the Earth, for relative dating (or determining which rocks are older or younger) of rock units scientists are guided by certain principles. Now let us learn those principles.

5.5.1 Principle of uniformitarianism

Uniformitarianism is the term given to a fundamental principle or doctrine that *geological processes and natural laws that are* *now operating on Earth have acted in the same regular manner and with essentially the same rate throughout the geologic time and that the past geologic events can be explained by the phenomena and forces observable today.* This doctrine holds the view that the processes that are operating during the present are the same processes that have operated in the past. The concept is often summarised as: '**The present is the key to the past**'. If we look at processes that occur today, we can infer that the same processes operated in the past.

5.5.2 Principle of superposition

This principle states that in an undeformed horizontal sequence of sedimentary rock (or layered igneous rock), the oldest beds are on the bottom with successively younger layers on top of these and the youngest one will be on the top. This is the basis of assigning relative ages to all strata.

Sedimentary rocks are formed particle by particle and bed by bed, and the layers are stacked one over the other. Thus, in any sequence of undisturbed layered rocks, a given bed must be older than any bed on top of it. The law of superposition was formulated in the 17th century by the Danish scientist Nicolas Steno. The cross sections given in the figure 5.6 shows a simple example of an undisturbed sedimentary rock. A is the oldest, D is the youngest.

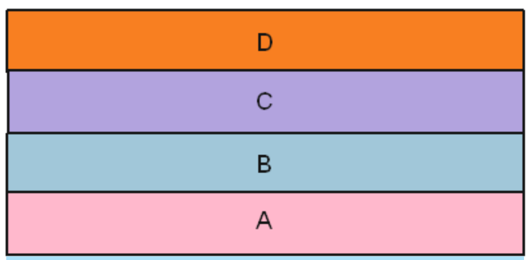


Fig.5. 6: Diagram showing the principle of superposition

Fossils are the keys to establish the sequence of the ages of layered sedimentary rocks, and they are the *direct proofs of the changes that have occurred in living organisms through time on our planet.* The principle of superposition also means that fossils found in the lowest levels in a sequence of layered rocks represent the oldest record of life in that locality. This principle is fundamental to understanding not only the relative age of rocks at any one place, but it also indicates the relative ages of the fossils they contain.

If certain fossils are typically found only in a particular rock unit and are found in many places worldwide, they may be useful as **index** or **guide fossils** in determining the age of undated strata. Index fossils are useful in identifying time-rock units and in correlation.

5.5.3 Principle of original horizontality

This principle states that sediments usually form flat-lying or horizontal (or nearly so) deposits on the Earth's surface (Fig 5.7). If the strata are not horizontal and found tilted, we can infer according to this principle, that they have been deformed after their formation by movements of the Earth's crust.

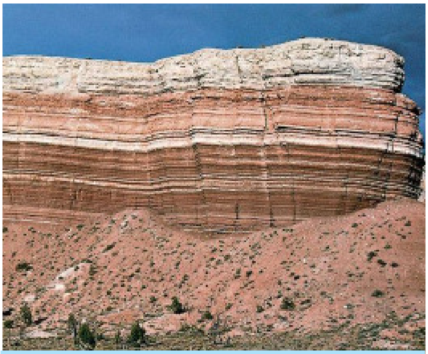


Fig. 5.7: Horizontality of strata

5.5.4 Principle of crosscutting relationship

Geologic features, such as faults and igneous intrusions are younger than the rocks they cut. Sometimes magma pushes, or intrudes, into cracks in existing rocks. When the molten rock cools and solidifies, the resulting feature is called an igneous intrusion. *An intrusive igneous body will be always younger than the rock it intrudes or cuts across.* The figures (Fig. 5. 8 a & b) given below show an intrusion (dyke) as seen in an outcrop and the schematic cross section indicating crosscutting relationship. See the disruption in pattern of rocks shown in the figures below and note that the intrusions are younger than the rocks that cut or intrude into.

Fig.5.8 : (a) igneous intrusions in an outcrop (b) in cross section

The crosscutting relationship is also an indicator of relative ages. It applies to igneous intrusions, faults, veins, erosional surfaces, etc.

5.5.5 Principle of faunal succession

This principle states that the groups of fossil plants and animals occur in the geologic record in a *definite and determinable order.* Fossils occur in a consistent vertical order in sedimentary rocks all over the world. The kinds of animals and plants found as fossils change through time.

Thus, rocks of the same age contain the same, or very similar, fossil species, even when the rock units extend over a large area or the exposures are not continuous. Therefore according to this principle, a period or any portion of geologic time can be recognized by its respective fossils.

The principle of original lateral continuity

Sediments generally accumulate in continuous layers. According to the principle of lateral continuity, strata originally extended in all directions until they either thinned to zero at their edges of deposition or they adjoin against the margin of the basin of deposition (Fig.5.9). If you find a

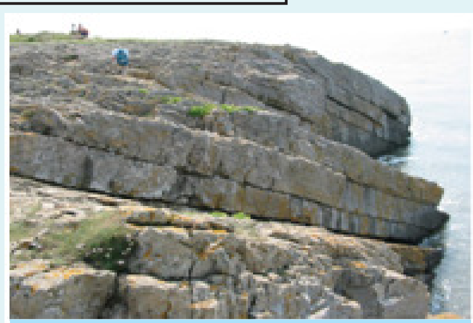


Fig. 5.9: Continuity of strata

sedimentary layer cut by a stream valley, then you can assume that the layer once extend continually, but was later eroded by the stream that formed the valley. Thus, matching strata on opposite sides of a valley can be correlated.

Principle of inclusion

If we find a rock fragment enclosed within another rock, we say the fragment is an inclusion. If the enclosing rock is an igneous rock, the inclusions are called xenoliths. The inclusions had to be present before they could be included in the younger rock. The principle of inclusion states that rocks containing inclusions are younger than the inclusions from which they came from.

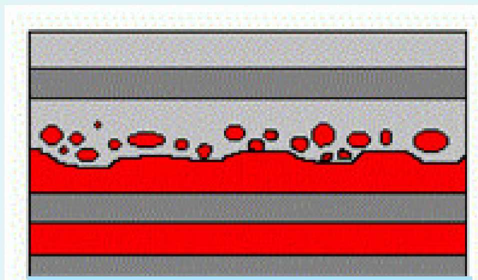


Fig 5.10: Clasts in an unconformity

Note the irregular erosional surface in the diagram above (Fig.5.10). It is an unconformity.

The clasts or pebbles shown in the diagram (in the bed above the unconformity) are derived from the underlying (older) bed. The gravel clasts are older than the layer which contains them. In other words, the layer containing the gravel must be younger than the layer from which the clasts originate.

We can use the principles of stratigraphy to establish the relative ages of rocks. Now, carefully study the figures given below (Fig.5.11 to 5.15) showing cross sections of different localities. What is the sequence of events that can be interpreted from these? For each of the following cross sections, determine the relative age sequence of the rocks. Place the answers making a list of increasing age. Remember; always start by looking for the oldest event first and working your way from oldest to the youngest. Don't forget to consider all intrusions and faults. The diagrams go from simplest to hardest to let you progressively improve your skills.

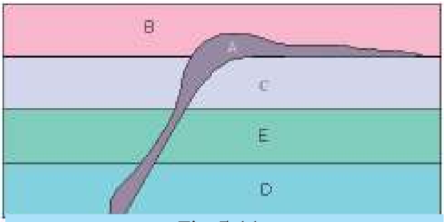


Fig. 5.11

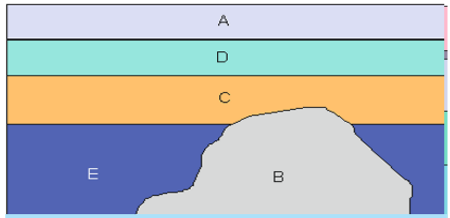


Fig. 5.12

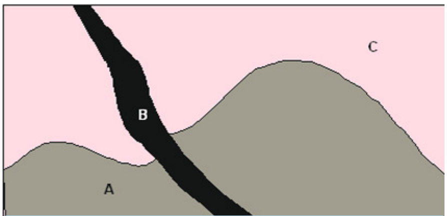


Fig. 5.13

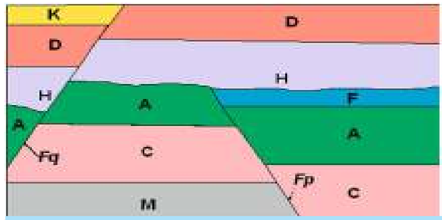


Fig. 5.14

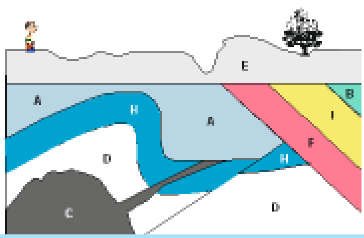


Fig. 5.15

Know your progress

1. What do you mean by the statement "The present is the key to the past"?
2. Why do we say rock layers are commonly deposited one above the other?
3. Describe how you will determine younger and older rock units in a sequence of strata based on each of the principles given below.
   i) Principle of superposition
   ii) Principle of cross cutting relationship

Let us conclude

Fossils that were contained in the rock could be used to determine relative ages of rock strata. Successive rock layers contain different groups or assemblages of fossil species. The law of uniformitarianism states that, the laws of nature do not change with time. According to the principle of fossil succession, there is a succession of fossils that relate to the age of the rock. With this information, in combination with the other principles of stratigraphy, geologists were able to recognize that the Earth has a history that long precedes mankind. On getting insight into the past, one can obtain a deeper and more detailed knowledge of processes on our planet.

Let us assess

1. Choose the right word from those given in brackets to mention the following:

   (Permineralization, Trace Fossils, Carbonization)

   (a) Signs of the organisms' activity.

   (b) Minerals deposited in pores.

   (c) Preservation of soft tissues of plants or animals as thin carbon films.

2. If a bed has a fault cutting through it, which one is older, the bed or the fault?
3. In which type of rock are fossils normally found?
4. Define Fossil.
5. Differentiate between relative age and absolute age.
6. What are moulds and casts?
7. What does the Law of uniformitarianism state?
8. Fossils are the remains or evidence of once living organisms. How these remains are preserved in rocks?

Chapter 06

Geology and Environment

Significant Learning Outcomes

After the completion of this chapter, the learner:

- Explains the importance of environment for sustaining life on Earth.
- Establishes the significance of geology in environmental management.
- Realizes the interaction among various sub systems of the Earth.
- Delineates the effects of mining on different spheres of the Earth.
- Describes the impacts of sand mining on our environment.
- Locates the major sources of contamination of groundwater.
- Appraises the problems associated with saline water intrusion.
- Examines the consequences of greenhouse effect and global warming.
- Recognizes the need of conservation of natural resources for sustainable development.

The Earth is the only suitable habitat for life, and as citizens of Earth, we have a vital relationship with our planet. We are fundamentally dependent on Earth resources for everything in our daily lives. While our population grows and our demands for resources increase, we have impacted the Earth system profoundly. Humans have changed landscapes, destroyed ecosystems, and added pollutants to the land, air, and water at a faster rate than the Earth system can absorb, process and neutralize.

Environment is the sum total of all the features and conditions surrounding an organism. Our physical environment includes air, water, rocks, soil, factors such as light and temperature and other organisms. The study of geology includes many areas of global concern. Environmental geology is the geology applied to living conditions.

6.1 Significance of Environmental Geology

Environmental geology involves the study of Earth systems, natural hazards, land use planning, hydrologic, atmospheric and global geologic processes. Environmental geology is an applied science and it aims to understand environmental problems, use geologic knowledge for problem solving, minimize environmental degradation, resolve conflicts related to land use, optimize the use of natural resources and maximize environmental benefits for the society. It focuses on important modern concerns, like how our global climate is changing and how that change may affect human activities, how to maintain and improve vital natural resources like drinking water, and how to manage and balance the quality of the environment in the face of improving the standards of life.

Environmental geologists objectively study geologic information and apply to contemporary environmental problems such as pollution, waste management, resource extraction, natural hazards and human health.

We are increasingly faced with environmental problems. An understanding of the influence of geologic processes and hazards on human activities and the geological aspects of pollution and waste disposal problems is essential to find an appropriate solution. The study of Earth's natural systems and their interactions with humans helps to solve conflicts in land use, minimize environmental degradation and maximize the beneficial results of using our environment.

6.2 Interaction among the Earth's sub-systems

The Earth system consists of *atmosphere, hydrosphere, lithosphere and biosphere.* It also includes the *cryosphere,* which is the portion of the Earth's surface where water is in solid form, including sea ice, lake ice, river ice, snow cover, glaciers, ice caps, ice sheets, and frozen ground (which includes permafrost). Another sphere of the Earth, the *anthrosphere* (also referred to as *technosphere*), which is that part of the environment that is made or modified by humans for habitats is also relevant.

You have learnt in the previous class that, the surface of the Earth, where the rocky part of our planet occurs, in contact with water, air, and/ or life, is generally where the spheres intersect and affect each other. The Earth surface represents the interface between the lithosphere, the hydrosphere and atmosphere. Most organisms constituting the biosphere exist at the interface where the lithosphere, hydrosphere and atmosphere meet. All these components interact with one another and comprise the Earth system.

As the Earth worked as a system, the changes made in anyone of the sphere affect all other Earth spheres and they are manifested in various ways. Each sphere interacts with the others to form a complex global system (Fig. 6.1.).

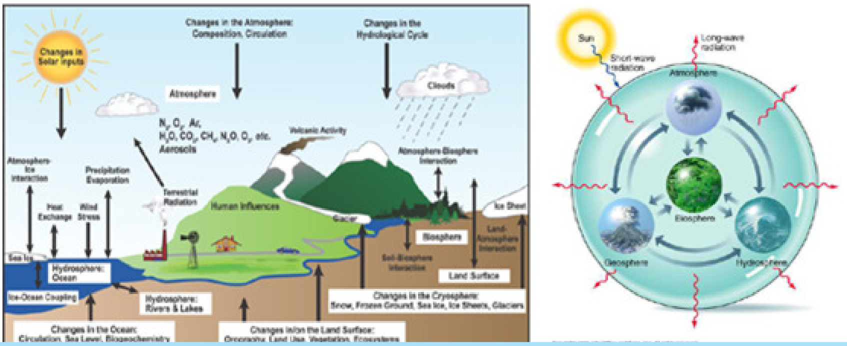


Fig. 6.1: Interaction among the various spheres of the Earth

Materials and energy tend to cycle from one sphere to another. Various materials such as water, carbon dioxide and many other chemical compounds or elements cycle among living and non-living components of the Earth system. Solar radiation drives the hydrosphere and circulation of the atmosphere and oceans. These in turn, cause erosion of the land surface. The earth's internal energy fuels the movements of plates and activities such as volcanism and uplift of mountains.

Everything, from a grain of sand on a beach to a lake, mountain range, or valley, exist because it was formed in a systematic way by an organized interaction of matter and energy. Dynamic geologic systems are governed by natural laws, which provide the keys to understanding Earth and all its landscapes and processes. Changes that take place in one part of the system have effects on other parts.

Understanding the Earth's systems and their interactions - processes that move matter and energy from one sphere to another- is critical in solving environmental problems.

6.2.1 Human interaction with the environment

Man has brought about lot of changes in the environment due to the utilization of the natural resources for his living, well-being and enjoying life. Throughout recorded history, mankind has struggled to manage his natural environment in order to improve its well being. The resources on which mankind is dependent are provided by various sources from the four 'spheres', viz., atmosphere, hydrosphere, lithosphere and biosphere.

The atmosphere provides the basic components of survival of life. It forms a protective shell over the Earth. The atmosphere is a complex dynamic system, if it is disrupted it adversely affects mankind and all. Human activities have polluted the atmosphere and most pollutants have both global and regional effects. Most of the major pollutants of the air are created by industries. The growing number of automobiles, which run by consuming fossil fuels, is a major cause of air pollution.

The hydrosphere provides mankind with water for his domestic, agricultural and industrial uses. Human activities such as deforestation create serious change in the hydrosphere. Water pollution by chemicals and effluents from industries and sewage threaten the health of communities.

The lithosphere comprises of soil, stones, sand, rocks, minerals as well as coal, oil and gas. Man's extraction and utilization of these natural resources for his beneficial purposes led to a deterioration of the natural environment. Man's activities such as quarrying and mining have produced immense impacts on the lithosphere over the years.

Biosphere is the relatively thin layer on the Earth in which life can exist. Biosphere includes sources of food from crops and domestic animals, food for all forms of life, the energy needs in the form of wood, timber and other construction materials.

Anthropogenic activities have made lot of changes on the environment. Industrialization, agricultural activities, urbanization and related activities have only been detrimental to the environment. Mankind as of today cannot live without carrying out these activities for its food, shelter, comfort, security and many other needs. However, the way we perceive and respond to our natural environment determines our attitude towards the protection of our environment. Managing the environment means managing human behavior.

All living beings including humans are dependent on the environment for their existence. But every man-made activity has some impact on the environment. Often these activities are more harmful than beneficial. Let us discuss a few of these environmental problems that are very relevant for mankind.

Know you progress

1. How does the study of geology help us to manage our environment?
2. Do you agree that anthropogenic activities have made harmful impacts on our environment? Why?
3. How do the land-sea-atmospheric interactions sustain life on this planet?

6.3 Environmental impacts of mining and quarrying

Mining is the extraction of valuable minerals or other geological materials from the earth, usually from an ore body, vein or coal seam. With growing knowledge of the mineral resources as well as due to technological and scientific developments, mining operations are expanding day by day without taking into considerations the impact on the environment. Hundreds and thousands of bore holes and tunnels are drilled each year to different depths, whose consequences may be felt even after many years. Mining activities can modify the environment in a variety of ways. Both underground mines and surface mines have their own sets of associated impacts. Most obvious is the presence of mine itself.

A quarry is a place from which dimension stone, rock, construction aggregate, sand or gravel has been excavated from the ground. Quarrying refers to the extraction of any building material or dimension stone from an openpit mine. The word quarry can also include the underground quarrying for stone.

Quarrying is necessary to provide much of the materials used in construction of buildings and traditional hard flooring, such as granite, limestone, marble, sandstone, slate and even just clay to make ceramic tiles. However, like many other man-made activities, quarrying causes a significant impact on the environment.

Effects of mining and quarrying on the environment may not be evident immediately; they are usually noticed after some years. If you live near an area where rocks or minerals have been quarried, there are environmental and social issues tied up with the removal of rock materials. It might destroy the appearance of the whole landscape, its stability and usability (Fig. 6.2).

Fig. 6.2: Effects of open cast mining and underground mining

Various types of mining activities like open cast mining and underground mining have adverse effects on the environment.

6.3.1 Effects on lithosphere

Deforestation: Large-scale deforestation is to be carried out in the areas where quarrying and mining have to be done (Fig. 6.3). Rainforests are the biggest source of oxygen, wood and medicines on this Earth. Besides clearing the mining area, vegetation in the adjoining areas also needs to be cut in order to construct roads and residential facilities for the mine workers.

Fig. 6.3: Large-scale deforestation for mining activities

Land degradation and land pollution: Release of the chemical waste of mining into the land changes the chemical composition of the land. Besides this, since the chemicals are poisonous, they make the soil unsuitable for plants to grow (Fig. 6.4). Also, the organisms that live in the soil find the polluted environment hostile for their survival.

Fig. 6.4: Land degradation due to mining

Land subsidence: Subsidence of surface takes place due to extraction of minerals. Subsidence is exhibited by cracks on surface and lowering of land in the worked out areas compared to surroundings. Land subsidence is common in areas where underground mining of coal had been progressing for prolonged periods and in areas of abandoned underground mines (Fig. 6.5).


Fig. 6.5: Land subsidence due to mining

Landslide: It is estimated that about 30% of the latest landslides were occurring due to mining. Landslides are frequent in areas of deep open cast mines (Fig. 6.6).


Fig. 6.6: Landslide hazards associated with mining

Accumulation of quarry waste: Similar to many other man-made activities, quarrying involves the production of significant amounts of waste. Some types of quarries do not produce large amounts of permanent waste, such as sand and gravel quarries, whereas others will produce significant amounts of waste material such as clay and silt. Furthermore, the treatment and disposal of the waste may produce more negative impacts on the environment. The accumulation of waste by-products will have to be stored and managed somewhere that will not affect the environment in an adverse manner.

6.3.2 Effects on Hydrosphere

Water pollution: Mining activities increasingly threaten the water sources on which we all depend. Chemicals like mercury, cyanide, sulphuric acid, and arsenic and methyl mercury are used in various stages of mining. Such compounds get mixed up in the local waterways and contaminate local rivers with heavy metals. Most of the chemicals are released into nearby water bodies, and are responsible for water pollution. In spite of tailings (pipes) being used to dispose these chemicals into the water bodies, possibilities of leakage are always there. When the leaked chemicals slowly percolate through the layers of the Earth, they reach the groundwater and pollute it.

Acid mine drainage: This refers to the outflow of acidic water from coal mines or metal mines. Metal sulphides are exposed during mining activities. When large quantities of rock containing sulphide minerals are excavated from an open pit mine or opened up in an underground mine; it reacts with water and oxygen to create sulphuric acid. When the water reaches a certain level of acidity, a naturally occurring type of bacteria called Thiobacillus ferroxidans may kick in, accelerating the oxidation and acidification processes, leaching even more trace metals from the wastes. The acid will leach from the rock as long as its source rock is exposed to air and water and until the sulphides are leached out. This process can last hundreds, or even thousands of years.

Acid is carried off the mine site by rainwater or surface drainage and deposited into nearby streams, rivers, lakes and groundwater.

Acid mine drainage severely degrades water quality, and can kill aquatic life and make water virtually unusable (Fig. 6.7 a). Release of toxic chemicals into the water is obviously harmful for the flora and fauna of the water bodies. Organisms in these water bodies do not have enough water for their survival (Fig. 6.7 b).

Fig. 6.7 (a) and (b): Acid Mine Drainage and loss of aquatic life

Lowering of groundwater table: Mining processes require water from nearby surface and groundwater bodies. For example, water is used to wash impurities from the coal. The result is that the water content of the river or lake from which water is being used gets reduced. Mining activities can also deplete groundwater supplies in an area. Rocks act as aquifers of groundwater. As we mine these rocks, we are losing these reservoirs.

6.3.3 Effects on Atmosphere

Air pollution: Air pollution is mainly due to the fugitive emission of particulate matter and gases including methane, sulphur dioxide and oxides of nitrogen. The mining operations like drilling, blasting, movement of the heavy earth moving machinery, collection, transportation, handling of ores, screening, and sizing are the major sources of such emissions (Fig. 6.8).

Fig. 6.8: Air pollution due to intense mining activities

Dust from quarry sites is a major source of air pollution, although the severity will depend on factors like the local microclimate conditions, the concentration of dust particles in the ambient air and the size of the dust particles.

The dust particles have physical effects on the surrounding plants, such as blocking and damaging their internal structures and abrasion of leaves and cuticles, as well as chemical effects which may affect long-term survival. It can cause possible health effects, in particular for those people with respiratory problems.

Noise pollution: Quarrying involves several activities that generate significant amounts of noise. It starts with the preparatory activities, such as establishing road or rail access, compound and even mineral processing facilities. Then the process of exposing the stone or mineral to be extracted is done by removing the top soil and other soft layers using a scraper, or hydraulic excavators and dump trucks. The excavation of the stone/mineral itself will involve considerable noise, particularly the blasting methods.

Noise pollution associated with mining may include noise from blasting, heavy earth moving machines, vehicle engines, drilling and mine handling machines, power generation, and other sources. Vibrations of the ground associated with blasting and many types of equipments used in mining operations have affected the stability of infrastructures, buildings, and homes of people living near large-scale open-pit mining operations.

6.3.4 Effects on biosphere

Destruction of habitat: Quarrying carries the potential of destroying habitats and the species they support. Even if the habitats are not directly removed by excavation, they can be indirectly affected and damaged by environmental impacts - such as changes to groundwater or surface water that causes some habitats to dry out or others to become flooded. Even noise pollution can have a significant impact on wildlife habitats and affect the successful reproduction of some species.

Damage to biodiversity: Biodiversity essentially refers to the range of living species, including fish, insects, invertebrates, reptiles, birds, mammals, plants, fungi and even micro-organisms. Biodiversity conservation is important as all species are interlinked, even if this is not immediately visible or even known, and our survival depends on this fine balance that exists within nature.

The forests that are cleared for mining purposes are home to a large number of organisms. Indiscriminate clearing of the forests leads to loss of habitat of a large number of animals. This puts the survival of a large number of animal species at stake. The cutting down of trees itself is a big threat to a number of plants, trees, birds and animals that dwell in the forests. Mine spills are dangerous to the aquatic life as a whole.

Now make a table as shown below giving the effects of quarrying and mining.

Lithosphere	Atmosphere	Hydrosphere
• Subsidence	• Noise and dust pollution	• Water logging
•	•	•
•	•	•

6.4 Environmental problems of sand mining

Sand is an important resource for our society that plays crucial roles as buffer against strong tidal waves and storms, habitat for a number of fresh water species and marine organisms, used for making concrete, filling roads, building sites, brick making, making glass, sandpapers, and so on.

Sand mining is a practice that is used to extract sand, mainly through an open pit. The process of removal of sand and gravel is becoming an environmental issue as the demand for sand increases in industry and construction. Sand mining can be in the form of either river sand mining (Fig. 6.9) or coastal sand mining (Fig. 6.10) both of which cause serious impacts on the environment.

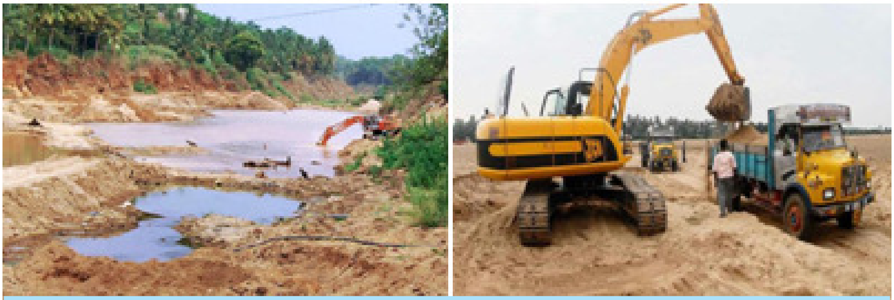


Fig. 6.9: River sand mining

Fig. 6.10: Coastal sand mining

River sand mining lowers the stream bottom, which may lead to erosion of river banks. Continued extraction may also cause the entire streambed to degrade to the depth of excavation. Excessive sand mining is a threat to bridges, river banks and nearby structures. Depletion of sand in the streambed and along coastal areas causes the deepening of rivers and estuaries, and the enlargement of river mouths and coastal inlets.

Sand mining also affects the adjoining groundwater system. Sand mining transforms the riverbeds into large and deep pits; as a result, the groundwater table drops leaving the drinking water wells on the embankment of these rivers dry. Over deepening of river channel and floodplains associated with sand mining aggravates saltwater intrusion into the fresh water body in the areas close to the sea.

Uncontrolled sand mining results in the destruction of aquatic and riparian habitat through large scale changes in the channel morphology.

Sand mining in Kerala

In Kerala, there has been a significant increase in sand mining since the beginning of the 1990s following a boom in the construction industry, and the activity reached alarming proportions in several areas. Water tables have dropped dramatically and a land once known for its plentiful rice harvest now faces scarcity of water. In the villages and towns around the river, groundwater levels have fallen drastically and wells are almost perennially dry. The river bed is lowering year after year due to uncontrolled sand mining .

Know your progress

1. How does sand mining result in lowering of water table in an area?
2. What do you mean by acid mine drainage?
3. How does mining and quarrying activities affect aquatic and wild life?

6.5 Pollution of groundwater

All of us need clean water to drink. Do you know if your water is safe to drink? We can go for weeks without food, but only days without water. Contaminated water can be a threat to anyone's health.

Groundwater may contain some natural impurities or contaminants, even with no human activity or pollution. Natural contaminants can come from many conditions in the watershed or in the ground. Water moving through underground rocks and soils may pick up magnesium, calcium and chlorides. Some groundwater naturally contains dissolved elements such as arsenic, boron, selenium, or radon, a gas formed by the natural breakdown of radioactive uranium in soil. In addition to natural contaminants, groundwater is often polluted by human activities. When groundwater is used intensively for irrigation and industrial purposes, a variety of land and water-based human activities are causing pollution of this precious resource.

6.5.1 Potential sources of groundwater contamination

Groundwater is the widely used source of potable water. Once fresh water is contaminated, its quality is difficult to restore. Groundwater contamination occurs when manmade products and chemicals get into the groundwater and cause it to become unsafe and unfit for human use. Analyse the diagram given below (Fig.6.11), and try to identify the means that contaminants from different sources find its way into the groundwater.

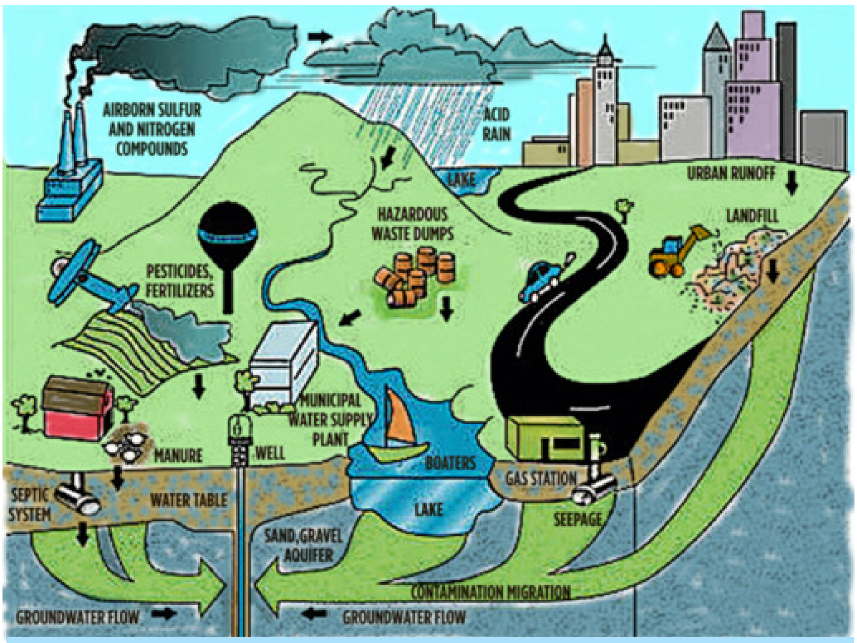


Fig. 6.11: Sources of Groundwater contamination

Materials from the land's surface can move through the soil and end up in the groundwater. For example, pesticides and fertilizers can find their way into groundwater supplies over time. Some of the major sources of groundwater contamination are described below.

(a) Chemicals and fertilizers

Chemicals include products used on lawns and farm fields to kill weeds and insects and to fertilize plants, and other products used in homes and businesses. When it rains, these chemicals can seep into the ground and eventually into the water. Intensive use of chemical fertilizers in farms results in leaching of the residual nitrate, causes high nitrate concentrations in groundwater. DDT, BHC, Endosulfan, etc. are the most common pesticides used. Fertilizers and chemical pesticides used in agriculture, often dispersed over large areas, is a great threat to fresh groundwater ecosystems (Fig 6.12).

Fig. 6.12: Chemicals and Fertilizers as potential contaminants of groundwater

The main contaminants of concern still include petroleum hydrocarbons such as benzene, toluene, and xylene; chlorinated organics such as perchloroethylene (PCE),trichloroethylene (TCE)and its associated daughter products; heavy metals such as lead, zinc, and chromium, and certain inorganic salts and also a variety of industrial effluents.

(b) Septic systems

Septic systems are designed to drain away human waste underground at a slow, harmless rate. An improperly designed, located, constructed, or maintained septic system can leak bacteria, viruses and other contaminants into the groundwater causing serious problems (Fig.6.13).

Fig. 6.13: Septic tanks as potential sources of groundwater pollution

(c) Uncontrolled hazardous waste

Today, there are numerous known abandoned and uncontrolled hazardous waste sites and the numbers grow every year. Industrial effluents contain highly hazardous chemicals that can contaminate groundwater (Fig. 6.14).

These contaminants can eventually make their way down through the soil and into the groundwater. Improper disposal of many common products can pollute groundwater. These include cleaning solvents, used motor oil, paints, and paint thinners. Even soaps and detergents can harm drinking water.

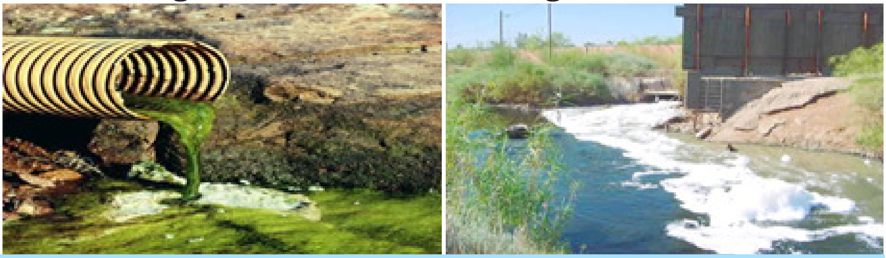


Fig. 6.14: Hazardous wastes from industrial effluents

(d) Storage tanks and landfills

Storage tanks may contain petroleum, natural gas, chemicals, or other types of liquids and they can either be above or below ground. Over time the tanks can corrode, crack and develop leaks. If the contaminants leak out and get into the groundwater, serious contamination can occur (Fig. 6.15 a).

Landfills are the places that our garbage is taken to be buried. Landfills are supposed to have a protective bottom layer to prevent contaminants from getting into the water. However, if there is no layer or it is cracked, contaminants from the landfill (paint, household cleaners, etc.) can make their way down into the groundwater (Fig. 6.15 b).

Fig. 6.15 (a) & (b): Storage tanks and landfills as sources of groundwater contamination

(e) Atmospheric contaminants

Since groundwater is part of the hydrologic cycle, contaminants in other parts of the cycle, such as the atmosphere or bodies of surface water, can eventually be transferred into our groundwater supplies.

6.5.2 Dangers of contaminated groundwater

Drinking contaminated groundwater can have serious health effects. A wide range of diseases such as hepatitis and dysentery may be caused by contamination from septic tank waste. Poisoning may be caused by toxins that have leached into well water supplies.

Mercury is reported to cause impairment of brain functions, neurological disorders, retardation of growth in children, abortion and disruption of the endocrine system, whereas pesticides are toxic or carcinogenic. Generally, pesticides damage the liver and nervous system. Tumour formation in liver has also been reported.

High fluoride content is often detected from such symptoms on human beings as yellowing of teeth, damaged joints and bone deformities, which occur from long years of exposure to fluoride containing water. Due to this reason, by the time the community realizes the "menace", a large section of the population is already affected.

Prolonged exposure to water containing salts (TDS-total dissolved salts- above 500 ppm) can cause kidney stone. Other long term effects such as certain types of cancer may also result from exposure to polluted water. Wildlife can also be harmed by contaminated groundwater.

6.6 Saline water intrusion

The movement of saline water into a freshwater aquifer or surface reservoir is known as saltwater intrusion and if the source of this saline water is sea water, then this process is known as seawater intrusion. Since groundwater is a major source of fresh water in the coastal region, protection of coastal aquifers from contamination through salt water ingress is of paramount importance. Over exploitation of groundwater, reduction in recharge of the aquifer, rise in sea level etc. can induce salt water intrusion in coastal areas.

The magnitude of salinity intrusion in coastal areas depends on sensible balance between fresh water flow and saltwater from the sea. Where aquifers form a coast line, a natural gradient exists towards the coast and groundwater discharges into the sea. Freshwater is slightly less dense (lighter) than saltwater, which tends it to float on top of the saltwater when both fluids are present in an aquifer. Because sea water is slightly heavier than fresh water, it intrudes into aquifers in coastal areas forming a saline wedge below the fresh water. The boundary, or interface, between the two is in a state of dynamic equilibrium, moving with the seasonal variations of the water table and daily tidal fluctuations (Fig. 6.16).

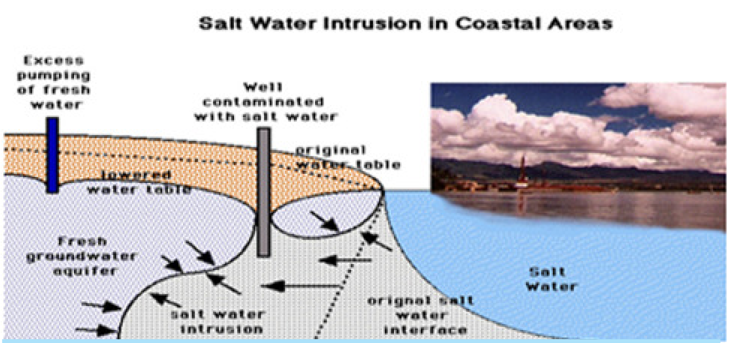


Fig. 6.16: Saline water intrusion in coastal aquifers

River water salinity adversely affects the natural environment, such as functioning of the ecosystem, sedimentation rates in tidal rivers, and human health. If intrusion problems become extreme, they can render an aquifer unusable for most purposes. Salinity has implication for economic activities, like agricultural crops production, fish and shrimp, and availability of water suitable for agriculture and industrial uses.

6.6.1 Prevention and control of saline water intrusion

A number of different measures have been used to control seawater intrusion and to protect the groundwater resources. The main principle of protection is to increase the volume of fresh groundwater and reduce the volume of saltwater. The following is a list of measures that can be taken to control salt water intrusion in coastal aquifer systems:

a. Reduce pumping or time-share pumping from a number of wells.

b. Relocate wells.

c. Increase the recharge rate of the aquifer directly.

d. Recharge fresh water into wells paralleling the coast creating a hydrodynamic barrier.

e. Create a trough parallel to the coast by excavating encroaching salt water from wells.

f. Extract sea water before it reaches the wells.

g. Construct impermeable surface barriers.

Know your progress

1. Why should communities ensure that septic tanks are maintained in goodcondition?
2. If you lived near the seashore and started to notice that your well water had a slightly salty taste, how would you explain the change in water quality?
3. ‘Protecting environment means preventing pollution' Justify the statement.

6.7 Greenhouse effect and global warming

Energy coming from the Sun is carried by electromagnetic radiation. Earth receives all wavelengths of solar radiation. But certain gases and other contaminants in the atmosphere have different effects on different wavelengths of radiation. Green house gases in the atmosphere absorb some of the longer wavelengths (infrared) radiation and keep some of it in the atmosphere (Fig. 6.17).

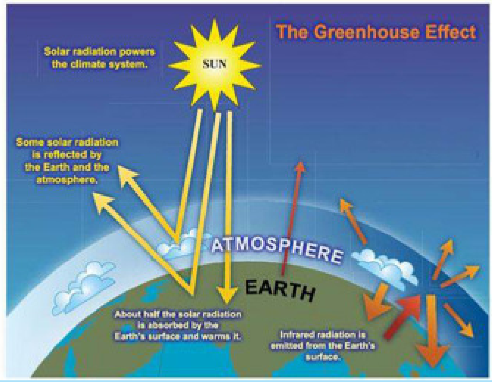


Fig. 6.17: The Greenhouse Effect

This keeps the atmospheric temperature relatively stable so long as the concentration of greenhouse gases remains relatively stable. The energy retained in the lower atmosphere causes the temperature at the Earth's surface to rise.

There are naturally occurring greenhouse gases in the atmosphere, such as water vapor (H_20) and naturally occurring carbon dioxide ($C0_2$), methane (CH_4) and Ozone (0_3). Water vapour is the most abundant greenhouse gas, but its concentration in the atmosphere varies with temperature. These gases help keep the Earth's surface warm and habitable. But anthropogenic greenhouse gases appear to be upsetting the balance.

The CO_2 concentration in the atmosphere has been increasing since the mid 1800s. The increase correlates well with burning of fossil fuels. Since the Industrial Revolution, there has been a significant increase in the amount of carbon dioxide and other greenhouse gases in the atmosphere. As a result, more of the solar radiation reaching the surface of the Earth is absorbed causing a significant increase in the average temperature worldwide.

Methane concentration in the atmosphere has also been increasing. Naturally this occurs due to decay of organisms, decomposition of organic excreta, and outflow from petroleum reservoirs. Humans have contributed through domestication of animals, increased production of rice, and leaks from gas pipelines and petroleum reservoirs.

Global warming is defined as an increase in the average temperature of the Earth's atmosphere, especially a sustained increase great enough to cause changes in the global climate. The term global warming is synonymous with enhanced greenhouse effect, implying an increase in the amount of green house gases in the Earth's atmosphere, leading to entrapment of more and more solar radiations, and thus increasing the overall temperature of the Earth. Whereas the greenhouse effect is a naturally occurring process, its enhancement due to increased release of greenhouse gases ($C0_2$ and other gases, such as methane and ozone) is called global warming.

6.7.1 Consequences of global warming

Detailed researches of climatic events of the past 150 years have revealed that the temperatures have risen all over the globe. Some of the indicators of global warming are:

(a) Changes in Ice patterns: Due to higher temperatures, ice in mountain glaciers will melt. Over the past 100 years, mountain glaciers in all areas of the world have decreased in size and so has the amount of permafrost in the Arctic. Greenland's ice sheet is melting too faster. Sea ice will be greatly reduced to the increased temperatures at the high latitudes, particularly in the northern hemisphere where there is more abundant sea ice.

(b) Rise of sea level: Since water also expands (increases its volume) when it is heated, global warming could also cause thermal expansion of sea water. Alongwith melting of mountain glaciers and reduction in sea ice, this will cause sea level to rise and flood coastal zones, where much of the world's population currently resides.

During the 20^{th} century, sea level rose about 15 cm (6 inches) due to melting of glacier ice and expansion of warmer seawater.

Models predict that sea level may rise as much as 59 cm (23 inches) during the 21st century, threatening coastal communities, wetlands, and coral reefs.

(c)Global climatic changes: A warmer atmosphere will lead to increased evaporation from surface waters and result in higher amounts of precipitation. The equatorial regions will be wetter than present, while the interior portions of continents will become warmer and drier than present. Higher temperatures cause a higher rate of evaporation in some areas and more droughts in other areas of the world. A warmer, wetter atmosphere will favour tropical storm development. There is evidence that the number of intense hurricanes has increased in the Atlantic since 1970.

(d) Changes in ecosystems: As temperatures warm, species may either move to a cooler habitat or die. Species that are particularly vulnerable include endangered species, coral reefs, and polar animals. Warming has also caused changes in the timing of spring events and the length of the growing season.

Know your progress

1. If the Earth warmed, causing evaporation from the oceans to increase greatly, how would the hydrologic cycle of today be altered?
2. How does the atmospheric pollution associated with the industrialization and urbanization lead to conditions of greenhouse effect and global warming?
3. How would you relate global warming with greenhouse effect?

6.8 Sustainable development and conservation of natural resources

Man has utilized the natural resources available to a wide extent and this will continue in the future also. He has now realized that the disturbance caused to the environment has reached very high levels and the resources are no longer usable uncontrollably.

The rapid increase in world's population and the accelerated rate of use of all the natural resources are making the consequences of misuse more drastic and more widespread. With the increasing industrialization and urbanization of the modern human society, the use of all the resources is rising. If they are not properly used and well managed, a serious scarcity will result. This will also upset the ecological balance. While living on the resource offered by the ecosystem it is necessary to maintain the sustenance levels of the ecosystem. This becomes very vital while taking up developmental activities.

6.8.1 Sustainable development

A developmental scenario in which no damage is done to the ecosystem can be ideally termed as *sustainable development.* It is the development that meets the needs of the present generation and conserves it for the future generation. So we should leave water, air, soil and other natural resources as pure and unpolluted as when it came on Earth. The prominent elements which need keen concern for sustainable developments include:

(a) Soils: Agricultural soils are seriously under threat. The formation of agricultural soils is a slow process taking place at the rate of a few millimeters per year. Man's activities such as deforestation, poor or totally absent landuse management techniques (e.g. slash and burn), and inadequate or excessive use of fertilizers and agro toxics, have resulted in extensive soil losses or soil degradation. Compost, the partly decomposed organic material can be used as fertilizer; thereby we can replenish the fertility of soil.

Overall, sustainable agriculture can only be achieved when soil erosion and degradation do not exceed replacement. At human time scales and with the current practices soil has become a non-renewable resource and a fundamental constraint to sustainable development. The foreseen reduction in fertile land area can be mitigated by developing measures to prevent soil loss both as a result of erosion and of soil contamination.

(b) Water: Water turns out to be the factor most limiting sustainable development. In the next decade the availability of fresh water will dictate all agendas of development, not only in developing countries, and might cause political instability in larger dry regions on Earth. The anticipated shortage of fresh water shall be alleviated through optimizing groundwater exploitation, by creating new aquifers through land reclamation and natural recharge, and by forecasting flow paths of pollutants in aquifers.

Surface runoff and degradation of soil can be controlled by adopting watershed based management strategies. It serves to integrate planning for land and water, taking into account both ground and surface water flow and recognizing the interaction of water, plants, animals and human land use found within the physical boundaries of a watershed.

(c) Waste disposal: Poor waste management often seriously obstructs sustainable development. Domestic waste is mostly stored on or near the surface near or in the immediate vicinity of urban centers. Too often such wastes dumps are poorly designed and lack an adequate lining underneath the dump or situated on permeable beds allow leaching to the aquifers. The availability of natural geological barriers preventing transport of contaminants into aquifers has to be taken into account.

(d) Energy: Non-renewable energy resources such as oil and natural gas are being gradually but irrevocably depleted. The need for energy keeps pace with population growth. Consequently, it is evident that the search for and wise use of energy resources deserves a prominent position in development agendas. The world's energy problems shall be met by developing methodologies for unconventional energy production and reducing wastage of energy resources during production, storage and transport.

(e) Mining: Large scale mining and quarrying activities may be allowed only based on the recommendations of scientific studies. Small scale mining and quarrying activities that are permitted in various local bodies should be planned and executed as a part of regional development plan. Mining should be avoided in the ecologically sensitive areas. Governments are increasingly concerned about the environmental impact of the mining and quarrying industry and impose severe environmental constraints on mining activities. The exercise of visualizing or assessing the effects of a project on the environment before taking it up is called 'Environmental Impact Assessment' .

6.8.2 Types of earth resources

The term "**resource**" means anything that we use from our environment to achieve our objective. For example, we require bricks, cement, iron, wood etc. to construct a building. All these items are called the resources for construction of building. A resource can be defined as any natural or artificial substance, energy or organism, which is used by human being for its welfare. Resources are broadly classified into **Natural Resources** and **Artificial** or **Man-made Resources.**

Natural and artificial resources

All that the nature has provided such as soil, air, water, minerals, coal, sunshine (sunlight), animals and plants, etc., are natural resources. Natural resources are naturally occurring substances that are considered as valuable in their relatively unmodified (natural) form. The resources, which have been developed by human being during the growth of civilization, are called artificial resources. For example, biogas, thermal electricity, plastics, etc. are manmade resources. These man-made resources are generally derived from some other natural resources.

Natural resources are mostly classified into renewable and non-renewable resources.

Renewable resources: Renewable resources are generally living resources (fish, animals and forests, for example), which can restock (renew) themselves if they are not over-harvested but used sustainably. The rate of sustainable use of a renewable resource is determined by the replacement rate and amount of standing stock of that particular resource. Once renewable resources are consumed at a rate that exceeds their natural rate of replacement, the standing stock will diminish and eventually run out. Water is an example for non-living renewable natural resource.

Non-renewable resources

The air we breathe and the light we get from the sun are available in unlimited quantity. What about coal, petroleum and gas resources? Do you ever think how long these precious materials of the nature will be available for our use? The resources, which cannot be replaced after the use, are known as non-renewable resources. These include minerals (copper, iron, etc.) and fossil fuels (coal, oil, etc.). The stock of these resources is limited and is depleting day by day.

6.8.3 Conservation of natural resources

The natural resources are depleting gradually and a day will come when most of these will not be available for our future generation. So it is high time to think about maintaining a balance between environment and development so that both present and future generations can derive proper benefits out of these resources. This has led to the concept of *conservation* of natural resources.

Conservation is the careful use of resources. It is the proper management of a natural resource to prevent its exploitation, destruction or degradation. It is thus, the sum total of activities, which can derive benefits from natural resources but at the same time, prevent excessive use leading to destruction or degradation. Most nonrenewable resources will run critically low in the near future. It is feared that unless proper steps are taken to conserve them in time, we will face tremendous hardship in future. Therefore we need to conserve the natural resources.

Strategies for conservation of mineral resources include recycling and substitution. Metallic minerals have a good recycle value. These minerals are not lost if once consumed. **Recycling** is the method of collecting and processing of used items so that they can be made into new products. Scraps produced during the production and consumption of fabrication works can be collected, melted and reused.

Replacement of a very scarce (rare in availability)mineral with a more abundant one is called **substitution**. By substitution, we can augment and supplement the use of scarce minerals. For example, worldwide shortage of copper is supplemented by aluminium. Scientists also develop artificial substitutes for many rare materials used in various industries.

Renewable energy sources, such as solar, wind, hydroelectric, and geothermal, are being developed. They will replace fossil fuels as those become scarcer, more expensive to retrieve from Earth, and undesirable due to environmental damage.

Non-renewable resources have to be extracted in such a way that does not damage the global environment, and provides for future generation. A utilization plan for a renewable resource such as water, forests, grasslands and fisheries that does not pollute the ecosystem and cause climatic change is the need of the mankind as a whole for his survival on this Earth.

Conservation of natural resources is now usually used in the broader conception of conserving the Earth itself by protecting its capacity for self-renewal. Sustainability is an environmental objective and thus we must sustain our environmental resources.

You should keep in mind that all elements of our natural environment such as soil, water, forest, minerals, fossil fuels, vegetation, etc., that man can utilize as a natural resource to promote his welfare have to be conserved.

The utilization of all kinds of natural resources is growing at an alarming rate, causing great concern for their conservation. Now conduct a seminar in your class on sustainable development and conservation of natural resources. A few issues that shall be addressed during the discussions on the topic are mentioned below.

- Overexploitation of natural resource
- Mismanagement of technology
- Energy crisis

- Conservation of the ecosystem
- Environmental degradation
- Problems of waste disposal and management
- Deforestation
- Organic farming
- Conservation of soil, water, mineral and fossil fuel resources

Know your progress

1. Does the Earth itself need to be preserved? Why?
2. What makes a resource renewable and nonrenewable?
3. How can we achieve the concept of sustainable development?

Let us conclude

Earth is a source for habitats and resources, and there is a geologic aspect in every environmental problem. It is certain that large-scale man-made activities create environmental impacts. Man has to visualize beforehand the impacts that may arise later due to his activities on the environment so that the developmental activities are harmonized with the environment. Environmental Geology focuses on the relationship between humans and their environment. Man has now realized the significance of environment for his survival on this Earth. Careful management and wise use of the planet and its limited resources tend to a socially just global economy. We have a moral obligation to the present and future Earth community to preserve and protect the environment.

Let us assess

1. Greenhouse gases absorb -----------.

   a) solar (short wave) radiation.

   b) long wave radiation emitted by the Earth.

   c) shortwave and long wave radiation equally well.

   d) neither shortwave nor long wave radiation.

2. Which among the following is an example for renewable resource?

   (coal, petroleum, groundwater, hematite)

3. The most important anthropogenic greenhouse gas among the following is:

   (carbondioxide, ozone, methane, water vapour)

4. What are the common contaminants in groundwater?

5. What might be done to control the saltwater intrusion?

6. Coal is a non-renewable source of energy whereas wood charcoal is renewable. Why?

7. Explain how the greenhouse effect works and how human activities influence global warming.

8. Describe the environmental impacts of sand mining.

9. What is meant by recycling?

10. Mention any three effects of mining on hydrosphere.

Chapter 07

Earthquakes

Significant Learning Outcomes

After the completion of this chapter, the learner:

- Describes the mode and causes of earthquakes.
- Explains the occurrence of earthquakes along the plate boundaries.
- Draws the major seismic belts of the world.
- Discriminates among different types of seismic waves.
- Illustrates seismographs and seismograms.
- Compares the magnitude and intensity scales of measuring the size of an earthquake.
- Identifies the effects of earthquakes as a natural calamity.

Civilization throughout the history has been gripped with fear of earthquakes because of their devastating effects. Earthquakes are the strongest, quickest and most unexpected of natural calamities. An earthquake is the shaking of the earth caused by the sudden release of energy from rocks under tectonic stress.

Seismology is the scientific study of earthquakes. Scientists who study earthquakes and seismicity (earthquake activity) are known as **seismologists.** The study of earthquake is of special significance for an engineering geologist and a civil engineer to design earthquake resistant buildings or other structures in earthquake-prone regions and to identify hazardous zone and formulate suitable building codes.

7.1 Causes of earthquakes

You have already learnt in Chapter IV (Geological structures) that, within the Earth, rocks are constantly subjected to forces that tend to bend, twist, or fracture them. The forces that cause deformation are referred to as *differential stresses* (i.e., stress being not equal from all directions). When rocks bend, twist or fracture they are said to *deform*. You have also learnt the three types of stress (called *tensional stress* or *extensional stress,* which stretches rock; *compressional stress*, which squeezes the rock; and shear *stress*, which result in slippage and translation of the affected portions) that deform rocks. When a rock is subjected to increasing differential stress it changes its shape, size or volume. Such a change in shape, size or volume is referred to as strain.

Recall the fact that we can also recognize three stages of deformation namely, *elastic deformation* - wherein the strain is reversible, *ductile deformation* - wherein the strain is irreversible and *fracture* - wherein the strain is irreversible and material breaks (Fig. 7.1). In general, rocks near the surface of the earth generally behave in a *brittle* manner. Thus, when they are acted upon by differential stress, they tend to fracture.

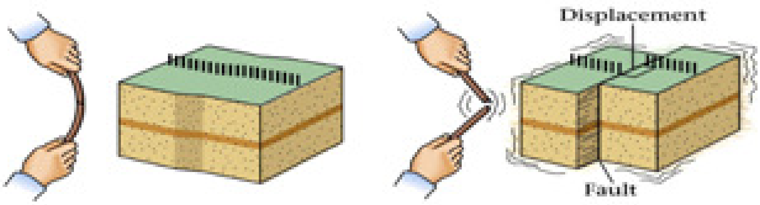


Fig. 7.1: Ductile Strain and Fracture

Faults occur when brittle rocks fracture and there is displacement of one side of the fracture relative to the other side.

Among the various causes, faulting constitutes the most widespread cause of earthquakes. Many theories have been put forward from time to time to explain rupture associated with faulting and consequent generation of earthquake vibrations.

7.1.1 Faulting and Elastic Rebound Theory

The elastic rebound theory, propounded by H. H. Reid in 1906, is widely acclaimed as a satisfactory explanation for most of the earthquakes. It involves the sudden release of progressively stored strain in rocks, causing displacement along a fault.

According to the elastic rebound theory, rock masses behave as elastic materials under operating stresses. When the rocks are stressed, they respond initially by elastic deformation and subsequently by plastic deformation. As the intensity of stress increases further, the rock mass reaches its limit of plastic deformation and rupture develops, accompanied with displacement of blocks along the rupture formed (Fig. 7.2).

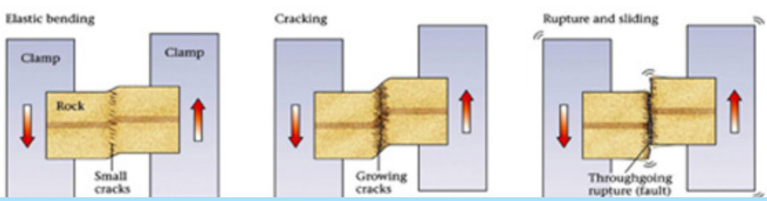


Fig. 7.2: Illustration of Elastic Rebound Theory

The elastic rebound theory suggests that if slippage along a fault is hindered then elastic strain energy builds up in the deforming rocks on either side of the fault. When the slippage does occur, the energy released causes an earthquake. Before the occurrence of an earthquake it was noted that the rocks adjacent to the fault were bending. These bends disappeared after an earthquake suggesting that the energy stored in bending rocks was suddenly released during the earthquake.

Friction between the blocks prevents the fault from moving again until enough strain has accumulated along the fault zone to overcome the friction and generate another earthquake. Once a fault forms, it becomes a zone of weakness in the crust, and so long as the stresses continue to be present more earthquakes are likely to occur on the fault.

The fundamental point of elastic rebound theory is that displacement of the rock masses is associated with a rebound of curvature developed due to stressing. At the time of this process of rebound, elastic energy stored during stressing is released at the place of displacement (focus) in the form of seismic waves.

Focus and epicenter of an earthquake

The point within the Earth where the fault rupture starts, constituting the actual location of the earthquake beneath the surface is called the **focus** or **hypocenter.** This is the exact location from where the seismic waves are generated. In other words, focus is the point of origin of an earthquake. Fracture begins at the focus and then spreads rapidly along the fault. The point on the surface of the earth directly above the focus is called the **epicenter** (Fig. 7.3).

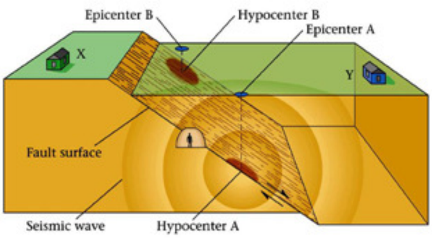


Fig. 7.3: Focus and epicenter of earthquakes

The focus of most earthquakes occurs relatively close to the earth's surface, although a few occur at much deeper levels. The maximum depth of focus for earthquakes is about 700 kilometers. Earthquakes may be classified into three groups according to their depth of focus:

a) Shallow focus earthquakes: Earthquakes that originate at depth between 0 - 70 km;

b) Intermediate focus earthquakes: Earthquakes that take place at 70 - 350 km depth; and

c) Deep focus earthquakes: Earthquakes that occur at 350 - 700 km depth.

Shallow focus earthquakes are most common; they account for 85% of total quake energy released. Intermediate (12%) and deep (3%) focus quakes are rarer because most deep rocks flow plastically when stressed or deformed and they are unable to store and suddenly release energy as brittle surface rocks do.

7.1.2 Tectonic causes of earthquakes

You have learnt that earthquakes are caused by faulting, a sudden lateral or vertical movement of rock along a rupture (break) surface. Earthquakes originate due to various reasons and among the various causes, faulting associated with tectonic activity constitutes the most widespread cause of earthquakes.

The tectonic earthquakes are by far the most common and destructive. The term 'tectonic' refers to structural changes of the crust due to deformation or displacement. Movements within the Earth's crust cause stress to build up at points of weakness, and rocks to deform.

The surface of the Earth is in continuous slow motion associated with Plate Tectonic activity. The plates cover the entire surface of the globe. Since they are all moving they rub against each other in some places (like the San Andreas Fault in California), sink beneath each other in others (like the Peru-Chile Trench along the western border of South America), or move apart from each other (like the Mid-Atlantic Ridge). At such places the rock masses along the edges of plates are distorted (what we call "strain"). As the motion continues, the strain builds up to the point where the rock cannot withstand any more distortion. Therefore the rock masses break and this event causes an earthquake.

7.1.3 Non-tectonic causes of earthquakes

Non-tectonic causes of earthquake include those associated with vibrations induced due to volcanic eruption, underground nuclear explosion, giant landslides, and impact of huge meteorite.

The earthquakes that are generated by volcanic activity are called volcanic earthquakes. Even in such cases the earthquakes result from a sudden slip of rock masses adjacent to the volcano and the consequent release of stored up energy. The geographic distribution of active volcanoes and frequent major earthquakes exhibit some correspondence, as in the case of the Circum-Pacific Belt and along mid oceanic ridges.

Volcanic earthquakes occur around active volcanoes, mainly due to explosive eruption and also due to hydraulic shocks of magma that forcibly fill underground chambers and channels. Earthquakes are sometimes caused by the detonation of large underground nuclear explosions, the excavation in mines, and the filling of large reservoirs behind dams.

Seismicity caused by impounding of water behind large and high dams is known as *'reservoir induced seismicity'* or as 'RIS'. Seismic effects of reservoir are most marked for those exceeding 100 metres in depth and 1 cubic km in volume. In India an earthquake in Koyna, which occurred in 1967 has been shown to be induced by the Koyna Dam and associated reservoir.

Along hill slopes landslides and rock falls of considerable magnitude often cause feeble tremors. Working of heavy machineries in industrial areas, movement of locomotives along railway tracks and in cities and even the heavy vehicles in motion, initiate feeble vibrations of the surface. Meteoric impact at the surface of the Earth may cause some tremors in the Earth.

7.2 Earthquakes and plate tectonics

The distribution and frequency of earthquakes is referred to as **seismicity** (Fig. 7.4). Most earthquakes occur along relatively narrow belts that coincide with tectonic plate boundaries. Some

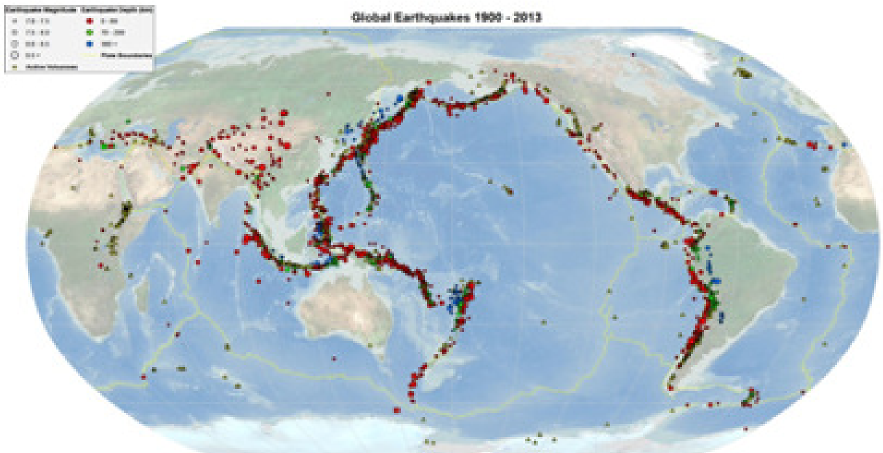


Fig. 7.4: World seismicity map

occur within plates and these are called **intraplate earthquakes.**

You have already learnt that plate boundaries are zones along which lithospheric plates move relative to one another. Analyse the figure given below (Fig 7.5) and try to identify the inter relationship between plate boundaries and zones of earthquakes.

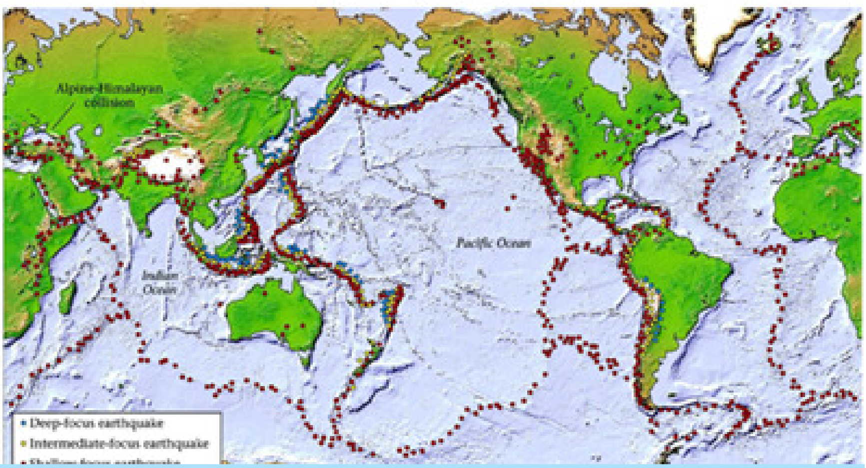


Fig. 7.5: Earthquake zones along lithospheric plate boundaries

7.2.1 Earthquakes at diverging plate boundaries

Diverging plate boundaries are zones where two plates move away from each other, such as the oceanic ridges. In such areas the lithosphere is in a state of tensional stress and thus normal faults and rift valleys occur. Earthquakes that occur along such boundaries show normal fault motion and tend to be shallow focus earthquakes, with focal depths less than about 20 km. Such shallow focal depths indicate that the brittle lithosphere must be relatively thin along these diverging plate boundaries.

7.2.2 Earthquakes at converging plate boundaries

Convergent plate boundaries are plate margins where two plates run into each other. Thus, they tend to be zones where compressional stresses are active and thus reverse faults or thrust faults are common. There are two types of converging plate boundaries, viz., (1) subduction boundaries, where oceanic lithosphere is pushed beneath either oceanic or continental lithosphere; and (2) collision boundaries where two plates with continental lithosphere collide.

Along subduction boundaries cold oceanic lithosphere is pushed back down into the mantle where two plates converge at an oceanic trench. Because the subducted lithosphere is cold, it remains brittle as it descends and thus can fracture under the compressional stress. When it fractures, it generates earthquakes that define a zone of earthquakes with increasing focal depths beneath the overriding plate (Fig. 7.6). This zone of earthquakes is called the **Benioff Zone**. Focal depths of earthquakes in the Benioff Zone can reach down to 700 km.

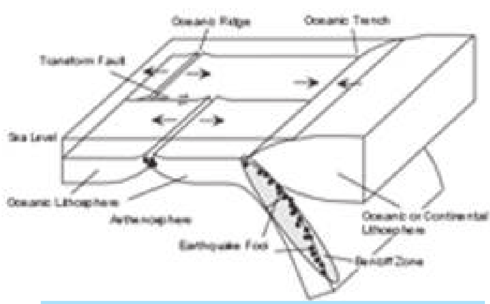


Fig. 7.6: Earthquake in relation to subduction zones

Along the collisional boundaries, two plates of continental lithosphere collide resulting in fold-thrust mountain belts. Earthquakes occur due to the thrust faulting and range in depth from shallow to about 200 km.

7.2.3 Earthquakes at transform fault boundaries

Transform fault boundaries are plate boundaries where lithospheric plates slide past one another in a horizontal fashion. The San Andreas Fault of California is one of the longest transform fault boundaries known. Earthquakes along these boundaries tend to be shallow focus earthquakes with depths usually less than about 50 km.

7.2.4 Intraplate earthquakes

These are earthquakes that occur in the stable portions of continents that are not near plate boundaries. Many of them occur as a result of re-activation of ancient faults, although the causes of some intraplate earthquakes are not well understood.

7.3 Seismic belts of the world

Studies on the occurrence of earthquakes on the globe show that they occur more frequently in certain places whereas in other places they are extremely rare and feeble. Most of the destructive earthquakes originate within two well defined belts or zones. They are: (1) The Circum Pacific belt, and (2) The Mediterranean and Trans-Asiatic Himalayan belt. Of these, the Circum Pacific belt which encircles the rim of the Pacific Ocean has the maximum concentration of earthquakes. This belt closely follows the deep ocean trenches and associated island arcs. It follows the western highlands of South and North America, crosses to Asia and extends southward along the eastern coast and related island arcs. This belt consists approximately 80 percent of world's shallow focus quakes, 90 % of the intermediate focus quakes and nearly 100% of the deep focus quakes.

The second major concentration of earthquakes is in the Mediterranean - Himalayan belt, which runs through the Mediterranean Sea, crosses the Middle East and the Himalayas and passes through the East Indies to meet the Circum-Pacific belt, of North Australia. This zone roughly follows the belts of Tertiary and recent mountain building areas. The earthquake zone lies inland and hence there are no associated trenches. Other earthquakes are located along the Mid-oceanic ridges and transform faults that intersect them.

You have learnt that, most of the earthquakes are located along the boundaries forming different plates. The earthquake belts are closely associated with the weaker zones and tectonically disturbed areas of the globe. Now prepare a map showing the seismic belts of the world in your *activity log.*

Know your progress

1. How are faults, foci and epicenters associated?
2. How do we explain the Benioff zone of deep focus earthquakes?
3. Earthquakes occur only in the rigid lithosphere, not in the plastic asthenosphere. Can you explain this phenomenon using the elastic rebound theory?

7.4 Seismic waves

You have learnt that, earthquake is an event of trembling or shaking of the ground, usually caused by the rupturing of a fault within the Earth and the energy stored in elastically strained rocks is suddenly released outward. The release of energy causes intense ground shaking in the area near the source of the earthquake and sends out waves of elastic energy, called **seismic waves,** throughout the Earth. The tremors of the crust last for a few seconds only rarely exceeding one minute.

Radiated energy that passes through the Earth during and after an earthquake are called seismic waves. A basic knowledge of waves in general is essential for understanding the type of seismic waves.

Waves are classified based on how particles of the medium through which the waves travel are moved by the wave propagation or how the wave causes the material it is travelling through to deform. Accordingly two types of waves can be recognized:

(1) **Longitudinal (Compressional) waves** - waves in which the motion of particles takes place parallel to the direction of the wave and causes the materials to contract and extend (back and forth) and the motion of particles will be parallel to wave direction(Fig. 7.7a). These waves can travel through any kind of medium (solids and fluids).

(2) **Transverse (Shear) waves** - waves in which the displacement of the medium is perpendicular to the direction of propagation of the waves (Fig. 7.7 b). A ripple on a pond and a wave on a string are easily visualized transverse type of waves. Transverse waves cannot propagate in a fluid (gas or a liquid).

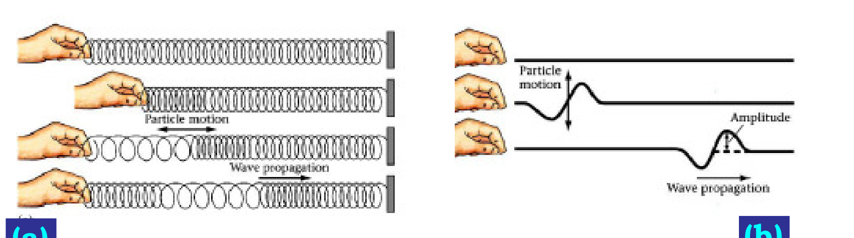


Fig. 7.7: (a) Longitudinal waves and (b) Transverse waves

On the basis of what the wave is travelling through / along, two types are recognized: (1) Body waves - these travel through the body or interior of the material, and (2) Surface waves - those travelling along the surface of the material. Earthquakes produce both body waves and surface waves. These can travel in several ways, and thus there are several different kinds of seismic waves.

7.4.1.Body waves

The body waves travel in all directions through the body of the Earth. They are emanating from the point of origin of an earthquake. There are two types of body waves:

(a) P-waves (Primary waves): Primary waves are compressional waves or 'push-pull' waves or longitudinal waves (Fig. 7.8 a). These travel with a velocity that depends on the elastic properties of the rock through which they travel. P-waves travel similar to sound waves in air. These are the fastest among the seismic waves, so they always arrive first at a seismological station.

(b) S-waves (Secondary waves): Secondary waves are shear waves or transverse waves (Fig. 7.8b). These body waves travel approximately at 60% the speed of P-waves. Hence S-waves arrive subsequent to P waves in a seismic station. The speed of S-waves depends mainly on the rigidity and density of the material through which they travel. The resistance to shearing of a material is the property called the rigidity. It should be noted that liquids have no rigidity, so the velocity of S-wave is zero in a liquid (i.e., they do not travel through liquids).

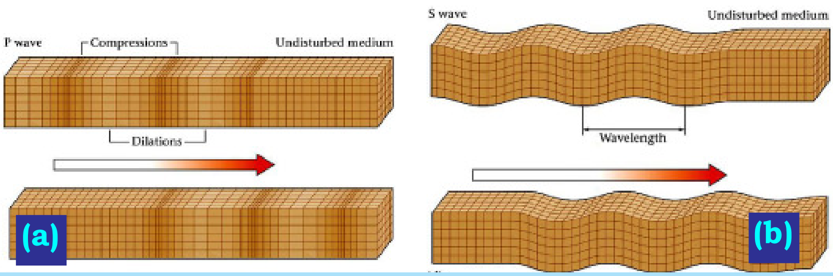


Fig. 7.8: (a) Primary waves and (b) Secondary waves

7.4.2 Surface waves

The second type of seismic waves, the so called surface waves differs from body waves in that they do not travel through the earth, instead travel along the surface of the earth. These have the slowest travel speeds. Two types of surface waves recognized are: (a) R-waves - (Rayleigh, named after a physicist) which are surface shear waves that make the ground move up and down in a retrograde elliptical motion in the vertical plane, and (b) L-waves - (Love, named after a seismologist) which are surface shear waves that cause the ground to move side to side in a horizontal plane (like a snake). Note that there are no surface compressional waves but only surface shear waves (Fig. 7.9).

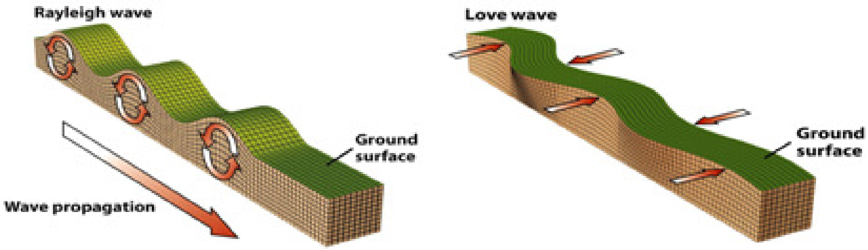


Fig. 7.9: Rayleigh and Love waves

Know your progress

1. When an earthquake occurs, waves are produced and sent into the earth. In what respect do the body waves and surface wave differ from one another?
2. Why are primary waves called as compressional waves?

7.5 Seismograph and seismogram

Seismic waves are detected and recorded by instruments called **seismographs** or **seismometers**. Seismologists use seismographs to measure vibrations of the Earth during and after an earthquake. A seismograph is an instrument used to record the vibrations produced during an earthquake and the resulting graph that shows the vibrations is called a **seismogram.**

The seismograph must be able to move with the vibrations, yet part of it must remain nearly stationary. This is accomplished by isolating the recording device (like a pen) from the rest of the Earth using the *principle of inertia* - resistance of a stationary mass to sudden movement or vice versa. For example, if the pen is attached to a large mass suspended by a spring, the spring and the large mass move less than the paper which is attached to the Earth, and on which the record of the vibrations is made.

Suspended heavy mass remains motionless as the ground vibrates. This stationary mass can be used to record the motion of the earth on a strip of paper attached to a rotating drum in the instrument because the drum vibrates as the ground shakes. Vibrations are recorded on the strip of paper on rotating drum. The paper that the pen writes is the seismogram.

Seismic waves cause motion of the earth. Seismographs detect this motion. Some seismographs are designed to detect vertical motion of the ground; others are designed to detect horizontal motion (in multiple directions - North-South, East-West). As the ground moves down, the seismograph records a positive or upward slope. A simple construction of a seismograph is shown in Fig. 7.10 (a) and (b).

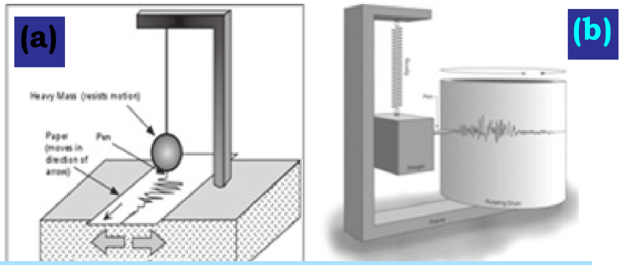


Fig. 7.10 (a) and (b): A simple construction of a seismograph

The record of an earthquake (a seismogram), as recorded by a seismograph, is a plot of *vibrations* versus *time*. On the seismogram time is marked at regular intervals, so that we can determine the time of arrival of the *first P-wave* and the time of arrival of the *first S-wave.*

We have already noted that since P-waves have a higher velocity than S-waves, the P-waves arrive at the seismographic station before the S-waves as you can see in the Fig. 7.11.

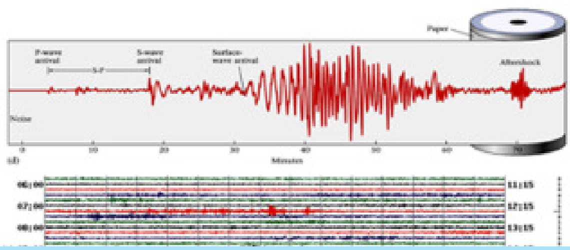


Fig. 7.11: Seismogram of P and S waves

Surface waves travel a little slower than S waves (which, in turn, are slower than P waves) so they tend to arrive at the seismographic station after the arrival of the S waves.

The surface waves have longer amplitudes and relatively a lower frequency. For all types of seismic waves the amplitudes of waves decrease with the distance travelled. So all things being equal, the farther you are from the source of an earthquake the less shaking you will feel. Surface waves are responsible for much of the shaking of the ground and generally cause most of the damage during earthquakes.

When you look at a seismogram, there will be wiggly lines all across it (Fig. 7.12). These are all the seismic waves that the seismograph has recorded. Most of these waves were so small that nobody felt them. These tiny **microseisms** can be caused by heavy traffic near the seismograph, waves hitting a beach, the wind, and any number of other ordinary events that cause some shaking

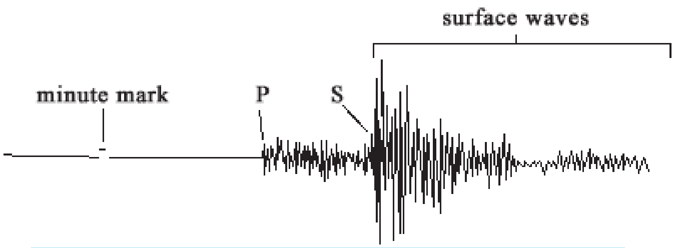


Fig. 7.12: Wiggly lines of a seismogram

So which wiggles are those of the earthquake? The P wave will be the first wiggle that is bigger than the rest of the little ones (the **microseisms**). Because P waves are the fastest seismic waves, they will usually be the first ones that your seismograph records. The next set of seismic waves on your seismogram will be the S waves. These are usually bigger than the P waves.

If there aren't any S waves marked on your seismogram, it probably means the earthquake happened on the other side of the planet. S waves can't travel through the liquid layers (outer core) of the earth so these waves never reach your seismograph.

Modern seismographs work on the same principles as those of the classic design, but these use a coil of wire placed inside a magnet (Fig. 7.13). Moving a wire through a magnetic field induces a current which can be measured by a computer. Modern seismographs can measure motions of a millionth of a millimeter. Seismographs all around the world are uniformly calibrated so that they all generate comparable data.

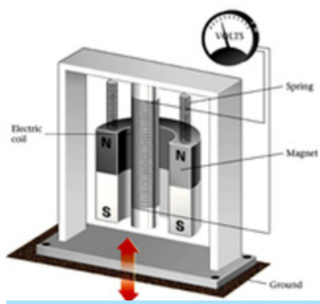


Fig. 7.13: Working of a modern seismograph

7.6 Measuring the size of an earthquake (Magnitude and Intensity)

Size of an earthquake is measured by two different means: (1) Magnitude (2) Intensity. While magnitude refers to the amount of energy released by the quake, intensity of an earthquake is determined on the basis of how much and what kind of damage the quake has caused.

a) Earthquake magnitude

A better measure of the size of an earthquake is the amount of energy released by the earthquake. Magnitude is a measure of the strength of an earthquake or of the energy released.

Earthquake magnitude is expressed by the amplitude of the seismic waves generated by an earthquake and recorded by seismographs. In 1935, the American seismologist Charles F. Richter set up a magnitude scale of earthquakes. This scale is a logarithmic scale (to the base 10) of the maximum seismic wave amplitude (in thousandths of a millimeter) recorded on a standard seismograph, at a distance of 100 km from the earthquake epicenter. For each increase in 1 in the Richter Magnitude, there is a ten-fold increase in amplitude of the wave. (Note that it is incorrect to say that each increase of 1 in Richter Magnitude Scale represents a ten-fold increase in the size of the Earthquake).

It has been found that each increase of 1 in magnitude scale represents a 31 fold increase in the amount of energy released. Thus, a magnitude 7 earthquake releases 31 times more energy than a magnitude 6 earthquake. A magnitude 8 earthquake releases 31 x 31 or 961 times more energy than a magnitude 6 earthquake. Table 7.1 depicts the worldwide frequency of earthquakes of different magnitudes.

Table 7.1: Worldwide frequency of earthquakes of different magnitudes

Magnitude	Number of earthquakes per year	Description
> 8.5	0.3	Great
8.0 - 8.4	1	
7.5 -7.9	3	Major
7.0-7.4	15	
6.6-6.9	56	
6.0-6.5	210	Destructive
5.0-5.9	800	Damaging
4.0-4.9	6,200	Minor
3.0-3.9	4,900	
2.0-2.9	3,00,000	
0-1.9	7,00,000	

Modified Mercalli Intensity Scale

Mercalli Intensity Scale - defines the **intensity of an earthquake** by the amount of damage it does and how much shaking is felt. The Modified Mercalli Scale was developed in the late 1800s to assess the intensity of ground shaking and building damage over large areas and the scale is denoted by Roman numerals ranging from I to XII. The intensity scale is applied after the earthquake by conducting surveys of people's response to the intensity of ground shaking and destruction. The Modified Mercalli Scale is shown in the table 7.2 below. *Note that correspondence between maximum intensity and Richter scale magnitude only applies in the area around the epicenter.*

Table 7.2: The Modified Mercalli Scale		
Intensity	**Characteristic Effects**	**Richter Scale Equivalent**
I	People do not feel any Earth movement	3.4
II	A few people notice movement if at rest and/or on upper floors of tall buildings.	
III	People indoors feel movement. Hanging objects swing back and forth. People outdoors might not realize that an earthquake is occurring.	4.2
IV	People indoors feel movement. Hanging objects swing. Dishes, windows, and doors rattle. Feels like a heavy truck hitting walls. Some people outdoors may feel movement. Parked cars rock.	4.3 - 4.8
V	Almost everyone feels movement. Sleeping people are awakened. Doors swing open/close. Dishes break. Small objects move or are turned over. Trees shake. Liquids spill from open containers.	4.9-5.4
VI	Everyone feels movement. People have trouble walking. Objects fall from shelves. Pictures fall off walls. Furniture moves. Plaster in walls may crack. Trees and bushes shake. Damage slight in poorly built buildings.	5.5 - 6.1
VII	People have difficulty standing. Drivers feel cars shaking. Furniture breaks. Loose bricks fall from buildings. Damage slight to moderate in well-built buildings; considerable in poorly built buildings.	5.5 - 6.1
VIII	Drivers have trouble steering. Houses not bolted down shift on foundations. Towers & chimneys twist and fall. Well-built	

	buildings suffer slight damage. Poorly built structures severely damaged. Tree branches break. Hillsides crack if ground is wet. Water levels in wells change.	6.2 - 6.9
IX	Well-built buildings suffer considerable damage. Houses not bolted down move off foundations. Some underground pipes broken. Ground cracks. Serious damage to Reservoirs.	6.2 - 6.9
X	Most buildings and their foundations destroyed. Some bridges destroyed. Dams damaged. Large landslides occur. Water thrown on the banks of canals, rivers, lakes. Ground cracks in large areas. Railroad tracks bent slightly.	7.0 - 7.3
XI	Most buildings collapse. Some bridges destroyed. Large cracks appear in the ground.Underground pipelines destroyed. Railroad tracks badly bent.	7.4 - 7.9
XII	Almost everything is destroyed. Objects thrown into the air. Ground moves in waves or ripples. Large amounts of rock may move.	>8.0

A given earthquake will have zones of different intensity all surrounding a zone of maximum intensity. The Mercalli Scale is very useful in examining the effects of an earthquake over a large area, because it will be responsive not only to the size of the earthquake as measured by the Richter scale for areas near the epicenter, but will also show the effects of the efficiency that seismic waves are transmitted through different types of material near the Earth's surface.

Know your progress

1. For each increase of 1 on the Richter Scale, how many times does the wave amplitude increase?
2. How many times more energy does an earthquake measuring 7 on the Richter scale release, than an earthquake with a magnitude of 5?
3. What is the measure of damage occurred during an earthquake?

7.7 Effects of earthquakes

Earthquake is a natural calamity. It never gives opportunity and scope to people to save their lives and escape. People are caught unaware and the catastrophe is so sudden and frequency so uncertain that there is not much scope to caution people beforehand. The earliest documented earthquake in China of 1556 killed 830,000 people in a matter of minutes. Since then, a number of earthquakes have visited Japan, Indonesia, Russia, Italy, India and many other parts of the world leaving behind trails of destruction and devastation.

In the twentieth century alone, millions of people were killed in different parts of the world due to earthquakes and much larger number physically disabled. The Gujarat earthquake of 26^{th} January 2001 of India, when the country was to celebrate its Republic day, killed and injured more than a million persons in a single day.

Earthquakes have varied effects that cause damage and destruction. These include modification of geologic features, damage to man-made structures, and impact on human and animal life. Some of these effects are direct or *primary* results of the ground shaking produced by the arrival of seismic waves and others are *secondary* effects.

(a) Modification of geological features: There may be both vertical as well as horizontal displacements of rocks causing development of slopes and sometimes fissures and open cracks. Groundwater and its movements often get disturbed by earthquakes. Sometimes the courses of streams change. In the most intensely damaged region, the effects of a severe earthquake are usually complicated and depend on the topography and the nature of the surface materials. They will be often more severe in regions of loose unconsolidated sediments such as alluvium than those of hard rock.

(b) Damage to structures: Earthquakes can cause significant damage to buildings, bridges, pipelines, railways, embankments, reservoirs, and other man-made structures (Fig.7.14). Damage caused to structures from ground shaking depends on the type of construction. Concrete and masonry structures, because they are brittle, they are more susceptible to damage than wood and steel structures, which are more flexible. Earthquakes may destroy the road communication and tear apart the water pipes and gas pipelines. Railway lines are buckled and twisted. Shaking of the ground caused by the passage of seismic waves is responsible for the collapse of most structures. The type and extent of damage caused are related primarily to the strength of the ground motions as well as to the behavior of the foundation.

Fig.7.14: Devastating effects of earthquakes

(c) Ground rupture: Ground rupture occurs only along the fault zone that moves during the earthquake. When this occurs, any man-made structures that are built across fault zones may collapse, whereas structures built adjacent to, but not crossing the fault may survive.

(d) Seismic sea waves or tsunami: Following certain submarine earthquakes, very long-wavelength water waves produced in oceans or seas sweep far inshore. These are the **seismic sea waves** or **tsunamis** (tsunami is a Japanese word for "harbour wave"). Tsunami are giant ocean waves that can rapidly travel across oceans. These waves sometimes come ashore to great heights-tens of metres above mean sea level-and may be extremely destructive to coastal settlements.

The figure given (Fig 7. 15 a and b) depicts the tsunami waves and their effects on the coastal areas.

Fig.7.15 (a) and (b): Effects of tsunami on coasts

The most destructive tsunami ever recorded occurred on December 26, 2004, after an earthquake displaced the seabed off the coast of Sumatra, Indonesia. More than 200,000 people were killed by a series of waves that flooded coasts from Indonesia to Sri Lanka (including those of India) and the associated waves even washed ashore the southern tip of Africa.

(e) Seiches: Rhythmic motions of water in nearly landlocked bays, canals or lakes are sometimes induced by earthquakes and tsunamis. These are known as **seiches.** Oscillations of this sort may last for hours or even for a day or two.

(f) Seaquakes: The seismic waves from an earthquake and their following refraction through the seafloor pass through the seawater often with a speed of about 1.5 km per second. If such waves meet a ship with sufficient intensity, they give the impression that the ship has struck a submerged object. This phenomenon is called a **seaquake.**

(g) Fire: Fire is a secondary effect of earthquakes. Because power lines may be knocked down and natural gas lines may rupture due to an earthquake, fires are often started closely following an earthquake. If water lines are also broken during the earthquake, there will not be a supply of water to extinguish the fires once they have started.

(h) Landslides and Debris/Rock falls: In mountainous regions subjected to earthquakes ground shaking may trigger rapid mass-wasting events such as landslides, rock falls and debris falls, slumps, and debris avalanches and so on. Sudden subsidence of a land near sea or lake results in coastal flooding and drowning.

(i) Flooding: Flooding is a secondary effect that may occur due to tsunami, rupture of human made dams and reservoirs, and as a result of ground subsidence after an earthquake.

(j) Liquefaction: Liquefaction is a process that occurs when the mechanical property of some water-saturated unconsolidated sediments turn from solid to liquid, during shaking caused by earthquakes. In areas underlain by such material, the ground shaking causes the grains to lose grain to grain contact, and thus the material tends to flow. Liquefaction may occur several minutes after an earthquake.

You can demonstrate this process to yourself next time you go the beach. Stand on the sand just after an incoming wave has passed. The sand will easily support your weight and you will not sink very deeply into the sand if you stand still. But, if you start to shake your body while standing on this wet sand, you will notice that the sand begins to flow as a result of liquefaction (Fig. 7.16), and your feet will sink deeper into the sand.

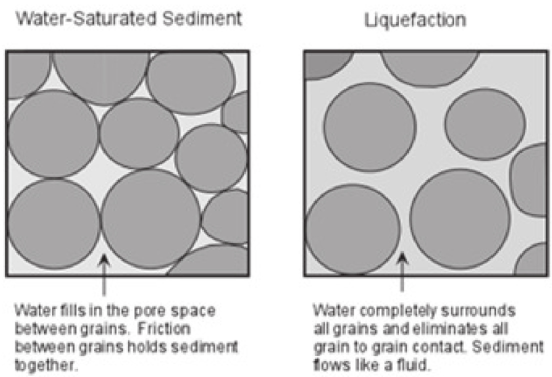


Fig. 7.16: Effects of liquefaction in water saturated sediments

(k) Aftershocks: Aftershocks are smaller earthquakes that follow the main shock. Earthquakes can change the stress state in rocks near the hypocenter and this may induce numerous earthquakes that occur after the main earthquake. These are always smaller earthquakes, but they can be numerous and last for many months after the main earthquake. Aftershocks are particularly dangerous because they can cause further damage to already damaged structures and make it unsafe for the conduct of rescue efforts in earthquake hit regions.

Know your progress

1. Can you list out the primary effects associated with ground shaking during an earthquake?
2. How does ground shaking during an earthquake depend on such things as distance from the epicenter and type of bedrock?

EARTHQUAKE PREDICTION

Some scientists believe that a practical method for predicting earthquakes would soon be found, but the continuing failure led many to question whether it was even possible. While some scientists still hold that, given enough resources, prediction might be possible, many others maintain that earthquake prediction is inherently impossible.

Long-term forecasting

Long-term forecasting of earthquakes is based mainly on the knowledge of when and where earthquakes have occurred in the past. Thus, knowledge of present tectonic setting, historical records, and geological records are studied to determine locations and recurrence intervals of earthquakes.

Short-term prediction

Short-term prediction involves monitoring of processes that occur in the vicinity of earthquake prone faults for activity that signify a coming earthquake. Anomalous events or processes that may precede an earthquake are called precursor events and might signal a coming earthquake. Despite the array of possible precursor events that are possible to monitor, successful short-term earthquake prediction has so far been difficult to obtain.

Among the precursor events that may be important are the following:

(i) Uplift and tilting of ground: *Measurements taken in the vicinity of active faults sometimes show that prior to an earthquake the ground is uplifted or tilts due to the swelling of rocks caused by strain building on the fault. This may lead to the formation of numerous small cracks (called microcracks). This cracking in the rocks may lead to small earthquakes called foreshocks.*

(ii) Foreshocks: *Prior to a 1975 earthquake in China, the observation of numerous foreshocks led to successful prediction of an earthquake and evacuation of the city of the Haicheng. The magnitude 7.3 earthquake that occurred, destroyed half of the city of about 100 million inhabitants, but resulted in only a few hundred deaths because of the successful evacuation.*

(iii) Abrupt changes of water level in wells: *As rocks become strained in the vicinity of a fault, changes in pressure of the groundwater (water existing in the pore spaces and fractures in rocks) occur. This may force the groundwater to move to higher or lower elevations, causing changes in the water levels in wells.*

(iv) Emission of radon gas: *Radon is an inert gas that is produced by the radioactive decay of uranium and other elements in rocks. Because radon is inert, it does not combine with other elements to form compounds, and thus remains in a crystal structure until some event forces it out. Deformation resulting from strain may force the radon out and lead to emissions of radon that show up in well water. The newly formed microcracks discussed above could serve as pathways for the radon to escape into groundwater. Increases in the amount of radon emissions have been reported prior to some earthquakes*

(v) Strange animal behavior: *Prior to a magnitude 7.4 earthquake in Tanjin, China, zookeepers reported unusual animal behavior. Snakes refusing to go into their holes, swans refusing to go near water, pandas screaming, etc. This was the first systematic study of this phenomenon prior to an earthquake. Although other attempts have been made to repeat a prediction based on animal behavior, there have been no other successful predictions.*

Let us conclude

Earthquakes are one among the major natural disasters for those living in earthquake prone areas. Most earthquakes are associated with rock movements along faults below the surface of the Earth. The elastic rebound theory explains how energy is stored in rocks. When an earthquake occurs, the elastic energy is released and sends out vibrations (seismic waves) that travel in all directions throughout the Earth.

The arrival of energy fronts released by rupture is recorded in seismographs during the events of an earthquake in the form of seismograms. Richter magnitude scale measures total amount of energy released by an earthquake. Intensity scale is subjective measure of the kind of damage done and people's reactions to it. The destructive effects of earthquakes include building collapse, ground failure, tsunami and fire. However, the seismic waves generated by earthquakes are invaluable for the study of the interior of the Earth.

Let us assess

1. Mention the terms used to describe the following:

   (a) The actual position of the earthquake's origin.

   (b) Location on the earth's surface lying directly above the focus.

   (c) Records obtained from seismograph.

2. Choose the correct answer from those given in brackets.

   (Seismology, Seismograph, Seismicity, Tsunami)

   (a) Seismic sea waves of very long wave length.

   (b) Instruments that detect arrival of seismic waves.

   (c) Scientific study of earthquakes.

   (d) The distribution and frequency of earthquakes.

3. Explain the elastic rebound theory on the cause of earthquakes.

4. What is the difference between the epicenter and the focus of an earthquake?

5. Compare and contrast the motion produced by P waves with movement created by S waves.

6. Which type of seismic waves causes the greatest destruction to buildings?

7. What is the difference between the magnitude and intensity of an earthquake?

8. How does the distribution of earthquakes correlate with plate boundaries?

9. Describe the major effects of earthquakes.

10. How does the Richter scale work in terms of ground motion and energy release?

Chapter 08

Geological Hazards and Disaster Management

Significant Learning Outcomes

After the completion of this chapter, the learner:

- Defines the terms associated with disaster management such as hazard, disaster, vulnerability, risk and capacity.
- Describes the various phases of the disaster management cycle.
- Identifies the steps to be taken to minimize the risks associated with earthquakes.
- Draws a conclusion about the mitigation of tsunami hazards.
- Explains the effects and mitigation of volcanic disasters.
- States the causes, adverse effects and mitigation of flood hazards.
- Demonstrates the controlling factors and mitigation strategies of landslides.
- Illustrates the causative factors of coastal erosion and evaluates the strategies of coastal zone management.

People have been living with risk ever since they first joined efforts, shared resources and assumed responsibilities in social groups. Social development and human well being have advanced only because people have taken risk. Over the recent decades there has been an alarming increase in the occurrence of natural disasters and the magnitude of their social, economic and environmental impacts. This extensive damage to lives, property and livelihood of the affected communities has turned back the development clock of the areas by decades.

The super cyclone of Orissa (1999), the Gujarat earthquake (2001), the Tsunami (2004), the Kashmir flood (2014) and the cyclone Hud Hud in Andhra Pradesh (2014) affected millions across the country leaving behind a trail of heavy loss of life, property and livelihood. Floods, cyclones and storm waves are recurring features causing untold human sufferings in different parts of the country. Earth processes are so powerful that humans cannot hope to prevent them. But, by understanding what causes these hazards and why they occur, we can do a great deal to reduce their harmful impacts.

8.1 Basic concepts in disaster management

People have to learn how to make the disasters less severe and less risky by taking timely actions in coping with natural hazards. Before we start to learn about management of disasters, we should get familiar with certain commonly used terms in disaster management. These include, *hazard, disaster, risk, vulnerability and capacity.*

8.1.1 Hazards and disasters

A hazard is a *situation* that poses a level of threat to life, health, property, or services, socio - economic disruption, or environmental damage. A hazard has only a theoretical or potential risk of creating harm. More specifically, the term hazard is applied for a *dangerous phenomenon, substance, human activity or condition* that may cause loss of life, injury or other health impacts, property damage and loss of livelihoods.

Hazards could be either man made or naturally occurring. Anthropogenic hazards are mostly associated with industries or energy generation facilities and include explosions, leakage of toxic waste, pollution, dam failure, wars or civil strife etc.

A disaster can be defined as *'a serious disruption in the functioning of the community or a society causing wide spread material, economic, social or environmental losses which exceed the ability of the affected society to cope using its own resources'.* A hazard is a physical event that can potentially trigger a disaster. Such a physical event itself need not necessarily result in a disaster. For example; an earthquake in an uninhabited desert cannot be considered as a disaster, no matter how strong the intensities are.

An *emergency* and a *disaster* are two different situations: An **emergency** is a situation in which the community is capable of coping. A **disaster** is a situation in which the community is incapable of coping.

Natural hazards are the result of naturally occurring processes that have operated throughout the Earth's history.

Classification of Natural Hazards

Natural hazards can be divided into several different categories. One of the classifications is shown in the figure given here (Fig 8.1).

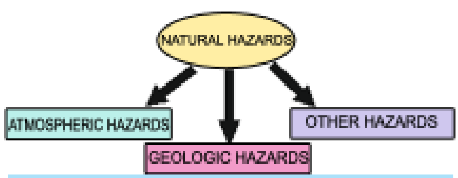


Fig 8.1 : Classification of Natural Hazards

Geologic hazards are geological processes or phenomena that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. **Atmospheric hazards** result from processes operating in the atmosphere. Natural hazards that do not fall into either geologic or atmospheric categories are grouped under '**other types of hazards**'.

8.1.2 Risk

Risk is a "measure of the expected losses due to a hazard event occurring in a given area over a specific time period". The risks associated with a disaster are the potential losses in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period. A community/locality is said to be at 'risk' when it is exposed to hazards and is likely to be adversely affected by its impact.

8.1.3 Vulnerability

In the context of disasters, the term vulnerability can be defined as *'the extent to which a community, structure, services or geographic area is likely to be damaged or disrupted by the impact of particular hazard, on account of their nature, construction and proximity to hazardous terrains or a disaster prone area.'* Communities and population settled in areas susceptible to the impact of a violent river or the violent tremors of the Earth are placed in situations of high vulnerability.

8.1.4 Capacity

It refers to the *'resources, means and strengths that exist in households, people and communities and which enable them to cope with, withstand, prepare for, prevent, mitigate or quickly recover from a disaster'.*

It is important to bring down the degree of vulnerability in order to reduce risk. To do this, it is essential that we should thoroughly understand the natural processes. This knowledge will enable us to develop appropriate actions intended to minimize the risk. Such *minimization of risk is called* ***hazard mitigation.***

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8.2 Disaster management

Disaster management can be defined as the organization and management of resources and responsibilities for dealing with all humanitarian aspects of emergencies, in particular preparedness, response and recovery in order to lessen the impact of disasters. It aims to avoid, lessen or transfer the adverse effects of hazards through activities and measures including prevention, mitigation and preparedness.

8.2.1 Phases of disaster management cycle

The different phases of disaster management cycle involve planned steps taken to minimize the effects of a disaster. The three important stages of activities that are undertaken during disaster risk management are: 1) Before a disaster (pre-disaster phase), 2) During a disaster (disaster occurrence phase) and 3) After a disaster (post-disaster phase).

Carefully analyse the diagram given below (Fig.8.2) on phases of disaster management cycle. Discuss and share the ideas you know with your peer learner, about the management strategies/ steps taken by the various government authorities/voluntary organizations in the event of any disaster that you have heard. Note down the ideas in your *activity log.*

Fig 8.2: Phases of Disaster Management Cycle.

Preparation or Preparedness: Preparedness refers to those measures that are to be taken up before a disaster event occurs, which are aimed at minimizing loss of life, disruption of critical services, and damage when the disaster occurs. It includes the formulation of viable emergency plans, the development of warning systems, the maintenance of inventories and the training of personnel.

Response: It involves activities taken during a disaster to minimize the losses created by a disaster. Examples: Public Warning Systems; Emergency Operations; Search and Rescue; Evacuation; Emergency relief.

Recovery: Recoveries are the activities following a disaster. Examples: Temporary Housing; Claims Processing and Grants; Long-term Medical Care, Counselling, and returning the community to normal conditions. This phase includes assessing damage, stabilization and salvage techniques, restoration of records, information and equipment, and resumption of operations.

Mitigation: (Activities that reduce the effects of disasters). This embraces the measures taken to reduce both the effect of the hazard and the measures to reduce the scale or intensity of a forth coming disaster. Mitigation measures include water management in drought prone areas, relocation of people away from the hazard prone areas and strengthening of structures to reduce damage when a hazard occurs. In addition to the physical measures, mitigation should also aim at reducing the economic and social vulnerabilities of potential disasters.

8.2.2 Effects of hazards

Hazardous process of any type can have primary, secondary, and tertiary effects. **Primary effects** occur as a result of the process itself. For example, damage due to floodwater, collapse of buildings during an earthquake, volcanic eruption, landslide, or hurricane. **Secondary effects** occur only because a primary effect has caused them. For example, fires ignited as a result of earthquakes, disruption of electrical power and water service as a result of an earthquake, flooding caused by a landslide into a lake or river. **Tertiary effects** are long-term effects that are set off as a result of a primary event. These include things like loss of habitat caused by a flood, permanent changes in the position of river channel caused by flood, crop failure caused by a volcanic eruption etc.

8.2.3 Prediction and warning

Risk and vulnerability can sometimes be reduced if there is an adequate means of **predicting** a hazardous event. Prediction is a statement made about the future and in the study of disasters it involves (a) A statement of probability that an event will occur based on scientific observation and (b) Such observation usually involves monitoring of the process in order to identify some kind of precursor events.

A **warning** is a message informing danger. It is a statement that a high probability of a hazardous event, based on a prediction or forecast.

The effectiveness of a warning depends on (a) the timeliness of the warning, (b) effective communication and public information systems to inform the public of the imminent danger, and (c) the credibility of the sources from which the warning came.

Know your progress

1. What is meant by disaster management? What are the different stages of disaster management?
2. Differentiate between natural disasters and manmade disasters with examples.
3. Explain with examples the difference between hazard and vulnerability.

Now let us discuss some of the significant geologic hazards in the context of disaster management. Geological hazards include earthquakes, tsunami volcanoes, landslides, floods, storm surges, ground subsidence, coastal erosion, avalanches, etc.

8.3 Earthquakes

You have already learnt the causes and effects of earthquakes in the previous chapter. Recall the fact that, earthquakes occur when energy stored in elastically strained rocks is suddenly released. The strain energy is released in waves that travel out in all directions from the focus. These waves of energy cause rocks to vibrate, making them extremely destructive.

8.3.1 Earthquake risk

Many seismologists hold the view that *"earthquakes don't kill people, buildings do"*. Each building may have different vulnerability. Most deaths from earthquakes are caused by buildings or other human construction falling down during an earthquake (Fig 8.3).

Fig 8.3 : Collapse of buildings during the event of earthquakes

Earthquakes located in isolated areas far from human population rarely cause any deaths. Thus, earthquake hazard risk depends on (1) **Population density** (2) **Construction standards** (This depends on building code. Building code is a set of ordinances or regulations and associated standards intended to control aspects of the design, construction, materials, alteration and occupancy of building that are necessary to ensure human safety and welfare, including resistance to collapse and damage), and (3) **Emergency preparedness.**

8.3.2 Mitigation of earthquake damage

As we discussed previously "earthquakes don't kill people, buildings do". Thus, if we can construct buildings and other structures in such a way that they do not collapse or fail during an earthquake, we can reduce the casualties and damage from earthquakes. Construction of buildings and other structures in such a way that they do not collapse or fail during an earthquake (seismic resistant construction), enforcement of zoning (where to build) and building codes (how to build) can reduce the risk associated with earthquakes to a certain extent. Even with construction to earthquake code, buildings fail for other reasons, like poor quality materials, poor workmanship, etc. that are not discovered until after an earthquake. Old buildings cannot cost-effectively be brought up to code, especially with yearly refinements to code.

The mitigation measures taken for possible risk reduction of earthquakes include community preparedness in the form of planning and public education and developing more of engineered structures. Every person living in areas susceptible to earthquakes should be educated the ways to minimize risk, before, during and after an earthquake.

In order to withstand an earthquake, buildings must be designed and built by taking into consideration the characteristics of earthquakes like ground acceleration, duration of shaking, frequency of seismic waves and resonance with building, including factors related to the geologic materials underlying the structure, horizontal shaking, strength of materials etc.

Resonance

All structures have natural frequencies or periods of vibration. If a structure has a period of vibration similar to a seismic wave it will resonate, and the longer it resonates, the more likely it will fail. Resonance can be eliminated by:

- Changing the height of building
- Changing the shape of building
- Changing the building materials
- Changing how the building attaches to foundation.

The structure can also be isolated from the underlying ground by base isolation, wherein devices on the ground or within structure are placed to absorb part of earthquake energy. This can be done by installing wheels, ball bearings, shock absorbers, 'rubber doughnuts', etc. to isolate building from worst shaking.

Utilities: Water supplies are often cut off as water pipes break during an earthquake. Failure of the water supply prevents control of secondary fires and slows recovery. Constructing the water supply system with flexible joints can prevent breakage of pipes. Gas mains and electrical meters can be fitted with devices that shut off automatically at the first sign of shaking. This will also aid in the prevention of secondary fires.

8.4 Tsunami

A **tsunami,** also known as **seismic sea wave** is a series of water waves caused by the displacement of a large volume of a body of water, generally an ocean or a large lake. Earthquakes, volcanic eruptions, and other under water explosion, landslides, and glacier calving, meteoric impacts and other disturbances above or below water all have the potential to generate a tsunami.

The most common cause of tsunami is the fault movements that occur on the sea floor thereby resulting submarine earthquakes. These submarine earthquakes release huge amount of energy and have the capacity to cross the oceans for far distances.

Tsunami differs from ordinary ocean waves, which are produced by the blowing of wind over the water. The tsunami waves travel much faster than ordinary ocean or sea waves. Normal ocean waves have wavelengths of about 100 meters. Tsunami has much longer wavelengths, usually measured in kilometers and up to 500 kilometers.

The tsunami is not just a single huge giant wave but may consist of a series of ten or more waves generally termed as 'tsunami wave train' (Fig.8.4). Compared to the normal ocean or sea wave speed of 100 kilometers per hour, the speed of tsunami waves may reach even up to 800 kilometers per hour in the deeper part of oceans.


Fig.8.4 : Tsunami wave train

Because tsunami occur suddenly, often without warning, they are extremely dangerous to coastal communities.

8.4.1 Mitigation of tsunami hazards

It is of course not possible to prevent a tsunami, but in certain tsunami prone countries adequate measures have been taken to reduce the damage caused on shore due to the tsunami. In order to be able to issue warnings about tsunami, several regional warning centers have been set up in areas prone to tsunami generating earthquakes. These include centers in Japan, Kamchatka, Alaska, Hawaii, French Polynesia, and Chile.

For areas located at great distances from earthquakes that could potentially generate a tsunami, there is usually plenty of time for warnings to be sent and coastal areas evacuated, even though tsunami travel at high velocities across the oceans. Still, deaths result from tsunami, especially when the source of the earthquake is so close to a coast that there is little time for a warning, or when people do not heed the warning or follow instructions associated with the warning.

Like all warning systems, the effectiveness of tsunami early warning depends strongly on local authority's ability to determine that there is a danger, their ability to disseminate the information to those potentially affected, and on the education of the public to heed the warnings and remove themselves from the area.

Japan has implemented an extensive programme of building tsunami walls of up to 4.5 m (13.5 ft) high in front of populated coastal areas. Fig. 8.5 shows tsunami walls built in populated coastal areas of Japan.

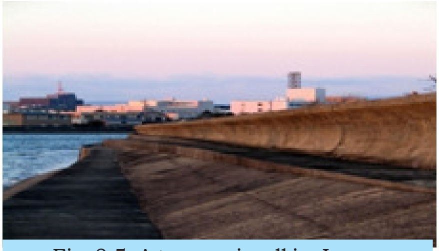

Fig. 8.5: A tsunami wall in Japan

Site planning and land management

Some other systematic measures to protect coastlines against tsunamis are site planning and land management. Site planning is an important tool in reducing tsunami risk because it determines the location, configuration, and density of development on particular sites.

- *Site selection: Avoid building or living in buildings within several hundred feet of the coastline as these areas are more likely to experience damage from tsunamis.*
- *Construct the structure on a higher ground level with respect to mean sea level.*
- *Increase the elevation of coastal homes: Majority of tsunamis have heights of less than 3 meters. Elevating the basement of houses will help to reduce the damage to property due to tsunami waves.*

8.4.2 Tsunami safety rules

Some of the tsunami safety rules are as given below:

1) A strong earthquake felt in a low-lying coastal area is a natural warning of possible, immediate danger. Keep calm and quickly move to higher ground away from the coast.

2) If an earthquake is located near or directly under the ocean, the probability of a tsunami increases. When you hear that an earthquake has occurred in the ocean or coastline regions, prepare for a tsunami emergency.

3) Tsunami can occur at any time, day or night. They can travel up rivers and streams that lead to the ocean. Never go down to the beach to watch for a tsunami. Tsunami can move faster than a person can run.

4) A tsunami is not a single wave, but a series of waves. Stay out of danger until an "ALL CLEAR" is issued by a competent authority.

5) Approaching tsunami is sometimes heralded by noticeable rise or fall of coastal waters. This is nature's tsunami warning and should be heeded.

6) A small tsunami at one beach can be a giant a few kilometers away. Do not let modest size of one make you lose respect for all.

7) During a tsunami emergency, your local emergency management office, police, fire and other emergency organizations will try to save your life. Give them your fullest cooperation.

8) Homes and other buildings located in low lying coastal areas are not safe. Do not stay in such buildings if there is a tsunami warning.

Know your progress

1. Why do we say that the earthquake risks depend on several factors and are greatly controlled by the nature of the underlying rocks and sediments?
2. What can we do to reduce the vulnerability associated with the collapse of building in the event of an earthquake?
3. Why are tsunamis so hazardous than ordinary ocean waves?

8.5 Volcanic eruptions

The term 'volcano' is generally used to mean the opening or *vent* at the Earth's surface through which the molten rock (called magma) and associated gases are expelled. When lava flows from the volcano it moves in large rivers across the land (Fig. 8.6). It burns anything in its path and leaves behind a layer of black lava that buries everything. There are thousands of volcanoes all over the Earth. They form on the floor of the ocean and on land.

Fig. 8.6: Volcanic eruption

8.5.1 Types of volcanoes

Depending upon the continuity of the volcanicity in time, the volcanoes are classified as: **Active, Dormant and Extinct** volcanoes.

Active volcanoes are presently active or have been active at least during the historic time. There are about 500 such volcanoes around the world, among which 283 border the Pacific Ocean, forming the well known Ring of Fire, and 98 occur in the Alpine-Himalayan belt. Vesuvius in Italy is an example for this type. About 50 of the active volcanoes erupt each year.

The volcanoes which are not active today are known as dormant**.** Some people describe them as *sleeping volcanoes*. Some of the dormant volcanoes are known to be active during the recent geologic past and some of these can be expected to become active again in the future. Barren Islands in Andaman and Nicobar (India) is an example for dormant volcanoes.

The volcanoes which are geographically ancient and have totally stopped all their activities today are grouped as *extinct volcanoes.*

The examples include Koh-i-Sultan in Baluchisthan and Kilimanjaro in Tanzania (Africa).

People who live near active volcanoes have to pay attention to the eruption warnings that are given by the scientists. Because the lifetime of a volcano may be on the order of a million years, dormant volcanoes can become active volcanoes all of a sudden. These are perhaps the most dangerous volcanoes. The people living near dormant volcanoes are sometimes difficult to convince when a dormant volcano shows signs of renewed activity.

8.5.2 Effects of volcanoes

Volcanoes are not disastrous always. There are many beneficial aspects of volcanism. Volcanism helps renew the soil, and the soils around active volcanoes are some of the richest on the Earth. However, over the last 500 years, volcanoes have been directly or indirectly responsible for over 2, 75,000 deaths. Some of the effects of volcanoes are discussed here.

(a) Lava flows

Amongst the liquid products of a volcanic eruption, the lava forms the chief component. Lava is hot molten rocky material. When first erupted from a volcanic vent, lava is a liquid with a temperatures ranging from 700 to 1,200 °C. Although lava flows have been known to travel as fast as 64 km/hr, most lava are sluggish and slower and give people enough time to move out of the dangerous zone. In general, lava flows are most damaging to property, as they can destroy anything in their path. Control of lava flows has been attempted with only limited success by bombing flow fronts to attempt to divert the flow, and by spraying with water to cool the flow.

(b) Pyroclastics

Violent eruptions and pyroclastic activity form the second kind of primary effect of volcanism. Solid rock fragments of varying sizes that are ejected from volcanoes are collectively known as '**pyroclastic**' material or **tephra.** Some of these may be as hot as

900°C; they move swiftly with velocities of up to hundreds of metre per second. They can travel so rapidly that few humans can escape from their path.

(c) Ash flows

Minute particles of diameter less than 0.20 mm to 0.40 mm constitute volcanic ash. Ash flows (Fig. 8.7) are turbulent mixtures of hot gases and pyroclastic material that travel across the landscape with great velocity.

Fig. 8.7 : Volcanic ashes moving out to surrounding areas

Ash falls can cause the collapse of roofs and can affect areas far from the eruption. These destroy vegetation, including crops, and can kill livestock that eat the ash covered vegetation. Ash falls can cause loss of agricultural activity for several years after an eruption.

(c) Toxic gases

The third kind of primary effect of volcanism is poisonous gas emissions. Among these poisonous gases are: hydrogen chloride (HCl), hydrogen sulfide (H_2S), hydrogen fluoride (HF), and carbon dioxide (CO_2). The chlorine, sulphur and fluorine gases can kill organisms by direct inhalation.

The poisonous, even lethal, gases ejected during the eruption of a volcano are transported away from vent as acid aerosols, as compounds absorbed on tephra and as microscopic salt particles. Sulfur compounds, chlorine and fluorine react with water to form poisonous acids causing suffocation, blood poisoning, burns, damages to lungs, eyes, skin and respiratory systems of living beings, even when these are in small concentrations. Most volcanic gases are harmful and can cause mass fatalities.

The secondary effects associated with volcanic activity include mudflows (lahars), debris avalanches and debris flows, flooding, tsunami, volcanic earthquakes and tremors, atmospheric effects and famine.

Volcanoes in cold climates can melt snow and glacial ice, rapidly releasing water into the drainage system and possibly causing floods.

8.5.3 Mitigation of volcanic disasters

The best mitigation against casualties from volcanic eruptions is to provide warning based on eruption forecasts and knowledge of the past behavior of the volcano, and call for evacuations. Evacuation plans rely on knowledge of when the volcano might erupt and how it will behave when it does erupt.

The preparation of volcanic hazard maps helps to determine whether a volcano is potentially hazardous and to assess the risk. For this, a detailed knowledge about the history and characteristics of the specific volcano is vital.

Early warning of some of the volcanic phenomenon is virtually impossible. The only effective method of risk mitigation is evacuation prior to such eruption from areas likely to be affected by pyroclastic flows. As the time available for early warning of gas release is extremely short, intensified investigation on such gas eruption, as well as keen observation of the respective locations, are absolutely necessary. As volcanic ash in the atmosphere has been known to cause problems with airplanes, a global warning system currently exist, to keep aircraft out of ash clouds.

Little can be done to protect property as the energy involved in volcanic eruptions is too great and few structures will survive if subjected to volcanic processes. Many of the hazards of ash-falls can be mitigated with proper planning and preparation. This includes clearing tephra from roofs as it accumulates, strengthening roofs and walls, designing roofs with steep slopes and wearing respirators or wet clothes over the mouth and nose.

Know your progress

1. If you live near an active volcano, what precautions do you take to save your life and property?
2. Why is lava, in itself, a comparatively minor hazard?
3. List out the toxic gases that are most abundantly associated with a volcanic activity.

8.6 Floods

Abnormally high amounts of water flowing in streams often leads to flooding, and flooding is one of the more common types of natural disasters. The following are the major causes of floods.

1. Excessive heavy rainfall and associated high surface run off.

Heavy rain from a series of storms moving over the same area can cause flooding when the rate of rainfall exceeds the drainage capacity of the area. Heavy down pour in areas prone to cyclonic storms often results in floods.

2. Less infiltration.

Water overflows the land when infiltration of water into the soil is less in a large river basin. The rate of surface runoff is controlled by how readily the water can seep into the soil. Flash floods occur when the rate of infiltration is low and heavy rains occur over a short period of time.

3. Melting of snow

Snowmelt in the ice caps and snow covered mountain peaks can increase the volume of water discharge through the streams.

Man-made factors such as large scale deforestation, improper farming practices and over-cultivation can also cause floods.

8.6.1 Hazards associated with flooding

Flood waters can undermine bridge structures, and cause collapse of buildings. Livestock, pets, and other animals are often carried away and drown. Humans that get caught in the high velocity flood waters are often drowned by the water. Floodwaters can concentrate garbage, debris, and toxic pollutants that can cause the secondary effects of health hazards.

Secondary effects involve disruption of services, health impacts such as famine and diseases. Contamination of water leads to outbreak of epidemics, diarrhea, viral infection, malaria and many other infectious diseases. Transportation systems and farm lands may be disrupted, resulting in shortages of food and clean-up supplies that often lead to starvation.

8.6.2 Mitigation of flood hazards

Mitigation involves the managing and control of flood water movement, such as redirecting flood run-off through the use of floodwalls and flood gates, rather than trying to prevent floods altogether. Mitigation of flood hazards can be attempted in two main ways: An engineering approach, to control flooding, and a regulatory approach designed to decrease vulnerability to flooding. Engineering approaches include: a) Channel modifications, b) Construction of dams, c) Making of retention ponds for trapping water, c) Construction of artificial levees, dikes, and floodwalls, and d) Construction of floodways or areas to provide an outlet to a stream and allow the flood waters into an area that has been designated as a floodway.

Engineering approaches of flood mitigation

(a) Channel modifications

In order to control floods, channel modification should involve increasing the channel cross-sectional area, so that higher discharge will not increase the stage of the river. Straighter channels also allow higher velocity flow and enable the stream to drain faster when discharge increases. Such channel modifications involve measures such as straightening of river channel, deepening or widening the channel, clearing vegetation from the banks, or lining the channel with concrete. Lining the channel with concrete provides a smoother surface over which the water can flow, thereby reducing friction and also increasing the velocity of the stream.

(b) Retention ponds

If open land is available, flood hazards along a stream can be greatly be reduced by the construction of retention ponds. Retention ponds are large basins that trap some of the surface run off, keeping it from flowing immediately into the streams. These can be elaborate artificial structures made of piled up soil or rocks, abandoned quarries etc.

(c) Levees

These are raised banks built along a stream channel. Some streams form low natural levees along the channel through sediment deposition during high water flows. Such levees may be enlarged purposefully, or created artificial levees where there exist no levees. Because levees raise the height of the stream banks close to the channel, the water can raise higher without flooding the surrounding land.

(d) Construction of flood gates

Mitigation of flood also involves controlling the flow of water through the use of flood gates (Fig. 8.8). These are adjustable gates, which may restrain outpouring water.

Fig. 8.8 : A flood gate in Aruvikkara-Kerala

Regulatory approaches of flood mitigation

Regulatory approaches to reduce vulnerability of floods include non-structural measures such as floodplain zoning and floodplain building codes.

(a) Flood plain zoning

Laws can be passed that restrict construction and habitation of floodplains. Lands that could be inundated can be restricted to land uses not involving much building activities. The land could be however used for livestock grazing or other recreation purposes. Floodplains can be thus zoned for agricultural use, recreation, or other uses wherein lives and property are not endangered.

(b) Flood plain building codes

Structures that are allowed within the floodplain could be restricted to those that can withstand the high velocity of flood waters and are high enough off the ground to reduce risk of contact with water. Constructions can be designed with the flood hazards in mind, so that such a design will at least minimize the danger of costly flood damage to the building (Fig.8.9).

Fig.8.9: A house constructed in flood zone.

Know your progress

1. Discuss the ways in which urbanization may increase flood hazards.
2. Describe in detail some possible risk reduction measures for floods.
3. How can we mitigate risks to lives and property in case of a flood hazard?

8.7 Landslides and other types of mass movements

Mass movement or mass wasting is defined as the down slope movement of rock and regolith near the Earth's surface mainly due to the force of gravity. Various kinds of mass wasting processes are occurring continuously on all slopes; some act very slowly, others occur very suddenly, often with disastrous results. You have already learnt in detail the various types and mechanism of mass wasting processes in the previous year. Here we are concerned only with the disastrous effects of this natural hazard.

Landslides constitute a major natural hazard in our country and it accounts for considerable loss of life and damage to communication routes, human settlements, agricultural fields and forest lands. The Himalayan regions are the worst affected. We in Kerala also faced this situation especially during the monsoon rains. In Kerala, some localities of the Western Ghats are very much vulnerable to landslides. Instances of such landslide hazards have occurred in the upland areas of Western Ghats, especially Thiruvananthapuram, Idukki, Wayanad, Kannur and Kozhikode districts during the last two decades or so (Fig 8.10).

Fig. 8.10: Effects of landslides

Torrential rainfall during the monsoon seasons falling on the deforested slopes of the Western Ghats is the main reason for the landslides in our state and human intervention in the form of removal of vegetation, slope modifications for construction of roads, buildings and settlements, crop cultivation, etc., have actually increased the risks of landslides in many localities.

8.7.1 Mitigation of mass movement hazards

We have already seen that mass movements can be extremely hazardous and result in extensive loss of life and property. But, in most cases, areas that are prone to such hazards can be easily recognized with some geologic knowledge. Slopes which are vulnerable can be stabilized or avoided, and warning systems can be put in place in order to minimize effects of such hazards to a certain extent.

Mitigation of a landslide means reducing the effects or the intensity of the landslide. Some of the measures include: proper land use practices, forestation of degraded upper slopes, detailed geotechnical studies prior to developmental activities, avoiding blockage of natural drainages during construction of roads, irrigation canals, etc., making mandatory the total avoidance of settlement in the risk zones, relocation of settlements and infrastructure that fall within the possible path of landslide, no construction of buildings beyond a certain degree of slope and so on.

Retaining walls can be built to stop land from slipping along the slope and surface drainage control works can be implemented to control and prevent the movement of landslides due to infiltration of rainwater and spring flows. Engineered structures with strong foundations to withstand down slope movement, should be the object of such construction. Increasing vegetation is of course the cheapest and most effective way of arresting landslides.

All slopes are susceptible to mass movement hazards if a triggering event occurs. So, all slopes should be assessed by field study for potential mass movement hazards. Some of the engineering techniques to make the slope more stable include the following:

- Steep slopes can be covered with concrete or with a wire mesh to prevent rock falls (Fig 8.11).

Fig.8.11: A slope covered with wiremesh

- If the slope is made of highly fractured rock, rock bolts may be emplaced to hold the slope together and prevent failure (Fig. 8.12).

Fig. 8.12 :Rock bolts to prevent slope failure

- Drainage pipes could be inserted into the slope to more easy flow of water from the slopes to avoid any increase in fluid pressure leading to increased weight due to addition of water (Fig 8.13).


Fig. 8.13: Drainage pipes along slopes.

- Over-steepened slopes could be graded or terraced to reduce the slope (Fig.8.14).


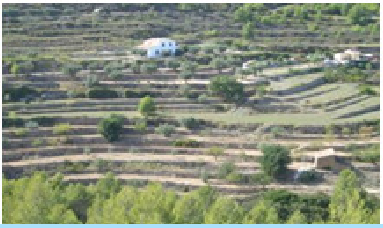

Fig.8.14: Grading or terracing to reduce the slope

- Construction of buttress (a buttress is a man-made mound or hill of soil fill slope or berm) placed at the toe of the slope (Fig.8.15). The buttress increases the resisting forces and thus prevents material from moving towards the toe of the slope. In some cases, it may also be a metal or concrete beam providing additional support to a retaining wall constructed at the toe of a slope.

Fig.8.15: A buttress at the toe of a slope

Some slopes, however, cannot be stabilized. In these cases, humans should avoid these areas or use them for purposes that will not increase susceptibility of lives or property to mass movement hazards.

Know your progress

1. What causes do you find for the occurrence of landslides in Kerala?
2. What are the measures recommended for making mass movement less likely or less vulnerable?

8.8 Coastal erosion

Coastlines are zones of interaction between the land and sea along which water is continually making changes. Waves can both erode rock and deposit sediment in their zone. The presence of ocean currents and waves make the coastal zone dynamically changing systems, even over short (human) time scales.

Coastal erosion is the wearing away of land and the removal of beach or dune sediments by wave action, tidal currents or high winds (Fig. 8.16).Coastlines are zones along which water is continually making changes. Waves can both erode rock and deposit sediment.

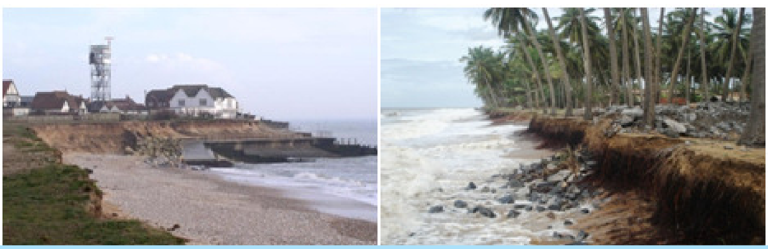

Fig.8.16 : Coastal erosion

8.8.1 Coastal hazards

a) Storms - Great storms such as cyclones or other winter storms can cause erosion of the coastline at much higher rate than normal. During such storms beaches can erode rapidly and heavy wave action can cause rapid undercutting and consequent mass-wasting events of coastal cliffs.

b) Sea level rise - Studies indicate that sea level is presently rising worldwide. The rate of sea level rising may increase due to the ongoing melting of the continental ice sheets in Greenland and Antarctica. Human habitation of low-lying coastlines may be in threat or danger in the near future. Higher sea level will make the low lying coastal areas more susceptible to other hazards, like storm surges and tsunamis.

8.8.2 Mitigation of coastal erosion

Options for combating coastal erosion are of two types: hard stabilization in which structures are built to reduce the action of the waves and soft stabilization which mainly refers to adding sediment back to a beach as it erodes away.

Hard structural/engineering option

Hard structural options use structures constructed on the beach or further offshore. Such options include sea walls, groins, jetties, break waters, etc. These options influence coastal processes to stop or reduce the rate of coastal erosion.

a) Seawall

A seawall is a structure constructed parallel to the coastline that shelters the shore from wave action. It can be used to protect a cliff from wave attack and thus improve slope stability. Sea walls can also dissipate wave energy on sandy coasts (Fig.8.17).

Fig.8.17: Sea walls built for coastal protection

b) Groins

A groin is a coastal structure constructed perpendicular to the coastline from the shore into the sea to trap sediments of long shore transport or control long shore currents. This type of structure is easy to construct from a variety of materials such as wood, rock or bamboo and is normally constructed on sandy coasts (Fig.8.18).

Fig.8. 18: Groins built for trapping long shore currents

c) Jetties

These are walls designed to protect the entrance of destructive waves and deposition of sediments in a harbour (Fig.8.19). These barriers are built on both sides of a harbour and extend into the ocean to protect the harbour from excessive sedimentation.

Fig.8.19 : Jetties

d) Breakwaters

These are offshore structures built parallel to the shoreline to absorb the force of large breaking waves and provide quiet water near shore (Fig.8.20). Breakwaters serve a similar purpose as sea walls, but are built slightly offshore, reducing the energy of the pounding waves and thus preventing the force of the waves from reaching the beach. Breakwaters, cause wave refraction, and alter the flow of the longshore current. Sediment is trapped by the breakwater, and the waves become focused on another part of the beach, not protected by the breakwater, where they can cause significant erosion.

Fig.8.20 : Breakwater

2. Soft structural/engineering options

Soft structural/engineering options aim measures to dissipate wave energy by mirroring natural forces and maintaining the natural topography of the coast. They include beach nourishment/feeding, dune building, revegetation and other non-structural management options.

a) Beach nourishment

The aim of beach nourishment is to create a wider beach by artificially increasing the quantity of sediment on a beach which is experiencing sediment loss. This method requires regular maintenance with a periodic supply of sediment. This practice is unlikely to be economical in regions of severe wave climates or where sediment transport is rapid.

b) Dune building/reconstruction

Sand dunes are unique among other coastal landforms (Fig.8.21). They provide an ideal coastal defence system; vegetation is vital for the survival of dunes.Maintenance of sand dune with a protective cover of vegetation is yet another practice in some regions for the prevention of coastal erosion.

Fig.8.21: Dune building

c) Coastal revegetation

The presence of vegetation in coastal areas improves slope stability, consolidates sediment and reduces wave energy moving onshore; therefore, it protects the shoreline from erosion to a certain extent (Fig. 8.22).

Fig. 8.22 : Coastal zone re-vegetation to protect shorelines

You can understand the effects of coastal hazards and strategies of coastal zone management by a field visit to a nearby coast. You have to prepare a report on the processes of coastal erosion and the measures adopted to reduce the coastal hazards.

In the preceding sections of this topic, you have learnt different strategies that are employed for coastal zone management. The structures constructed on the beach are intended either to reduce the action of the waves or to interrupt the flow of sediment along the beach. These can be categorized as hard stabilization/ engineering techniques, which aim to mitigate coastal processes from occurring in certain intended sites. Such options influence coastal processes to stop or reduce the rate of coastal erosion.

At the same time, the stabilization measures that are accomplished by adding sediment to the beach as it erodes away can be grouped as soft stabilization techniques, which try to work with nature to protect the coast. Now, make a table as given below, dividing the options for combating coastal erosion into two categories.

Hard stabilization techniques	**Soft stabilization techniques**
• Sea walls • •	• Beach nourishment • •

Know your progress

1. What happens to longshore drift of sediments when a groin is built?
2. What is meant by the term beach nourishment? What are some of the problems associated with beach nourishment?

Let us conclude

Natural disasters are produced by processes that have been operating since the Earth formed. The dynamic geologic processes were responsible for things that make the Earth a habitable planet for life. However, the same system can also create hazards such as earthquakes and tsunami; volcanoes, landslides, flooding, and coastal erosion, threatening our lives and homes. Such processes are beneficial to humans because they are responsible for things that make the Earth a habitable planet for life. Throughout the Earth's history, volcanism has been responsible for producing much of the water present on the Earth's surface, and for producing the atmosphere. Earthquakes are one of the processes responsible for the formation of mountain ranges which direct water to flow downhill to form rivers and lakes. Erosional processes, including flooding, landslides, and windstorms replenish soil and help to sustain life.

These processes are only considered hazardous when they adversely affect humans and their activities. Natural hazards can be characterized by their magnitude or intensity, speed of onset, duration, and area of extent. In some cases hazards may be coupled, as in the flood caused by a cyclone or the tsunami that is created by an earth quake. Over the recent decades there has been an alarming increase in the occurrence of natural disasters. The magnitudes of their social, economic and environmental impacts are also being increased.

Let us assess

1. Which among the following is not a geologic hazard?

   a) Landslide b) flood c) pollution d) earthquake

2. Which of the following will not help prevent landslide?

   (Drainage of water, retaining wall, grading to reduce steepness of slopes, removal of vegetation)

3. What is the name given to solid rock fragments ejected from volcanoes?
4. Explain with examples the difference between hazard and disaster.
5. Briefly discuss the Disaster Management Cycle with suitable examples.
6. Identify any three major mitigation measures to reduce earthquake risk.
7. How can we prepare ourselves to minimize the vulnerability of tsunami hazards?
8. Suggest five risk reduction measures that can be taken up to prevent landslides.
9. List out some of the causes and adverse effects of floods.
10. Sketch briefly any three measures to be taken for protection of coastal zones.

Appendix

Mineral and Rock Identification

An unknown mineral/rock specimen can be identified based on certain sets of unique features exhibited by it. However it is always not an easy task to identify all specimens by megascopic observation only.

For the purpose of identification of some common rock forming minerals and major metallic and non metallic minerals, their characteristic physical properties have been given in the subsequent section of this appendix.

Tables illustrating the texture and mineralogical composition of certain important rocks are also provided herewith.

Learners can make use of the data given in respective tables and try to identify the specimens of minerals and rocks given as part of their laboratory work.

I. Mineral Identification

Minerals are characterised by a unique set of physical and chemical properties. Specimens of various minerals can be identified by their diagnostic properties. The table 1.1 given in the appendix, lists some of the common rock forming minerals. The salient physical properties of minerals such as Form/Habit, Colour, Streak, Lustre, Cleavage, Fracture, Hardness and Specific Gravity are also listed under the respective columns.

The appendix 1 gives you an idea of the physical properties exhibited by some of the major rock forming minerals.

The Appendix II provides the texture and mineral composition of igneous, sedimentary and metamorphic rocks.

The tables in Appendix-III.1 & III.2 lists the physical properties of ore and industrial minerals respectively.

II. Rock Identification

Rocks are broadly classified into three types: Igneous, Sedimentary and Metamorphic rocks.

Igneous rocks

Appnedix II.1 gives a brief account of the textural and minerological characters of igneous rocks.

Igneous rocks can be classified on the basis of their texture and mineralogical composition. Most of the rocks can be identified noting their texture as well as mineralogy. In the case of fine grained rocks, their mineral content may not be determined megascopically. Microscopic study may be required for the accurate identification of fine grained crystals of the rock. A visible interlocking texture is a characteristic feature of crystalline rocks.

Sedimentary rocks

Appendix-II.2 gives an illustration of texture and mineral content of sedimentary rocks.

Sedimentary rocks can also be classified on the basis of texture and mineralogy. With the help of a magnifying glass or hand lens, identification of mineral grains may be possible. The clastic texture of the rock can be easily identified with the help of the magnifying glass. If the grains are cemented together, the rock may be clastic. The following description will help you to distinguish the various types of clastic rocks.

Conglomerate:-Rock composed of rounded grains, coarse pebbles and gravels.

Sandstone:- Rock composed of sand sized particles.

Shale:- Rock with fine grained (too small to see even with the hand lens) minerals and may exhibit a laminar structure.

Limestone may be fine or coarse grained, and may or may not contain visible fossils. The rock effervesces when applying a small amount of dilute hydrochloric acid on to the surface of the rock.

Metamorphic rocks

Appendix-II.3, gives an account of the texture and mineralogical composition of metamorphic rocks.

Metamorphic rocks are largely identified on the basis of their textures. The foliated and non-foliated textures can be easily distinguished. Determination of mineralogical composition of the rock may be necessary for naming the rocks. Non-foliated rocks are identified chiefly on the basis of their mineral content.

Quartzite:- Consists mostly of quartz and the grains show interlocking granulose texture.

Marble:- Consists of interlocking grains of calcite

Foliated rocks such as Schist, Gneiss and Slate can be identified on the basis of the type of foliation.

Schist:- Composed mostly of visible grains of platy or flaky minerals that are arranged in approximately parallel layers.

Gneiss:-Composed of dark and light coloured minerals arranged in alternating layers.

Slate:-Consists of fine grained minerals and can be split into sheet like slabs.

Appendix I

	Name	Talc $[Mg_6[Si_8O_{20}](OH)_4]$	Biotite $[K(MgFe)_3(AlSi_3O_{10})(OH)_2]$	Muscovite $[KAl_2(AlSi_3O_{10})(OH)_2]$	Calcite $[CaCO_3]$	Dolomite $[CaMg(CO_3)_2]$	Fluorite $[CaF_2]$
Physical Properties	**Form/Habit**	Foliated to fibrous masses	Irregular foliated masses	Foliated masses and scaly or massive	Well formed crystals of rhombohedron and prism, also massive and granular	Rhombohedra common, usually with curved faces, , granular, massive	Cubes very common, or massive
	Colour	White, silvery white, apple green, greenish grey, dark green	Black, green to black, dark brown	Colourless, white or pale yellow, black, brown or red	Colourless or white, milky-white, grey, yellow, blue, red, brown or black tints	Shades of brown, red, grey, green and black	Variable or Colourless
	Streak	White to pearl green	Colourless	Colourless	White	White	White
	Lustre	Pearly	Pearly	Pearly	Vitreous to dull or earthy	Pearly to dull	Vitreous
	Cleavage	Perfect basal	Perfect basal	Perfect basal	Perfect rhombohedral	Perfect rhombohedral	Perfect
	Fracture	Flat surfaces uneven fracture	Uneven	Uneven	Conchoidal	Conchoidal to uneven	Conchoidal to uneven
	Hardness	1.0	2.5-3	2.5 - 3.0	3.0	3.5 - 4.0	4.0
	Specific Gravity	2.58 - 2.83	2.8-3.2	2.77 - 2.88	2.71	2.84 - 2.86	3.0 - 3.25

Table -1 Identification Chart (Rock forming Minerals)

Appendix I

	Name	Apatite $[Ca_5(PO_4)_3$ (F,Cl,OH)]	Orthoclase Feldspar $[K(AlSi_3O_8)]$	Plagioclase Feldspars $[NaAl Si_3O_8$ - $CaAl_2Si_2O_8]$	Garnet (Almandite) $[Fe_3Al_2Si_3O_{12}]$	Quartz $[SiO_2]$	Corundum $[Al_2O_3]$
Physical Properties	**Form/Habit**	Tabular, prismatic crystals, massive, compact or granular, fibrous to columnar, globular or botryoidal	Usually prismatic, also tabular and elongated	Usually prismatic, also tabular	Well-formed, distinct dodecahedral and trapezohedral crystals, also as grains, massive or rounded crystals	Crystals occur as hexagonal prisms , also as massive, granular	Barrel-shaped or pyramidal crystals, also as massive and granular forms
	Colour	Pale sea green, bluish green, yellowish green and greenish yellow, also shades of blue, grey, red, violet, pink and brown	Flesh red,pink,light pink or red	Variable, usually white or light coloured, also grey and colourless	Deep crimson, deep red, brownish red, or dark brown,	Colourless or white when pure but some varieties may be coloured	Reddish but occasionally colourless, brown; pink to pigeon-blood-red
	Streak	White	White	White	Colourless	Colourless	Colourless
	Lustre	Subresinous to vitreous	Vitreous	Vitreous, semi-vitreous to pearly	Vitreous	Vitreous	Vitreous to dull, adamantine
	Cleavage	Indistinct or poor	Perfect two directional	Two directional	Absent	Absent	Absent
	Fracture	Conchoidal to uneven	Uneven	Uneven and splintery	Conchoidal to uneven	Conchoidal	Conchoidal to uneven
	Hardness	5.0	6	6.0 - 6.5	7.0 - 7.5	7	9.0
	Specific Gravity	2.9 - 3.5	2.57	2.55 - 2.76	3.5 - 4.3	2.65	3.98 - 4.02

Table -1: Identification Chart (Rock forming Minerals)

Appendix-II

Rock	Texture	Compositional Characters	Essential Mineral(s)	Accessory Mineral(s)	Type	Petrogenesis
Granite	Holocrystaline phaneritic coarse grained equigranular/ porphyritic	Felsic	Quartz and Feldspar (Plagioclase/Orthoclase)	Biotite, muscovite, hornblende or other amphibole and pyroxene	Intrusvie	Forms deep in the earth's crust from cooling magma, with high content t of silica. Slow cooling in deep seated condition produces the large crystals in granite.
Pegmatite	Holocrystaline phaneritic very coarse grained pegmatitic equigranular	Felsic	Quartz and Feldspar (Plagioclase/Orthoclase)	Biotite muscovite garnet beryl tourmaline and several other rare minerals		Form during the final stages of crystallization. Pegmatite generally forms in fractures that develop on the margins of the batholiths or other large plutons.
Gabbro	Holocrystaline phaneritic coarse grained equigranular	Mafic	Ca Plagioclase feldspar and pyroxene	olivine; Sometimes contains: magnetite, chromite, titanite and ilmenite.		Forms from a magma that is rich in iron and magnesium, and poor in silica (quartz). The magma cools and crystallizes deep below the earth's surface.

Table 2.1 : Identification Chart (Igneous Rocks)

Appendix-II

Rock	Texture	Compositional Characters	Essential Mineral(s)	Accessory Mineral(s)	Type	Petrogenesis
Dolerite (Diabase)	Mesocrystalline phaneritic medium to fine grained equigranular/ porphyritic	Mafic	Ca Plagioclase Feldspar and Pyroxene	Quartz	**Intrusive**	Forms from a magma that is rich in iron and magnesium, and poor in silica often forms dikes or sills.
Basalt	Holohyaline Aphanitic Finegrained Equigranular	Mafic	Ca Plagioclase Feldspar and Pyroxene	Olivine	**Extrusive**	Forms from a magma that is rich in iron and magnesium, and poor in silica (quartz). The magma erupts from a volcano or a fissure (a crack in the earth's surface) as lava.
Dunite	Holocrystaline Phaneritic Medium to fine grained Equigranular	Ultramafic	Olivine	Pyroxene,Chromite, Magnetite	**Intrusvie**	Forms from the accumulation of dense, early crystallizing grains of olivine that sink to the bottom of low silica magma. Intrusions of dunite form sills or dikes.

Table 2.1 : Identification Chart (Igneous Rocks)

Appendix-II

Rock	Texture	Major Mineral(s)	Minor Mineral(s)	Type	Petrogenesis
Conglomerate	Clastic rounded and very coarse grained	Any rock type (quartz or chert grains most common)	Any rock type	Clastic	Conglomerates form in high-energy environments (such as steep-gradient streams). Sand and pebbles of conglomerate collect along sea shores, lake shores, or river banks. They are compacted by the weight of sediments that collect above them and cemented by material dissolved in the water that later seeps through them.
Sandstone	Clastic rounded and coarse grained	Quartz grains	Feldspars, mica, glauconite, magnetite, garnet, rutile, ilmenite	Clastic	Quartz sand produced by the weathering of other quartz bearing rocks is deposited by rivers, waves, or wind. The sand is buried under later sediments get compacted by the weight of those sediments, and cemented by material dissolved in water that seeps through it,
Shale	Clastic fine grained lamination present	Clay sized particles; < 1/256 mm	Fine matrix	Clastic	Sediments composed of clay sized particles when buried and compacted become shale. Iron oxides ,calcium carbonates etc.often help to cement the particles together.
Limestone	Medium to coarse grained	Calcite ($CaCO_3$) fizzes with dilute HCI	Dolomite (Ca,Mg) $(CO3)_2$	Non clastic	Most limestone are formed by a precipitation from in sea water. Some limestones are formed materials derived from buried coral reefs

Table 2.2: Identification Chart (Sedimentary Rocks)

Appendix-II

Rock	Texture	Major Mineral(s)	Minor Mineral(s)	Type	Petrogenesis
Slate	Shiny due to increased size of micaceous minerals Fine grained, minerals not visible	Very fine grained-no visible minerals Minerals with basal cleavage: commonly mica, graphite, etc.	Very fine grained-no visible minerals	Foliated	Slate is usually formed from clay sediments or shale that has been heated and put under pressure. The pressures and temperatures that give rise to slate are lower than those that required lower than that required form schist.
Schist	Medium to coarse grained;	Muscovite, biotite, chlorite, talc, garnet, kyanite, staurolite,	Muscovite, garnet ,quartz feldspar, tourmaline, and many others	Foliated	Schists are usually formed from shales that were formed from clay or sandy clay with a little lime, sometimes these form from rocks and sediments formed from volcanic activity.
Gneiss	Alternating layers of light (felsic) and dark (mafic) minerals Medium to coarse grained	Feldspar, quartz, mica, ferromagnesian minerals	Hornblende, garnet	Foliated	Gneiss is formed from another low grade metamorphic rock, called schist. Gneiss can also be formed from some igneous rocks, especially granite. It is usually formed under great pressure and temperature conditions.
Marble	Medium to coarse grained and non oriented grains	Calcite	Dolomite	Non Foliated	Marble forms from the metamorphism of limestones
Quartzite	Medium to coarse grained and non oriented grains	Quartz	Feldspar	Non Foliated	Most quartzites are metamorphosed sandstones
Charnockite	Coarse grained, and non oriented grains minerals .	Hypersthene, Feldspar, Quartz	Garnet	Non Foliated	By recrystallisation under deep seated metamorphism of quartzo-feldspathic rocks of igneous origin.

Table 2.3 : Identification Chart (Metamorphic Rocks)

Appendix III

Physical Properties: Mineral	Magnetite [Fe_3O_4]	Hematite [Fe_2O_3]	Chalcopyrite [$CuFeS_2$]	Bauxite [$AL_2O_3.2H_2O$]	Galena [PbS]	Pyrolusite [$Mn_2O_3.H_2O$]
Form/Habit	Octahedral or Massive	Tabular ,granular, and compact	Massive or Tabular	Granular,earthy, concretionay or oolitic	Cubic, massive or granular	Massive, Reniform or granular
Colour	Iron Black	Steel gray to Brownish red	Golden yellow	Grayish white, brownish white	Lead gray	Iron Black
Streak	Black	Cherry red	Greenish black	Grayish white	Lead gray	Black
Lustre	Metallic	Metallic	Metallic	Dull or earthy	Metallic	Metallic
Fracture	Uneven	Sub conchoidal or uneven	Uneven	Sub conchoidal	Even to sub conchoidal	Uneven
Cleavage	Indistinct	Indistinct	Indistinct	Absent	Perfect cubic	Absent
Hardness	6	5.5-6.5	3.5-4	2	2.5 2.5	2-2.5
Specific Gravity	5.1	5.2	4.2	2.5	7.5	4.8

Table 3.1: Identification Chart (Ore Minerals)

Appendix III

Physical Properties	Mineral	Asbestos-Chrysotile $[Mg_6(Si_4O_{10})(OH)_8]$	Gypsum $[CaSO_4 2H_2O]$	Barite $[BaSO_4]$	Graphite [C]	Clay (Kaolin) $[(Al_4Si_4O_{10})(OH)_8]$	Magnesite $[MgCO_3]$
	Form/Habit	Fibrous	Tabular or prismatic	Usually tabular or bladed	Massive,scaly	Massive	Massive and compact
	Colour	Shades of White or green	Colourles or white	White or gray	Black	White	White,gray,yellow or brown
	Streak	White	White	White	Steel gray	White	White
	Lustre	Silky ,greasy or earthy	Vitreous/pearly/silky	Vitreous, pearly to dull.	Metallic	Earthy	Vitreous, semivitreous or earthy
	Fracture	Hackly	Conchoidal	Even	Even	Even	Conchoidal
	Cleavage	Perfect	Perfect	Perfect in 1direction.	Perfect	Perfect	Perfect
	Hardness	2-5 Usually 4	2	3 to 3.5	1	2-2.5	3.5-5
	Specific Gravity	2.2	2.32	4.5	2.2	2.6-2.65	3.0-3.2

Table 3.2: Identification Chart (Industrial Minerals)

Glossary

absolute age : *The geologic age of a fossil organism, rock or geologic feature or event given in units of time.*

aftershocks : *An earthquake which follows a larger earthquake or main shock and originates at or near the forcus of the larger earthquake.*

alloy : *A material composed of two or more metals or a metal and a nonmetal*

amplitude : *The change between crest (highest amplitude value) and trough (lowest amplitude value, which can be negative.*

anticline : *A fold which is convex upward.*

axial plane : *The plane or surface that divides the fold as symmetrically as possible. The axial plane may be vertical, horizontal, or inclined at any intermediate angle.*

batholith : *A large generally discordant , plutonic mass of igneous rock that has more than 100 km^2 of surface exposure and with no visible floor.*

body waves : *Earthquake waves that travel through the interior of the Earth.*

bog : *A bog is a type of wetland where peat or deposit of dead plant material-often mosses, accumulates*

breccia : *A coarse-grained clastic rock composed of large angular and broken rock fragments that are cemented together in a fine-grained material.*

cast : *A fossil formed when an animal, plant, or other organism dies, its flesh decays and bones deteriorate due to chemical reactions; minerals gradually enter into the cavity, resulting in a fossil, with the general form of the original organism.*

cementation : *Hardening and welding of clastic sediments (those formed from preexisting rock fragments) by the precipitation of mineral matter in the pore spaces.*

clastic rock : *Rocks composed of fragments, or clasts, of pre-existing minerals and rock. (A clast is a fragment of geological detritus, chunks and smaller grains of rock broken off from other rocks by physical weathering).*

compaction : *The process by which a sediment progressively loses its porosity and reduction in bulk volume in response to increasing weight of overlying materials that is continually being deposited . Compaction forms part of the process of lithification.*

compressional waves (longitudinal waves) : *Waves that produce compression and rarefaction when travelling through a medium. (The other main type of wave is the transverse wave, in which the displacements of the medium are at right angles to the direction of propagation).*

correlation : *The study concerned with establishing age relationships between two different local successions of strata.*

crude oil : *Petroleum in its natural state as it emerges from a well or unrefined petroleum.*

crystallization : *The natural or artificial process of becoming solid crystalline from a fluid or dispersed state (precipitating from a solution, melt or more rarely deposition directly from a gas).*

deformation : *The action or process of deforming or distorting solid rock (folding or faulting) as a result of various earth forces causing compression , shearing or extension of the rocks.*

differential stress : *Stress that acts with different magnitudes in different directions.*

dip : *The magnitude of the inclination, below horizontal, measured at right angles to strike.*

drilling mud : *A water-based or oil-based suspension of fine-grained clays, pumped contiuously down into an oil well, under hydrostatic pressure during rotary drilling in order to lubricate the mechanism, seal off porous rock layers, equalize the pressure, cool the bit, and flush out the cuttings.*

ductile deformation : *The response of a rock mass to stress by bending or flowage, like clay without any breakage.*

earthquake zone (seismic hazard zones, seismic zone) : *A region in which the rate of seismic activity remains fairly consistent . This may mean that in an earthquake zone seismic activity is very rare, or it is very common. Thus these are areas with an increased risk of seismic activity.*

ecosystem : A community of living organisms (plants, animals and microbes) in conjunction with the nonliving components of their environment (things like air, water and mineral soil), interacting as a system.

elastic strain : A form of strain in which the distorted body returns to its original shape and size when the deforming force is removed.

eon : An indefinitely long period of time. In formal usage, eons are the longest portions of geologic time (eras are the second-longest).

epicentre : The point on the earth's surface vertically above the focus of an earthquake (or underground nuclear explosion)

epoch : A division of geologic time that is a subdivision of a period and is itself subdivided into ages, corresponding to a series in chronostratigraphy.

era : A major division of time that is a subdivision of an eon and is itself subdivided into periods.

evaporite : Layered crystalline sedimentary rocks that form from sea water generated in areas where the amount of water lost by evaporation exceeds the total amount of water from rainfall and influx via rivers and streams. The term is also applied for a natural salt or mineral deposit found in the sedimentary deposit of soluble salts that is left after the evaporation of a body of water.

fern : Any of several non-flowering vascular plants belonging to the lower vascular plant division Pteridophyta and possessing true roots, stems, and complex leaves and that reproduce by spores.

fissure : A long, narrow opening or line of breakage made by cracking or splitting, especially in rock or earth:

foliation : Planar arrangement of structural or textural features in any rock type resulting from the alignment of constituent mineral grains of a metamorphic rock of the regional variety along straight or wavy planes.

foot wall : A mass of rock lying beneath a fault plane.

fossilization : The process of converting a plant or animal that existed in some earlier age, or of being converted, into a fossil or cause (something) to become a fossil.

friction : *The force that resists the sliding or rolling of one solid object over another.*

glass : *An amorphous material formed from a melt by cooling to rigidity without crystallization such as a usually transparent or translucent material consisting typically of a mixture of silicates or a material (as obsidian) produced by fast cooling of magma.*

grain : *A sedimentary particle (a mineral or a rock particle) of all sizes.*

green house effect : *The process of warming of the Earth's surface and troposphere (the lowest layer of the atmosphere), caused by the trapping of radiation emitted by the sun by the presence of water vapour, carbon dioxide, methane, and certain other gases in the air that allow incoming sunlight to pass through but retain heat radiated back from the planet's surface.*

greenhouse gases : *Any gas (such as Carbon dioxide, methane, water vapour, surface-level ozone, nitrous oxides, and fluorinated gases) that has the property of absorbing infrared radiation (net heat energy) emitted from Earth's surface and reradiating it back to Earth's surface, thus contributing to the phenomenon known as the greenhouse effect.*

hanging wall : *The block positioned over the fault plane in a non-vertical or dipping fault.*

headland : *A narrow piece of land or a promontory extending from a coastline into into the sea or lake.*

hinge : *The point of maximum radius of curvature in a folded surface .*

hydrocarbon : *An organic compound that are made of only hydrogen and carbon atoms such as any of those which are the chief components of petroleum and natural gas.*

inertia : *The tendency of a body at rest to remain at rest or of a body in straight line motion to stay in motion in a straight line (including changes to its speed and direction))unless acted on by an outside force.*

interlocking texture : *The kind of texture exhibited by the mineral grains of an igneous rock in which there is no space between individual crystals, because the crystals grew into one another.*

kerogen : *A mixture of organic chemical compounds that make up a portion of the complex fossilized organic matter in sedimentary rocks and found in oil shale and other sedimentary rocks, and when heated to the right temperatures in the Earth's crust, release crude oil or natural gas, collectively known as hydrocarbons (fossil fuels).*

lagoon : *A relatively shallow, quiet body of water usually saline water , situated in a coastal environment and having access to the sea but separated from the open marine conditions by a barrier; the barrier may be either a sandy or shingly wave-built feature (such as a sandbar or a barrier island), or it may be a coral reef.*

leaching : *The process of removal of soluble or other constituents by the action of rain water of a percolating solution.*

limb : *The generally planar region of a fold which lies between two adjacent hinge lines or the side of a fold which is common to adjacent folds.*

lithification : *Lithification is the processes of conversion of unconsolidated sediments into sedimentary rocks, through processes such as compaction under pressure, expulsion of contained fluids, and cementation.*

longshore current : *Current that flows parallel to the shore, within the zone of breaking waves, generated by approach of waves oblique to the shore.*

mafic : *Said of an igneous rock, composed of one or more ferromagnesian , dark coloured minerals.(e.g. gabbro and basalt)*

manganese nodules (polymetallic nodules) : *A small rock concretions (that generally range between 5 and 10 cm in diameter) , formed of concentric layers of iron and manganese hydroxides around a core and occurring in large numbers in sediment of the ocean-floor .*

marsh : *An area of low-lying land which is flooded in wet seasons or at high tide, and typically remains waterlogged at all times.*

mass extinction : *The extinction of a large number of species within a relatively short period of geological time, thought to be caused by factors such as a catastrophic global event or widespread environmental change that occurs too rapidly.*

mean sea level : *the sea level halfway between the mean levels of high and low water.*

melt : Molten or liquefied material(such as rock) formed by intense natural or artificial heating.

metamorphism : Solid state alteration of the mineralogic composition or texture of a pre-existing rock by heat, pressure, or other natural agency.

metasomatism : Change in the composition of a rock as a result of the introduction or removal of chemical constituents, during metamorphism.

migmatite : a rock composed of two intermingled but distinguishable components, typically a granitic rock within a metamorphic host rock.

mine : An opening or excavation made into the Earth for the extraction of mineral deposits or building stones.

mould : A type of fossil, consisting of an impression made in the earth or rock material by the exterior (external mould) or interior (internal mould) of a fossil shell or other organic structure.

mylonite : A fine-grained metamorphic rock, typically banded, resulting from extreme grinding or crushing of other rocks, along zones of faulting.

native metal : Any metal that is found in its metallic form, either pure or as an alloy, in nature.

obsidian : A hard, dark, glass-like volcanic rock formed by the rapid solidification of lava without crystallization.

oil field : A region with an abundance of oil wells extracting petroleum (crude oil) from below the ground surface.

oil shale(kerogen shale) : An organic-rich fine-grained sedimentary rock containing kerogen (a solid mixture of organic chemical compounds) from which liquid hydrocarbons called shale oil (not to be confused with crude oil occurring naturally in shales) can be produced.

oil trap : A localized accumulation of petroleum in a reservoir rock under such conditions that its further migration and escape is prevented.

ore : (1). A metal-bearing mineral or rock, or a native metal, that can be mined at a profit., (2). a mineral or natural product serving as a source of some non-metallic substance, as sulphur.

outcrop : (1). The visible exposure of bedrock on the surface of the Earth.(2). That part of a geologic formation or structure that appears or exposed at the surface of the Earth.

ozone : A colourless unstable toxic gas with a pungent odour and powerful oxidizing properties, formed from oxygen by electrical discharges or ultraviolet light. It differs from normal oxygen (O2) in having three atoms in its molecule (O3).

permineralization : A process of fossilization whereby the original hard parts of an animal or plant have additional mineral material deposited in their pore spaces.

petrification : A process of fossilization whereby organic matter is converted into a stony substance by the infiltration of water containing dissolved inorganic matter (eg. $CaCO_3$, silica SiO_2 etc;) which replaces the original organic material- sometimes retaining the original structure.

phenocryst : A term widely for a relatively large conspicuous crystal in a rock with porphyritic texture.

plastic deformation : Permenant deformation of the shape or volume of a substance, without rupture , and which once begun is continuous without increase in stress.

plunge : The angle of inclination of the axis of a fold , as measured from the horizontal

pluton : A body of intrusive igneous rock , the size, composition, shape, or exact type of which is in doubt. (when such characteristics are known, more limiting terms such as sill dyke etc; can be used) .

protolith : The original, unmetamorphosed rock from which a given metamorphic rock is formed. (e.g. the protolith of a slate is a shale or mudstone)

pumice : A light coloured , very light , vesicular or porous volcanic rock formed when a gas-rich froth of glassy lava solidifies rapidly.

pyroclastic : Composed chiefly of rock fragments of explosive origin, especially those associated with explosive volcanic eruptions (Volcanic ash, obsidian, and pumice are examples of pyroclastic materials) .

quarry : A surficial mine or place, typically a large, deep pit, from which building stone or other materials are, or have been, extracted.

recrystallization : *The process of formation of new crystalline mineral graoins in a rock , essentially in the solid state, under situations of intense temperature and pressure associated with metamorphism of rocks.*

relative age : *The geologic age of a fossil organism, rock or geologic feature or event defined relative to other organisms, rock, or feature or event.*

reservoir rock : *A rock with adequate porosity to contain migrating liquid or gaseous hydrocarbons . (A sandstone has plenty of pore spaces inside it to hold oil, just like a sponge has room inside of it to soak up water. It is for this reason that sandstones are the most common reservoir rocks).*

scoria : *Basaltic lava ejected as fragments from a volcano, typically with a frothy or vesicular texture.*

sediment : *Solid fragmental material, or a mass of such material, either inorganic or organic that originates from weathering of rocks, and is transported by, suspended in, or deposited by air, water or ice or that is accumulated by other natural agents such as chemical precipitation from solution or secretion by organisms, and forming layers on the Earth's surface at in a loose unconsolidated form. e.g. sand, gravel, silt, mud, loess, alluvium.*

seismicity : *the occurrence or frequency of earthquakes in a region.*

silicic : *Said of silica rich igneous rock or magma (silica percentage in rock is >65%)*

sorting : *A term used to describe the distribution of grain size of sediments (either in unconsolidated deposits or in sedimentary rocks) . Very poorly sorted indicates that the sediment sizes are mixed (large variance); whereas well sorted indicates that the sediment sizes are similar (low variance).*

storm : *Violent disturbance of the atmosphere with strong winds and usually accompanied by rains, thunder and lightning .*

strain : *The amount of deformation an object experiences compared to its original size and shape. Or change in the shape or volume of a body as a result of stress.*

stratigraphic column : *A stratigraphic column is a representation used in geology and its subfield of stratigraphy to describe the vertical location of rock units in a particular area.*

stress : Load (force) per unit area that tends to deform the body on which it acts. Compressive stress tends to squeeze a body, tensile stress to stretch (extend) it, and shear stress to cut it.

strike : The trend of the line of intersection between the planar feature and a horizontal plane

swamp : A wetland that is intermittenmtly or permenantly covered with water and having shrub and tree -type vegetation, essentially without peat-like accumulation and unsuitable for cultivation.

tabular intrusion : An intrusion with broad and flat top and bottom.

tension : A force which tends to stretch an object

topography : The arrangement of the natural and artificial physical features of an area or the general configuration of a land surface or any part of Earth's surface , including its relief and the position of its natural features.

undercutting : Cutting wearing away or removal of material at the base of a steep slope or cliff by the erosive action of running water or sand-laden wind in a desert or by wave action along the coast .

vesicles : A cavity of variable shape in a lava formed by the entrapment of a gas bubble during solidification.

volatiles : In igneous petrology, the term more specifically refers to the volatile components of magma (CO_2, SO_2, O_2, Cl_2, and particularly H_2O) that is present in dissolved state under high pressure and affect the appearance and explosivity of volcanoes and crystallization history of magmas.

wave length : The distance between corresponding points of two consecutive waves.

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