

BLOCK**2****EVOLUTION OF LANDFORMS****UNIT 4** **69****THEORIES OF DEVELOPMENT OF MAJOR LANDFORMS****UNIT 5** **95****TECTONIC PROCESSES AND LANDFORMS I****UNIT 6** **111****TECTONIC PROCESSES AND LANDFORMS II****GLOSSARY** **139**

MGG-002 GEOMORPHOLOGY

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BLOCK 2: EVOLUTION OF LANDFORMS

This block discusses the evolution of landforms. A landform is a natural or human-made feature on the Earth's surface. On the Earth's surface, we may see a variety of topographical features such as mountains, valleys, plains, sand dunes, glacial deposits, volcanoes, and so on. Landforms evolve throughout a variety of time scales. Geoscientists think that the Earth is around 4.5 to 5 billion years old. Some landforms emerge instantly, such as landslide facets, while others, such as escarpments or inselbergs, evolve over millions of years. These landforms might be the result of simple or complicated processes. Landforms are dynamic in nature, evolving throughout time as a result of endogenetic and exogenetic processes.

The study of landform evolution is required to comprehend the properties of landforms, such as their shape, material composition, and spatial distribution throughout the Earth's surface. There are several scientists explained the Earth's interior in different ways, some of them are Eduard Suess, Van der Gracht, Arthur Holmes, R.D. Oldham, Beno Gutenberg, Inge Lehmann, Mohorovicic and Conard. According to George Airy, the crust is comprised of lighter SIAL and floats above the substratum, which is made of denser SIMA. He proposed that the Himalayas are floating in denser magma, with their maximum amount plunged into the magma to balance the weight. This notion is easily grasped by imagining an iceberg floating in water, with just one-tenth of the iceberg visible and the rest nine parts submerged in water. After Airy, Pratt, Hayford and Bowie, Joy perceived the idea of a level of compensation of the Earth's major relief features.

Endogenic factors are agents supplying energy for actions that are located within the Earth. Endogenic factors have their roots deep under the Earth's surface. These forces mainly two types: diastrophic and sudden forces those are responsible for the major relief features of the Earth's surface. Land upliftment, subsidence, folding and faulting are resultant processes influenced by epeirogenic and orogenic movements of diastrophic forces. While sudden movements result into sudden and rapid events such as earthquakes and volcanic eruptions which produce volcanic mountains and lava plateaus. Whereas, exogenic factors are agents supplying energy for actions that are located at or near the Earth's surface. Exogenic factors are usually driven by gravity and/or atmospheric forces.

This block introduces you to Evolution of Landforms dealing with theories of development of major landforms, tectonic process and landforms in three units.

Unit 4: Theories of Development of Major Landforms

In this Unit, we have explained the theories of major landform formation by describing Earth's structure, theories of isostasy, eustasy, continental drift, and plate tectonics.

Unit 5: Tectonic Processes and Landforms I

In this unit we have discussed about endogenic movements. Upliftment and subsidence are two important processes that dealt under epeirogenic movements, while folding and faulting are explained under orogenic movements. The landforms related to these movements are also discussed in this unit.

Unit 6: Tectonic Processes and Landforms II

Volcanism and type of volcanoes are explained in this unit. The distribution of volcanoes and earthquakes and their effects on human life are discussed. The landforms associated with volcanoes are elaborated broadly in this Unit.

We hope after studying this block, you will better understand the theories of development of major landforms along with various tectonic processes and resultant landforms.

Our best wishes are with you in this endeavour.

We suggest for any assistance regarding this course, you can contact at: knrao@ignou.ac.in and dr.krishnakumar@ignou.ac.in



THEORIES OF DEVELOPMENT OF MAJOR LANDFORMS

Structure

4.1	Introduction	4.6	Plate Tectonics
	Expected Learning Outcome	4.7	Summary
4.2	Earth's Internal Structure	4.8	Terminal Questions
4.3	Isostasy	4.9	Answers
4.4	Eustasy	4.10	References and Suggested
4.5	Continental Drift		Further Reading

4.1 INTRODUCTION

In Block 1, you learned the fundamentals of geomorphology, such as the evolution of geomorphology, basic geomorphological postulates, geomorphic systems, and concepts. You have probably heard that different theories explain distinct reasoning when it comes to understanding the concept of geomorphology. Block 2 discusses the evolution of landforms. In this Unit, we will study on the theories of major landform formation by describing Earth's core structure, theories of isostasy, eustasy, continental drift, and plate tectonics.

Expected Learning Outcomes

After studying this unit, you should be able to:

- Explain what landform is;
- Elaborate the Earth's internal structure;
- Define the concept of isostasy and eustasy;
- Illustrate continental drift theory; and
- Elucidate how the continental drift theory aid in evolving the plate tectonics theory.

4.2 EARTH'S INTERNAL STRUCTURE

Before we start understanding internal structure of the Earth, let us understand what is a landform? **Landform** is a natural or human made

feature on the surface of the Earth. We generally observe numerous topographical features such as mountains, valleys, plains etc., on the Earth's surface. Were these features there when the planet Earth was created, or did they emerge through time? The topographical characteristics of the Earth have changed over time, owing mostly to forces/processes acting in the Earth's crust. Assemblages of landforms are together called as **terrain**. The arrangement of landforms in a landscape is referred to as topography. Landforms include mountains, plateaus, valleys, sand dunes, glacial deposits, volcanoes, ocean basins and trenches. Landforms are identified as single or assemblage of individual landforms and named accordingly. They vary in size, shape and extension and are categorized by their size from first order continental scale to fourth order smaller features like sand ripples or lineaments.

Landforms develop over a range of different time-scales. Some landforms develop instantaneously like landslide facets to longer time scale or millions of years like inselbergs. These landforms can be product of relatively simple or processes of complex nature and involve a combination of multiple processes and denudational agents. Landforms are dynamic in nature and have been continuously changing over time due to endogenetic and exogenetic processes.

There are various characteristics of landforms which are measured or quantified to understand their form, shape and suitability for use. Landform classification and landform mapping are two significant components of landform studies. Anthropogenic activities are also changing the landforms through regular, cyclic and periodic use of the Earth surface features. Landforms are also altered for various economic uses such as mining or construction of reservoir, etc. Study of the evolution of landform is necessary to understand the characteristics of the landforms, their shape, material composition, spatial distribution over the Earth's surface. The Earth scientists have believed that the age of the Earth is nearly 4.5 to 5 billion years.

Now you must have understood what a landform is. Let us now study about Earth's internal structure. It is very essential to know about the internal structure of the Earth as it helps to understand in detail the changes that are happening over the Earth's surface related to the motion of the plates and volcanic eruptions, etc. It is possible to get some ideas about the interior of the Earth from the ancient igneous and metamorphic rocks which were formed much below the Earth's surface but are now exposed as a result of prolonged sub-aerial denudation. The direct observations of the crustal layers of the Earth are also possible to record from the petroleum and natural gas oil wells. In addition, the heat of the Earth's interior can be assessed during volcanic eruptions and other surface manifestations.

The knowledge about the interior of the Earth is completely based upon the investigations carried out by geologists, geophysicists and other Earth scientists with the help of different instruments and extremely complex methods. Thus, understanding the Earth's interior is not as simple as understanding the surface features as we have to rely on many direct and indirect sources. For example, the direct sources are including deep earth

mining and drilling, and volcanic eruption. Whereas the indirect sources may be as follows:

- With depth, pressure and density increases and hence temperature.
- Meteors and Earth are solar system objects that are born from the same nebular cloud. Thus, they are likely to have similar internal structures.
- The geodynamic effect helps scientists understand what's happening inside the Earth's core. Shifts in the magnetic field also provide clues to the inaccessible iron core.

Three important parameters like temperature, pressure and density are discussed below which play a key role in understanding the internal structure of the Earth.

(1) Temperature

The average rate of temperature with increasing depth is 1°C for every 32 meter of descent. With such rate of increase in temperature, the rocks and metals cannot remain in solid state at a depth of about 48 kilometres as the temperature should increase to somewhere between 1200°C to 2000°C . It appears that the magma erupted from volcanoes must lie at about this depth, as the temperature of the lava inside the craters has been usually found to be 1200°C and above. Thus, we can assume that temperature goes on increasing at this rate till the centre of the Earth. On the basis of evidences by several geophysical studies it has been estimated that the temperature at the bottom of the mantle should be about 3000°C and that at the centre of the Earth should be about 4000°C with variation of $\pm 1000^{\circ}\text{C}$.

(2) Pressure

Pressure in the interior of the Earth exerts a powerful influence on the physical properties of the rocks and their reactions to different forces. Atmospheric unit is used to measure the pressure inside the Earth. At a depth of 15,000 miles the pressure is estimated to be 3.5 million atmospheres. There is the pressure of the entire mass of the Earth.

(3) Density

The average density of the Earth is 5.5 grams/cm^3 . This means that the weight of the Earth is 5.5 times the weight of an equal volume of water. The density of granite is 2.6 and that of basalt is 3.0, these are the two most common rocks found on the upper surface of the Earth. In other words, it can be said that while the average density of the Earth is 5.5 grams/cm^3 , the density of the surface rock is less than 3 grams/cm^3 . Therefore, from here we can say that the density of materials in the core of the Earth is much more than the density of rocks found in the upper layer of the Earth.

Various scientists explained the Earth's interior in different ways, some of them are described below:

4.2.1 Internal Structure of Earth According to Suess

Eduard Suess (1835-1909) an Austrian geologist proposed a three layered structure of the Earth's interior in 19th century as Sial, Sima and Nife.

- i) **SiAl (Silica and Alumina):** The top layer, immediately under the continents, is composed of a rock layer that is similar to granites and gneisses. This layer was named by Suess as Sial as Silica (Si) and Aluminum (Al) are the principal elements of this layer. The specific density of this layer is 2.75 to 2.90 g/cm³.
- ii) **SiMa (Silica and Magnesium):** The intermediate layer has a predominance of high density igneous rocks such as basalt and gabbro. This layer has been called Sima as Silicon (Si) and Magnesium (Ma) are the principal elements in the rocks. The density of this layer is 2.90 to 4.75 g/cm³.
- iii) **NiFe (Nickel and Ferrum):** The last layer is the central core, also called Nife by Suess as it consists of dense and heavy metals like Nickel (Ni) and Ferrum or Iron (Fe). The density of this layer ranges between 9.5-14.5 g/cm³.

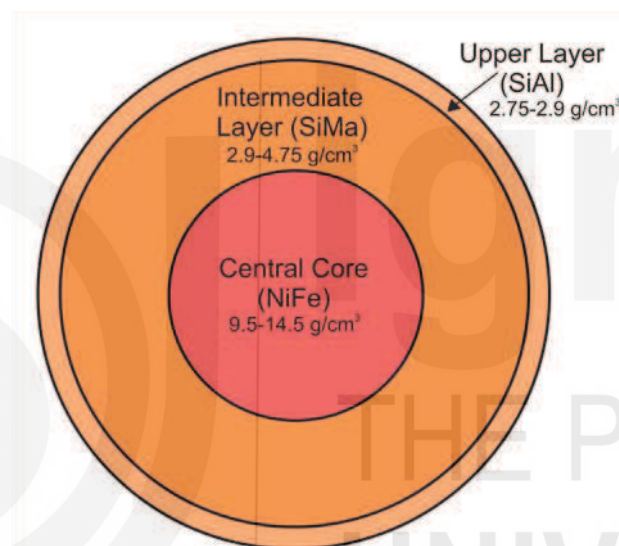


Fig. 4.1: Internal Structure of Earth according to Eduard Suess.

4.2.2 Internal Structure of Earth According to Van der Gracht

Van der Gracht, a German geologist in 1928 identified four zones of the interior of the Earth. He summarized the various properties of the Earth's interior with varying figures regarding the number, thickness and density properties in the following way.

S. No.	Name of the layer	Density (g/cm ³)	Thickness
1.	Outer Silicate Zone	2.75 - 2.90	60 km below the continents
2.	Inner Silicate Zone	3.1 - 4.75	60-1140 km
3.	Zone of Mixed Silicates and Iron	4.75 - 5.0	1140-2900 km
4.	Metallic Core	11.0	2900-6371 km

4.2.3 Internal Structure of Earth According to Arthur

Holmes

Arthur Holmes has recognized two major layers of the Earth and suggested that instead of *Sial* and *Sima*, it is preferable to use the term Crust for the upper layer and Substratum for the middle layer. Holmes classification helps us in understanding the influence of the internal forces on the formation of the landforms on the surface of the Earth as given in Fig. 4.2.

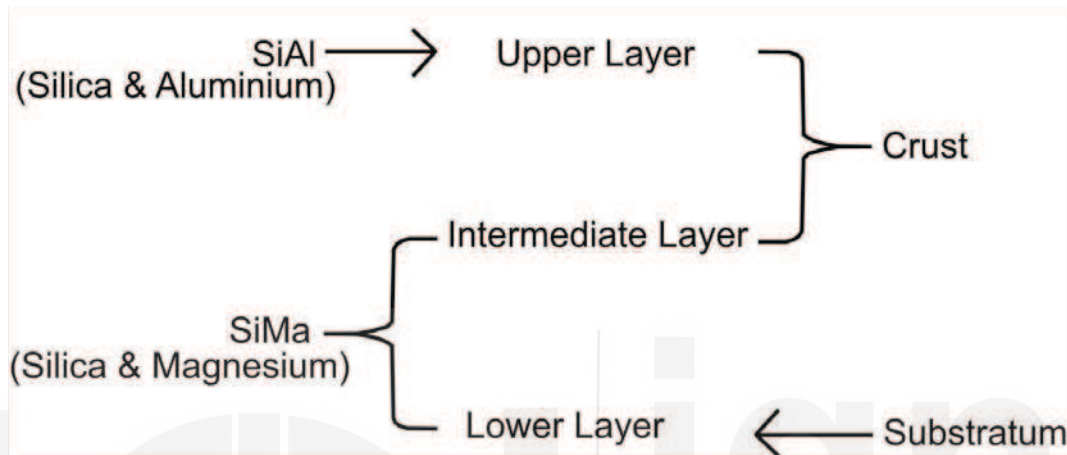


Fig. 4.2: Internal Structure of Earth - Holmes Classification.

4.2.4 Recent Studies on Internal Structure of Earth

Knowledge of the Earth's interior has recently expanded as a result of technological advancements and thorough research of seismic waves. An earthquake causes vibrations that travel through the Earth and are known as **seismic waves**. These seismic waves are distinct from one another in terms of propagation speed, wavelength, course of travel, and vibrational type. Seismic waves are two types - **body waves** (P and S waves) and **surface waves**.

P-waves, also known as longitudinal waves, are compression waves because they move through solid, liquid, or gaseous materials in a series of compressions and expansions. P-waves have the power to push or pull material particles in the direction of their motion while liquids and gases are not conducive to shear wave propagation. They are shear waves that move objects perpendicular to their direction of motion. **S-waves** have different names: secondary waves or shear waves or transverse waves or transitional waves (Fig. 4.3).

In a big shallow focus earthquake, **surface waves** are typically the ones that cause the greatest damage. Low frequency, long wavelength, and low velocity characterize them. These are two types: love waves and Rayleigh waves. Unit 6 of this block will teach you in great detail about the many kinds of seismic waves and earthquakes.

Based on the propagation of the earthquake waves and study of the changes in the velocity of seismic waves that passes through the interior of the Earth, it is

possible to divide the Earth's interior into three concentric layers – i) **The Crust**, ii) **The Mantle**, and iii) **The Core**.

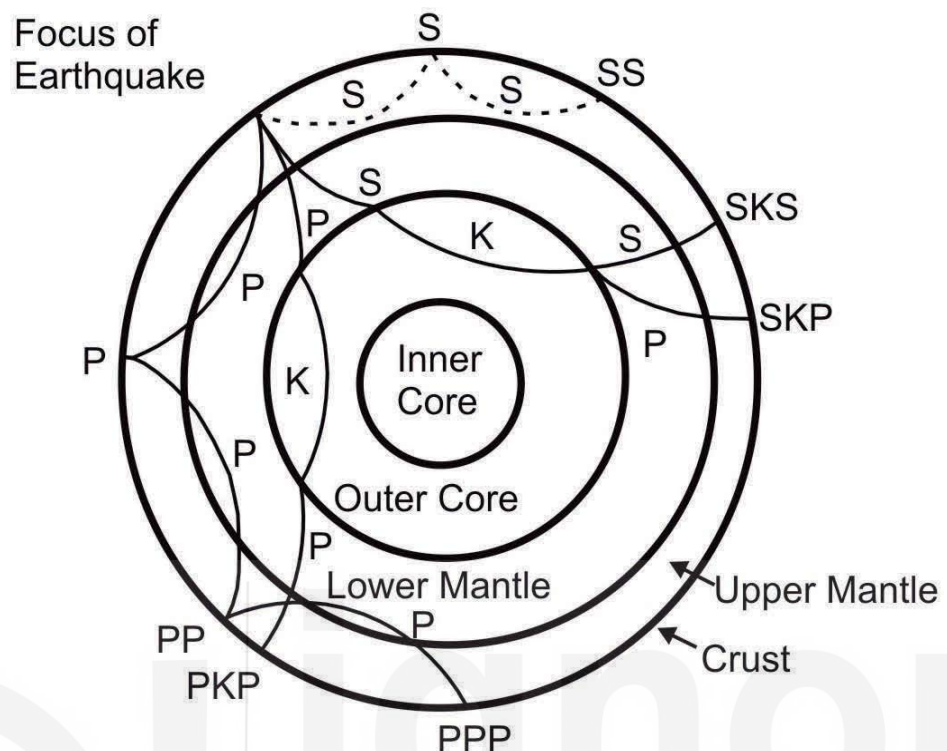


Fig. 4.3: Propagation of the Earthquake waves in different layers of the Earth's interior. Solid lines marked *P* are compressional waves; dashed lines marked *S* are shear waves. *S* waves do not travel through the core but may be converted to compressional waves (marked *K*) on entering the core (*PKP*, *SKS*). Waves may be reflected at the surface (*PP*, *PPP*, *SS*).

(Source: USGS, 2011; <https://pubs.usgs.gov/gip/interior/>)

Thus, seismology has made a significant contribution to the understanding of the internal structure of the Earth.

Let us discuss all the three layers one by one.

(a) The Crust

The upper and the thinnest layer of the interior of the Earth is the crust. It is composed of different kinds of silica-rich rocks of different ages. There are two different types of crust, each has its own distinctive physical and chemical properties. They are:

- i) **Oceanic Crust** which is high in density and is composed of magma that erupts underneath the ocean and cools down to form the oceanic crust.
- ii) **Continental Crust** is relatively low in density and is made up of different types of igneous, metamorphic and sedimentary rocks. The contract zone between the upper mantle and the crust is **Mohorovicic** or **Moho Discontinuity**. It is named after the Croatian geophysicist Andrija Mohorovicic who first discovered it in 1909.

The boundary between the upper crust and the lower crust is called the **Conard Discontinuity**. You may refer to Fig. 4.4, for understanding depth and density of rocks in different layers of Earth.

Name of Layer		Depth (km)	Density (10^3kg/m^3)	Type of Rock
Crust	Upper	0	2.8	Silicic rocks
	Lower	17		
Mantle	Upper	33	3.0	Andesite, basalt at base
		700	3.3	
	Lower	2890	4.3	Peridotite, eclogite, olivine, spinel, garnet, pyroxene
		5100	5.5	Perovskite, oxides
Core	Outer	5100	10.0	Magnesium and silicon oxides
		6378	12.3	
	Inner	6378	13.3	Iron + oxygen, sulfur, nickel alloy
			13.6	Iron + oxygen, sulfur, nickel alloy

Fig. 4.4: Density Variations of Different Layers of Earth's Interior.

(Source: USGS, 2011; <https://pubs.usgs.gov/gip/interior/>)

(b) The Mantle

The mantle layer of the Earth's interior is above the core and just below the crust. Its thickness is nearly 2900 km and contains about 80% of the Earth's volume (Fig. 4.5). The two most important things about the mantle are i) it is made of mostly dense iron and magnesium silicates and ii) it is hot.

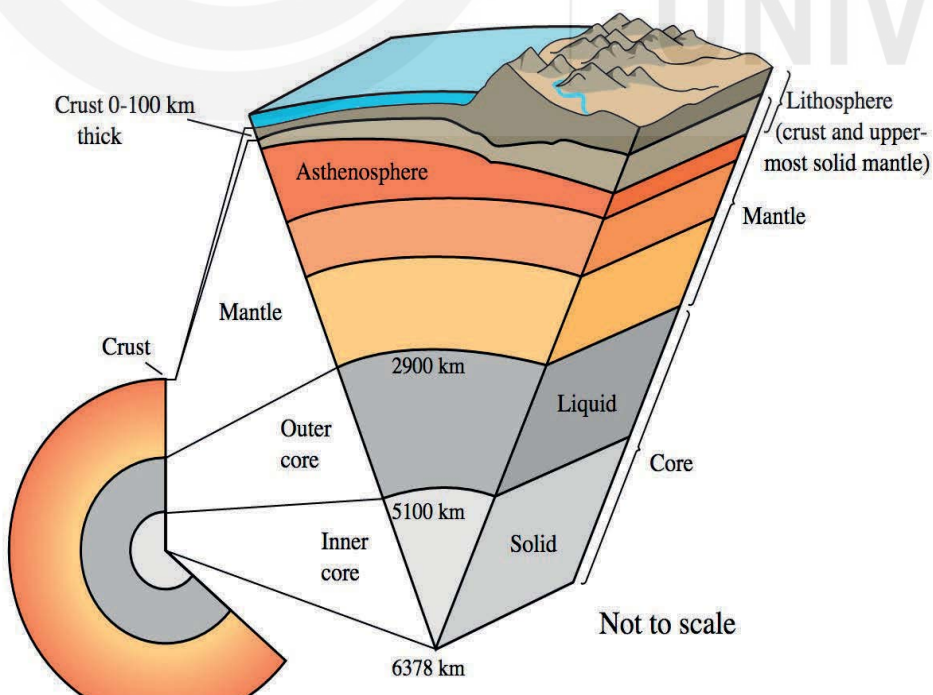


Fig. 4.5: Internal Structure of the Earth.

(Source: <https://www.usgs.gov/media/images/cutaway-views-showing-internal-structure-earth-left>)

According to different studies, it has been revealed that the mantle is subdivided into thinner layers each containing a distinctive group of minerals. But broadly it can be subdivided into two parts – the lower mantle or the mesosphere and the upper mantle or the asthenosphere. The boundary between the upper mantle and lower mantle is called **Repetti Discontinuity**. The rocks in the upper mantle are cool and brittle enough to break under stress and produce earthquakes. However, the rocks in the lower mantle are hot and soft and flow when subjected to forces instead of breaking

(a) The Core

R.D. Oldham in 1906 established the existence of the core of the Earth and significance of seismology in the study of the structure of the Earth's interior. The boundary of the core of the Earth from the surface was accurately delineated at 2900 km (1800 mi) by Beno Gutenberg in 1912. This depth represents the boundary between the core and mantle which is also known as **Gutenberg Discontinuity**. The core is mostly composed of nickel and iron which is in a fluid condition. In 1936, Inge Lehmann showed through seismic studies that the inner core is solid and the boundary between the outer core and inner core is called **Lehmann Discontinuity**. Thus, the core of the Earth was divided into two parts – the inner core and the outer core.

On the basis of different experiments, it can be said that the inner core is pure iron and the outer core is a mix of iron, nickel, silicon, sulphur and oxygen. The outer core also acts as a giant self-exciting dynamo, which raises convection currents of liquid iron that carry electric currents and interact with the Earth's magnetic field.

SAQ I

- What are three key parameters must know in understanding the Earth's internal structure?
 - Where can you find Gutenberg Discontinuity?
 - What is the average density of *nife* layer?
-

4.3 ISOSTASY

Let us now discuss about the concept of Isostasy and the development of views on this concept by different scholars. The word **Isostasy** is derived from the Greek word *Isostasio* meaning: a state of balance. American geologist C. Dutton was the first to use the term isostasy in the year 1889 to show the state of gravitational equilibrium that exists between large upstanding areas of the Earth's surface, mountain range and plateau.

According to Dutton the height of these different features was related to their density. In other words, the higher features were composed of rocks of lower density. For example, the upstanding parts of the landform must be compensated by lighter rock material from beneath so that the crustal reliefs should remain in an equilibrium state.

4.3.1 The Concept of Isostasy by Sir George Airy

According to George B. Airy (1855), the crust which is made of lighter *sial* is floating over the substratum which is built of the denser *simā*. In simple words, *sial* is floating over *simā*. Thus, he suggested that the Himalaya is floating over the denser *simā*. He also said that the Himalayas are the lighter rocks of the mountain that extended their roots deep down into the denser material below the surface. In other words, the Himalayas are floating in the denser magma with their maximum portion sunk in the magma to balance the weight. This concept can simply be understood with the help of an iceberg floating in the water and thus the principle of floatation can be easily understood. When the iceberg float in the water, only one-tenth of the iceberg can be seen and the remaining nine parts immerse in the water Fig. 4.6).

According to Airy, landmass can be considered as wooden blocks of different heights floating in the water. The blocks emerged under the water which is proportional to their height so the block which rises high above the water is also the block that goes deepest into the water. Thus, these blocks are said to be in the state of hydrostatic balance or equilibrium. Thus, Airy came to the conclusion that the continents are resting, or rather floating in a denser mass and that excess of matter above the upper surface of the substratum is balanced by the deep projection of lighter material into the substratum.

4.3.2 The Concept of Isostasy by A. Pratt

Archdeacon Pratt while studying the difference of gravitational deflection observed at Kaliana and Kalianpur, found the differences to be more than the observed deflection. After calculating the average density of the Himalayas, he found that the gravitational forces of the Himalayas were less than the mass of the mountains as the mountains were made of much lighter materials or rocks of much lower density. He then continued his study with the densities of the rocks of the mountains, plateau and plains and came to the conclusion that the rocks of mountains should have a lower density than those of plateaus, rocks of plateaus have a lower density than the plains and the plains lower than the rocks of the ocean floor.

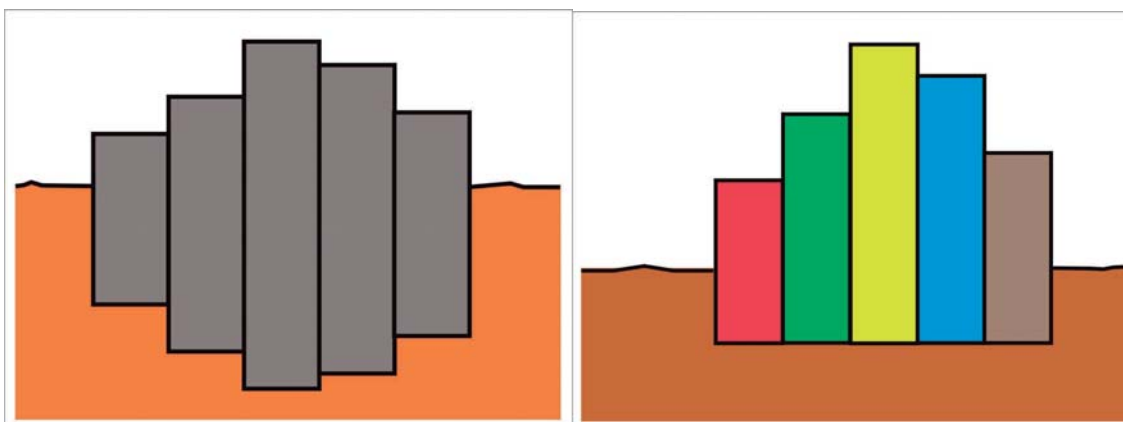


Fig. 4.6: a) Airy theory exhibits that the blocks of same densities with different masses b) Pratt theory explains that the blocks of same mass with different densities.

According to Pratt, there is an inverse relationship between the height of the relief features and density. Higher the column, lesser the density and the smaller the column, greater the density. He was of the view that there was a level above which the changes in density were found and below that the density remains uniform. He presumed an uniform level at a certain depth below the crust over which different earth blocks rest with varying density and height naming it as the “compensation level”.

4.3.3 The Concept of Isostasy by Hayford and Bowie

After Pratt’s concept, Hayford and Bowie perceived the idea of a level of compensation, or in other words, it is the level of uniform pressure where the compensation of the Earth’s major relief features by the underlying differences of density is said to be complete. Above this level of uniform pressure, there is a variation in density and the density is inversely proportional to the height for contiguous columns of equal cross-section.

You may refer to the Figure 4.7, which explains that the four columns of interior plain, plateau, coastal plain and off-shore region extends up to the level of compensation. There can be seen a difference in the height but they keep the balance due to different densities. The pressure of the columns is thus equal at the level of compensation.

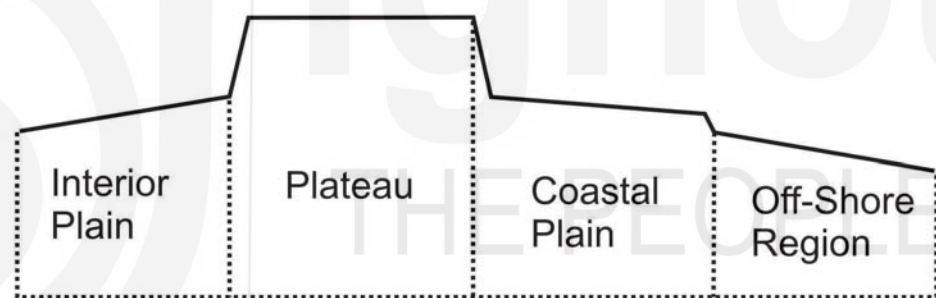


Fig. 4.7: Level of Compensation.

Bowie tried to explain the concept of level of compensation and the theory of isostasy with the help of an experiment using different metals. He took eight pieces of iron, silver, copper, lead, zinc, pyrite, tin and nickel, of equal width and thickness but of different heights. He then places them in a basin filled with mercury. The experiment shows that the bottom of all eight pieces lay at the same level but their height above the mercury differs. The pieces with lower density floated higher and those with higher density stood lower.

4.3.4 The Concept of Isostasy by Joly

Joly, while presenting his view on isostasy in 1925, supported the views given by Airy and criticized the views of Hayford and Bowie. Joly has objected to the depth of the level of compensation as suggested by Hayford, at a depth of 100 kilometer where the temperature would be too high that all rocks would become liquid and the level of compensation would not be possible.

According to him, there exists a 10-mile-thick layer below the areas having a similar low density. The areas with low density penetrate into this thick layer while the higher density rocks rise to higher levels. Thus, Joly conceived the

level of compensation not as a straight-line but a surface closer to the floatation theory of Airy.

Joly applied the principle of floatation and came to the conclusion that if the average density of the continental rocks is 2.67 and that of the substratum as 3, then nearly eight times the height of the rocks above the substratum should penetrate into the denser substratum. So, following Joly's view of floatation, in Airy's concept, it can be understood that in case of the mountain range of the Himalayas, the rocks of relatively low density must extend in to the depths by nearly eight times inside the sub-stratum. In other words, we can say that the density of the rocks must be relatively low, down to the considerable depths below these mountains. Through the concept given by Airy, we can say that the Earth's major relief features are balanced by differences in their density, the individual mountains and valleys are not separately balanced or compensated as the crustal rocks have enough strength to maintain and hold in positioning the minor relief features of the Earth surface.

4.3.5 The Concept of Isostasy by Arthur Holmes

Holmes supported the views of Airy, and agreed that the higher relief features of the Earth's surface are composed of a lighter material and their major portions lie buried in the heavier and denser rocks below to keep them in a state of hydrostatic balance. According to him, exploration of the crust by Earthquake waves confirms the inference that mountain ranges have roots largely composed of sialic rocks, going down to depths of 50 to 60 kilometer. In the coastal region, the thickness of the *sial* and other crustal rock is only 30 kilometer or less than that and beneath larger parts of the deep ocean floor, the *sial* is either extremely thin or totally absent. Holmes tried to explain the concept of isostasy with the help of a diagram shown in Figure 4.8 and illustrates the relationship between the surface features and crustal structure.

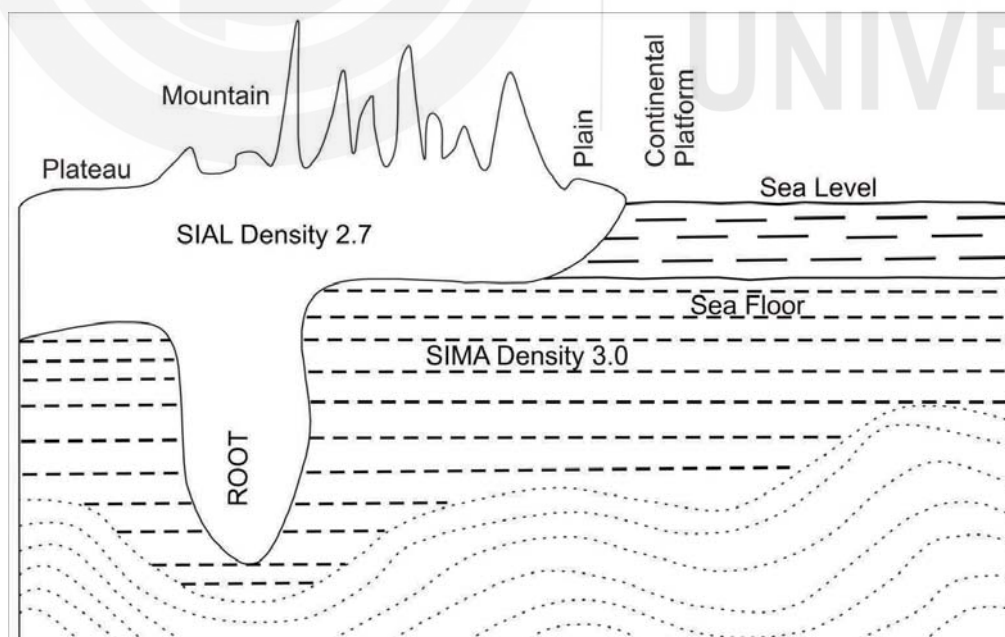


Fig. 4.8: Depth of *sial* below Mountains, Plateaus, Plains and the Ocean Floor.

This explanation is an elucidation and confirmation of Airy's views to the knowledge about the distribution of *sial*, crustal *sima* and mantle *sima* as

revealed by Earthquake waves. When the Moho discontinuity, separating the lighter crust from the denser mantle was found, it was the crust with the solid fluid sub-stratum. It can be considered that the lithosphere to be the floating layer while the asthenosphere provides the fluid sub-stratum.

The theory of isostasy is no longer considered as a theory but is accepted as a fact. It also helps in understanding the internal structure of the Earth, variation of surface relief, drifting of the continents, and also the rising and falling of land and sea. It thus plays an important role in controlling the topography of the Earth's surface.

4.3.6 The Isostatic Adjustment

It can be said that there is no complete isostatic adjustment over the surface of the Earth as the agent of erosion keeps on working continuously and the crust is reduced by the weight of the material that has been eroded away and are being deposited in the region which receives a corresponding increase of load. At the base of the crust the pressure exerted by the unloaded column is decreased, while the pressure exerted by the loaded columns is increased. The pressure differences in the mantle are a sub-crustal slow flow of *sim* from under the loaded column towards the base of the unloaded column. The loaded column sinks while the unloaded column rises. This process through which isostatic equilibrium is restored is called isostatic adjustment.

SAQ 2

Differentiate the views of Airy and Pratt on Isostasy.

4.4 EUSTACY

For a long time it was thought that sea level does not change. With the theory of isostasy, change in sea level was thought to be due to isostatic changes and the concept was also seen through the Davis' theory of Geographic cycle where absolute relief is subjected to erosion and removal of mass. Indian plate movement and differential impact of collision created coast of emergence along Bay of Bengal and coast of submergence along Gujarat and Konkan coast along Arabian Sea. However, growing submergence of coast in certain areas and shrinking coverage of glacier and snow melt led to an alternative concept i.e. **Eustacy**, where in it was theorised that global scale sea level change is caused by change in volume of water.

Eustatic sea level is defined as the distance from the centre of the Earth to the sea surface. Change in this eustatic sea level can be generated due to change in glaciation rate, spreading rates of the mid-oceanic ridges. The former is linked to climate change and the latter is linked to plate movements. Eustatic sea level is not relative to local surfaces, because relative sea level is dependent on many factors including tectonics, continental rise and subsidence.

a) Sea Level Rise and Eustatic Changes

Earth's climate has changed throughout history. A number of criteria have been used to study worldwide trends in sea level. Figure 4.9 generated by Vail and others (1977) depicts variations in sea level from the Cambrian Period to the Pleistocene Epoch. The curves were created through research of the overlap of coastal deposits in maritime sequences. The early Tertiary sea level was often substantially higher than the late Tertiary sea level. Sea level was greater throughout the middle Miocene and part of the Pliocene than it is now, but it was lower during the late Miocene and much of the Quaternary.

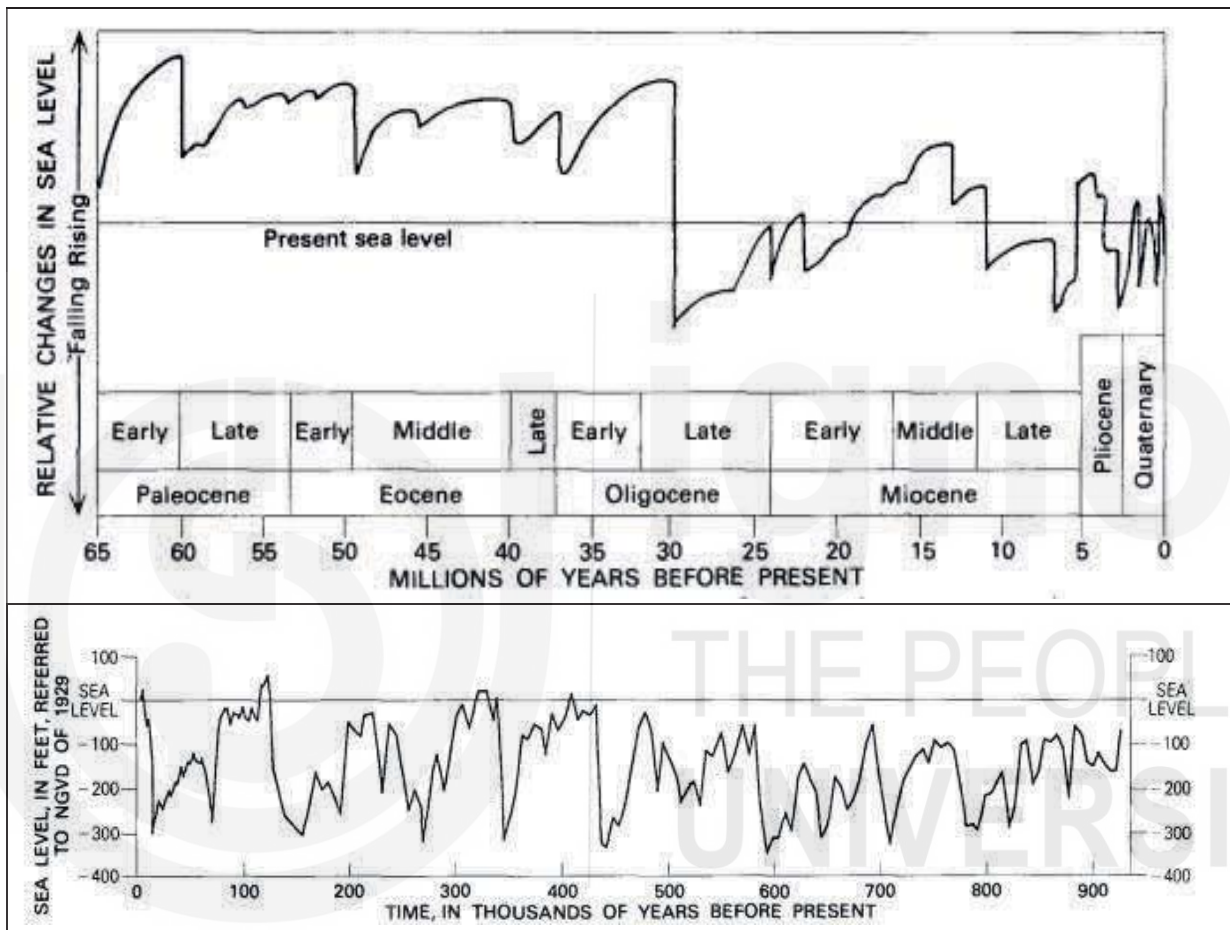


Fig. 4.9: Variations in Sea Level during Early Period.

(Source: <https://pubs.usgs.gov/wsp/2255/>)

Using oxygen isotope data, more comprehensive sea-level curves during the Quaternary Period have been constructed. The curve shows eight large-scale sea-level fluctuations with an amplitude of more than 200 feet occurred over the previous 900,000 years, according to estimates of sea-level shifts based on oxygen-isotope data. Eight more sea level changes occurred, and their amplitudes ranged from 100 to 200 feet. The research also noted that temperatures in the oceans were usually higher during 1 to 2.3 million years ago than in the previous 1 million years. Therefore, during the earlier period, glacial ice amounts were typically lower and sea levels were generally higher. The average Quaternary sea level was about 50 to 100 feet lower than current sea level.

There have been seven cycles of glacial advance and retreat in the last 650,000 years, with the abrupt end of the last ice age approximately 11,700

years ago marking the beginning of the current climatic era — and of human civilization. The oceans, which cover over 70% of the Earth's surface, have a two-way link with weather and climate. The oceans impact weather on a local to global scale, and changes in climate can fundamentally alter many properties of oceans and its features. As greenhouse gases capture more solar energy, the seas absorb more heat, resulting in higher sea surface temperatures and increasing sea levels.

According to the independent research showed in Figure 4.10, the quantity of heat stored in the ocean has grown significantly since the 1950s. The heat content of the ocean influences not only sea surface temperature but also sea level and ocean currents. Since 1880, global mean sea level has increased by around 21-24 centimetres, with about a third of the increase occurring in the previous two and a half decades. The rising water level is caused mostly by melt water from glaciers and ice sheets, as well as thermal expansion of saltwater as it warms. Additional sea level rise is unavoidable as global temperatures continue to climb, and it is dependent on the rate of greenhouse gas emissions.

Even if greenhouse gas emissions remain relatively low in the following decades, global mean sea level is expected to rise by at least one foot by the end of the century. Aside from that, the ice sheets in Antarctica and Greenland are melting gradually, bringing massive amounts of water to the ocean. This is a very worrisome scenario, and we must act now to benefit our future generations and our mother planet Earth.

Do you know how sea level is measured? It is essential to understand how global sea levels are monitored. Tides and satellite altimeters are the two main methods for monitoring sea level. Tides gauge stations throughout the world have utilised a variety of manual and automatic sensors to record daily high and low tides for more than a century. Using data from thousands of locations throughout the world, scientists can calculate a global average and adjust it for seasonal variations. Since the early 1990s, sea level has been monitored from space using radar altimeters, which compute the height of the sea surface based on the return speed and strength of a radar pulse aimed towards the ocean. The higher the sea level, the faster and stronger the return signal.

b) Impact of Eustatic Changes

As sea level rises, dry land and wetlands can turn into open water because of low elevations. Changes in water temperature, ocean acidification and deoxygenation are leading to changes in oceanic circulation and chemistry there by impacting coastal geomorphological processes. The majority of the world's population lives in coastal areas, where sea level affects floods, coastline erosion, and storm-related risks. According to the United Nations Atlas of the Oceans, eight of the world's ten largest cities are located near a shore. Rising sea levels jeopardise infrastructure in urban centres along the world's coasts, including highways, bridges, water supplies, power plants, sewage treatment plants, landfills, and so on. Higher sea levels also mean more regular high-tide flooding, which may be both disruptive and dangerous. As sea levels rise, saltwater contaminates freshwater aquifers, many of which provide municipal and agricultural water sources as well as natural habitats.

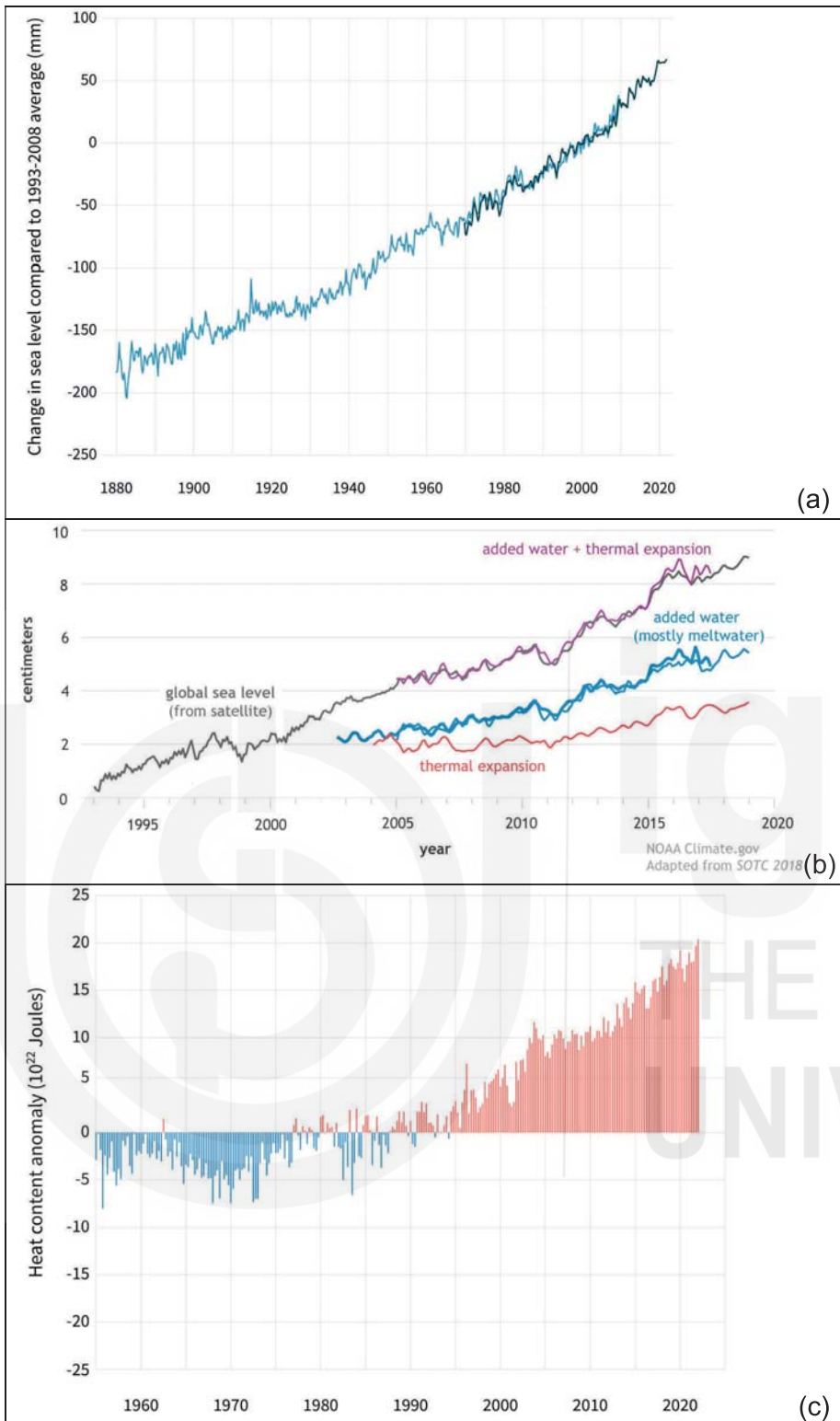


Fig. 4.10: a) The data are shown as a change in sea level in millimetres from the 1993-2008 average; b) Observed sea level from the beginning of the satellite altimeter record in 1993 (black line), with independent estimates of the various components to sea level rise: thermal expansion (red) and added water, primarily owing to glacier melt (blue line). When these individual predictions are added together (purple line), they match the observed sea level extremely well, and c) Since the mid-1990s, the worldwide ocean's heat content has been regularly above-average (red bars); data from 1955-2006 average.

(Source: a) NOAA, 2022- <https://www.climate.gov/media/14659>; b) <https://www.climate.gov/media/12868>

c) <https://www.climate.gov/media/14872>)

Eustatic sea-level rise caused by glacial melting has occurred over thousands of years, resulting in the submergence of coastal areas, coastal wetlands, and changes in geomorphological processes along the shore zones. Many modifications have occurred on existing coastal landforms, and new landforms such as fjords, elevated beaches and wave-cut platforms, relict cliffs, and coastal plains, among others, have been formed as a result of eustatic sea level fluctuations.

SAQ 3

Write a significant impact of Eustatic changes.

4.5 CONTINENTAL DRIFT

In 1858, Antonio Snider Pellegrini, a geographer, suggested the possibility of continent drifting. He created the charts depicting his interpretation of how the American and African continents may have previously fit together before splitting apart. He depicted the continents that had previously been united before (*avant*) and after (*après*) their separation. In 1910, F.B. Taylor of America invoked the hypothesis of horizontal displacement of continents with the view to explaining the distribution of mountain ranges.

Later a German meteorologist Alfred Lothar Wegener in 1912 put this idea in the form of a theory and published a detailed discussion on it in 1915 in a book entitled 'Die Entstehung der Kontinente und Ozeane' published in German language.

Wegener wanted to explain the change of climates in the geological past with the help of this theory. There are many geological evidences that show the change of climate in the geological past of the world. For example, the presence of coal in the cool mid-latitude zones indicates that the climate of this region was hot and humid and the natural vegetation was a dense forest which resulted in the formation of huge coal deposits during the Carboniferous period. But the conclusion that can be reached from these views is that either the climatic zones have moved or the landmass has shifted across the globe. There were many difficulties in postulating the shift in climatic belts of the world and thus the conclusion came into being that probably the landmasses have changed their positions.

Wegener collected evidences in support of his view and postulated that in the carboniferous period all the continents were joined together and formed a huge landmass. He called this landmass as **Pangaea** (meaning in Greek "all lands"). The southern block of this landmass includes Australia, Antarctica, Peninsular India, Africa and South America which together was called the **Gondwanaland**. North America, Europe and Asia form the northern block called the **Laurasia**. Later these two blocks were separated by an inland sea called the **Tethys**. Wegener gave the name **Pangaea** to the whole landmass and **Panthalassa** to all the surrounded water-mass (Fig. 4.11).

According to Wegener, the super-continent of Pangaea started separating during the carboniferous period and the present shape and position of the

continent is the result of the fragmentation. The supercontinent Pangaea's disintegration is depicted in the pictures below. Pangaea was a key figure in the idea of continental drift, which was the antecedent to the theory of plate tectonics.

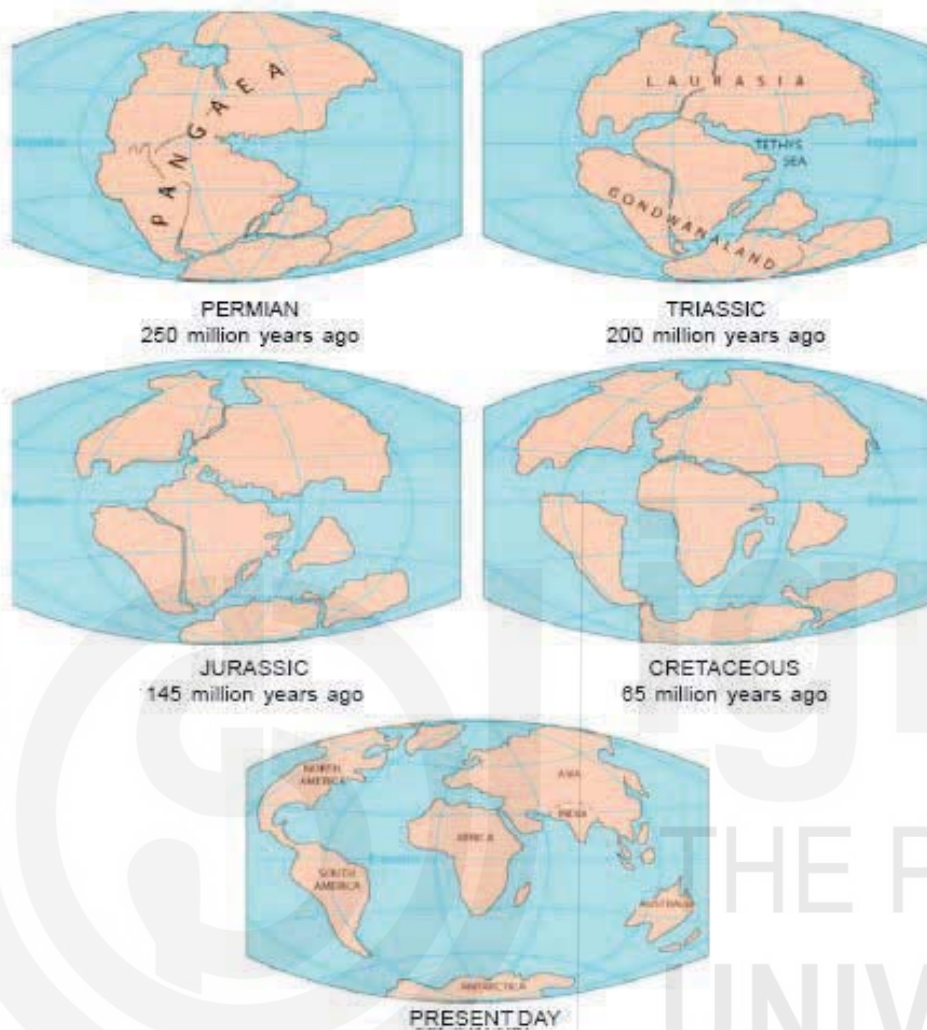


Fig. 4.11: Wegener's Reconstruction of the distribution of Continents.

(Source: USGS, 2012-<https://pubs.usgs.gov/publications/text/historical.html>)

4.5.1 Evidences in Favour of the Continental Drift

Theory

Evidences in support of the theory from different sources are:

- 1) The geographical similarity between the two sides of the Atlantic Ocean was a prime evidence of Wegener in support of the theory of continental drift. The shapes of both the coastlines were such that they can be easily joined together. Again, the eastern coast of South America can be fitted with the western coast of Africa and so as the eastern coast of North America can be fitted with western coast of Europe. This was called '*jig-saw fit*' of both the coastlines of the Atlantic ocean by Wegener.
- 2) There is also similarity in the geological structure and history of the lands on the two coasts of Atlantic Ocean. On both the coast the structural and relief features are found to be similar. For example, Appalachian Mountains of North America which come right up to the coast and then

continue their trend in the old Hercynian fold mountains of South-west Ireland, Wales and Central Europe. Even Brazil and Africa have great resemblances in their structure and rock formations.

- 3) The distribution of the Permo-Carboniferous glaciation presents solid proof of the fact that at one time these landmasses were together and the evidence of this glaciation was found in Brazil, Falkland Island, South Africa, Peninsular India and Australia.
- 4) Another evidence is the presence of fossil remains of land animals and plants and of the fresh-water species in the distant lands now separated by oceans as these species could have migrated only across united landmass and not on an intervening ocean (Fig. 4.12).

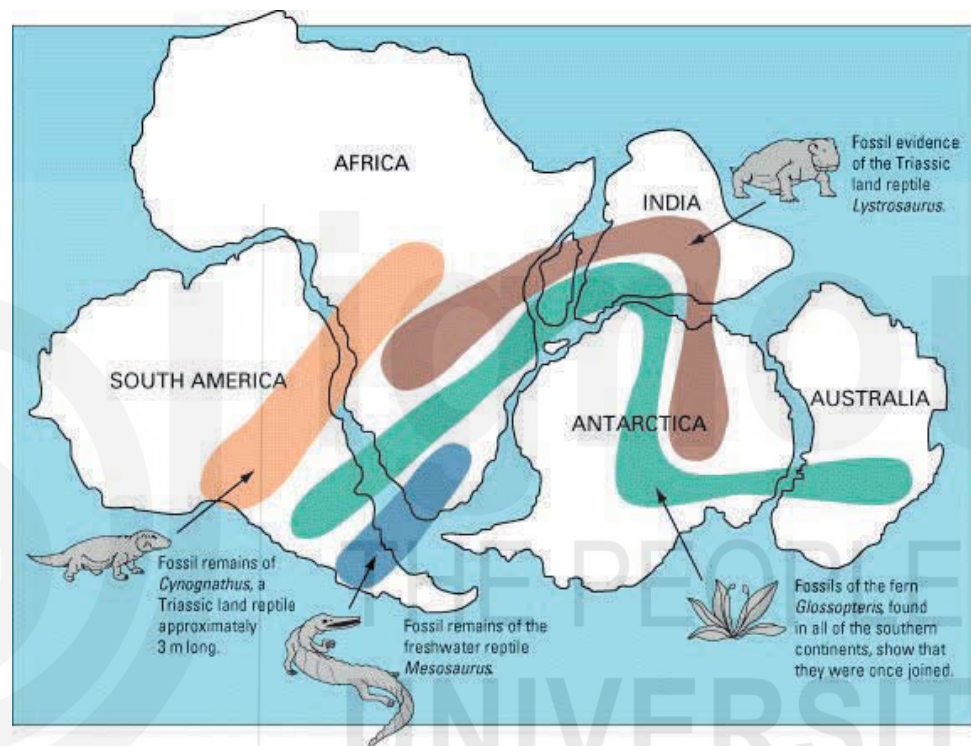


Fig. 4.12: Pieces of Evidence from Distribution of Fossils of Different Species during Pangea Stage.

(Source: USGS, 1999- <https://pubs.usgs.gov/publications/text/continents.html>)

4.5.2 Criticism of Wegener's Theory

- 1) One of the greatest criticisms of Wegener's theory has been the force that was invoked was inadequate to cause a drifting process of huge land masses.

Wegener proposed that the continents simply plowed through the ocean bottom, but Harold Jeffreys, a prominent English geophysicist, rightly stated that a vast mass of solid rock could not plowed through the ocean floor without breaking apart.

- 2) Second criticism against the theory was that the Rockies and Andes Mountain systems could not have been formed in the manner envisaged by Wegener because if the sial was floating over sima, then the sima could not offer so much resistance to the westward movement of the continents.

Wegener also sought to tackle the problem of the genesis of Tertiary folded mountains using his Continental Drift theory. The frontal margins of the westward moving continental blocks of North and South America crumpled and folded against the resistance of the sea floor rocks, resulting in the formation of the western cordilleras of North and South America (Rockies, Andes, and other mountains). Similarly, the Alpine ranges of Eurasia were folded as a result of the equatorward shift of Eurasia, Africa, and Peninsular India. Wegener proposed opposing viewpoints in this case. Wegener claimed that SIAL was floating on SIMA with little friction or resistance, but later in his theory he stated that mountains formed at the frontal edge of floating and drifting continental blocks due to the friction and resistance provided by SIMA.

- 3) The third objection was that the jig-saw fit of the opposing coasts of the Atlantic Ocean was not so perfect as it was envisaged.
- 4) The structural and stratigraphic similarity on both the sides of the Atlantic Ocean would not be matching so perfectly to conclude that one has an extension of the other and was joined together.

Undaunted by rejection, Wegener spent the rest of his life searching new data to support his theory. Unfortunately, he died during an expedition across the Greenland ice cap in 1930. Following his death, however, additional data from ocean floor excavation and other investigations reignited interest in Wegener's idea, eventually contributing to the formation of plate tectonics theory.

4.6 PLATE TECTONICS

Four major scientific developments pushed the plate-tectonics theory forward: (1) demonstration of the ocean floor's ruggedness and youth; (2) confirmation of repeated reversals of the Earth magnetic field in the geologic past; (3) emergence of the seafloor-spreading hypothesis and associated recycling of oceanic crust; and (4) precise documentation that the world's earthquake and volcanic activity is concentrated along oceanic trenches and faults.

The term plate was first used by Tuzo Wilson in 1965 but the hypothesis of plate tectonics was first outlined by W.J. Morgan in 1967. Thus Morgan, Mackenzie and Parker through their research findings laid the foundation of plate tectonics. The conventional current theory and sea-floor spreading paved the way for the Plate Tectonics theory.

According to the Plate Tectonics theory, the Earth's lithosphere is broken into distinct plates which are floating horizontally on the asthenosphere. The lithospheric or the tectonic plates vary in size from minor plates to major plates, continental plates to oceanic plates and combination of both continental and oceanic plates. The movement of these plates causes the formation of various landforms and is the main cause of explaining the origin of major landforms of the Earth.

The **lithosphere** is the solid outer layer of the Earth that extends to a depth of around 100 kilometres. As you studied, the lithosphere consists of the crust as well as the brittle upper portion of the mantle. The lithosphere is the Earth's coldest and most rigid layer. Tectonic activity explains the interaction of

massive lithosphere slabs known as tectonic plates. The major plates are: African Plate, Pacific Plate, North American Plate, Antarctic Plate, Eurasian Plate, Indo-Australian Plate and South American Plate. The important other minor plates are: Cocos Plate, Filipino Plate, Juan de Fuca Plate, Caribbean Plate, Scotia Plate, Nazca Plate, Arabian Plate, etc.

Refer to the Figure 4.13, which shows the distribution of major and minor plates of the Earth. The plate margin is the edge or marginal part of a particular plate, while the plate boundary is the surface trace of the zone of motion between two plates. Two neighbouring plate margins meet at a common plate boundary.

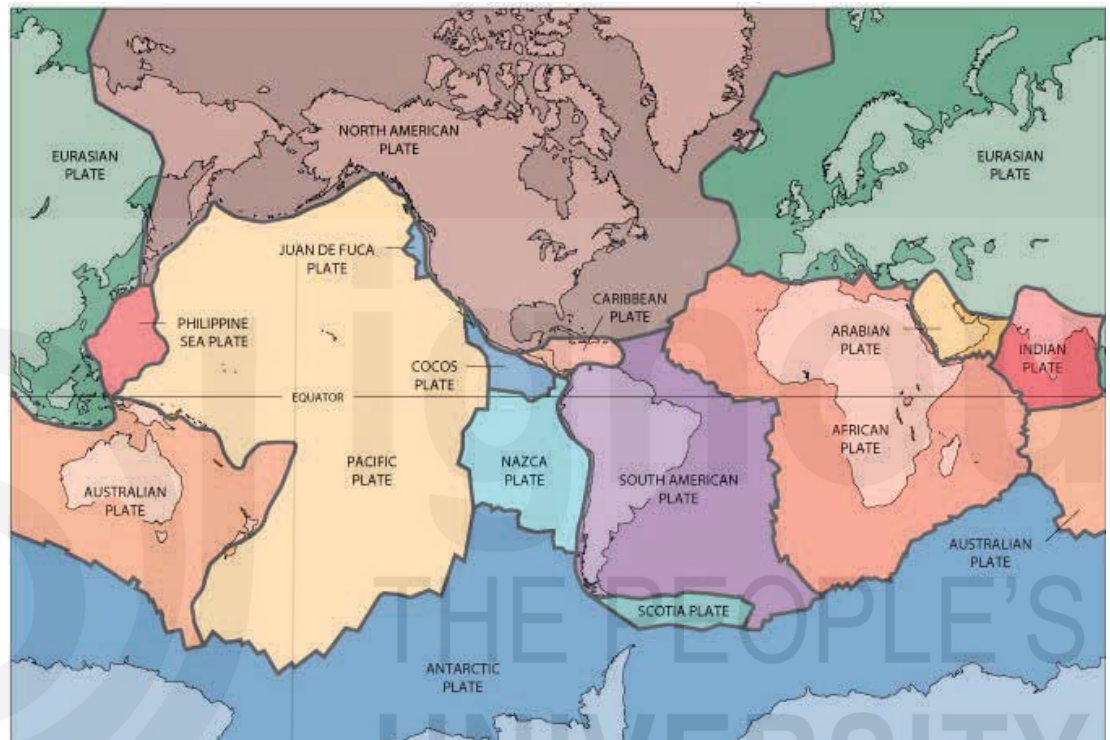


Fig. 4.13: Major and Minor Plates.

(Source: <https://pubs.usgs.gov/gip/dynamic/slabs.html>)

Plate tectonics is caused by sluggish motion of lithospheric plates floating on the **asthenosphere**, a process related with continental drift, earthquakes, mountain creation, and volcanoes. Because the asthenosphere is not liquid, tectonic plates are not truly floating.

Tectonic plates are only unstable at their boundaries and hot spots. The denser, weaker layer underneath the lithospheric mantle is known as the asthenosphere. It is located between about 100 and 410 kilometers beneath the Earth's surface. The asthenosphere's temperature and pressure are so high that rocks soften and partially melt, becoming semi-molten. In general, the asthenosphere is more viscous than the lithosphere.

You will learn that recognised plate boundaries and margins are classified into three types: constructive or divergent plate boundaries, convergent or destructive plate boundaries, and lateral or transform plate boundaries (Fig. 4.14 and 4.15).

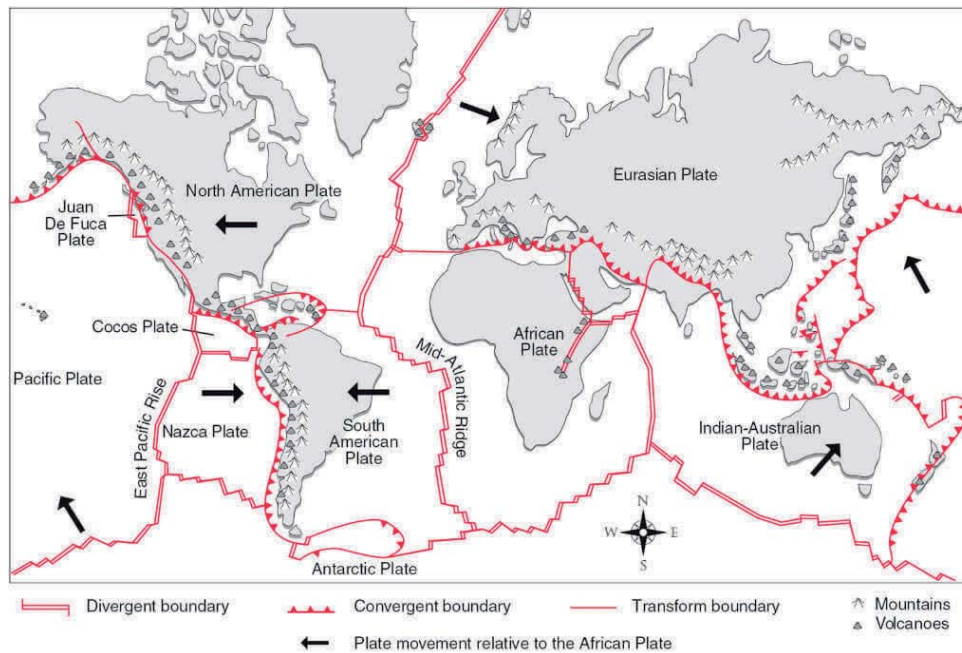


Fig. 4.14: The Three Types of Plate Boundaries.

(Source: <https://pubs.usgs.gov/gip/dynamic/understanding.html>)

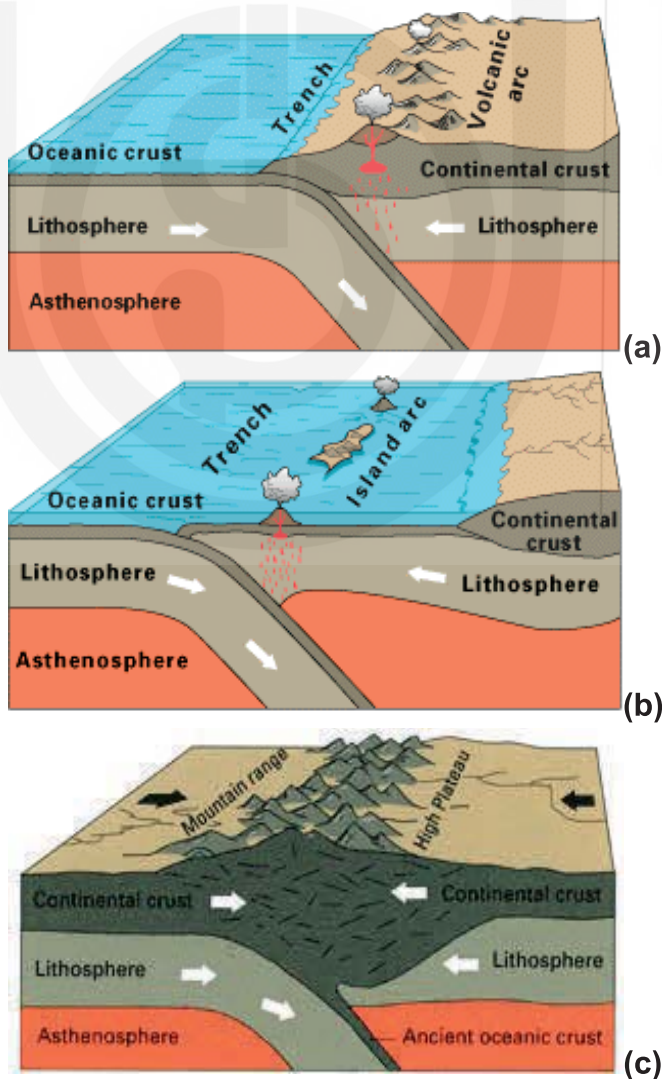


Fig. 4.15: Plates Convergence a) Oceanic-Continental b) Oceanic-Oceanic and c) Continental-Continental.

(Source: <https://pubs.usgs.gov/gip/dynamic/understanding.html>)

1. **Constructive or Divergent Plate Boundaries:** In this kind of interaction, the plates diverge or move away from each other. Divergent boundaries form along spreading centres when plates are moving apart and magma rising up from the mantle creates new crust. For example, Mid-Atlantic Ridge is formed due to such kinds of plate margins. The Mid-Atlantic Ridge spreads at a pace of around 2.5 centimetres per year or 25 kilometres in a million years. Volcanic eruptions are common along such edges or margins.
2. **Convergent or Destructive Plate Boundaries:** In this kind of interaction, two lithospheric plates collide against each other. The zone of collision may undergo crumpling and folding and folded mountains may emerge for example, the Himalayan Mountain. When one of the plates is an oceanic plate, it gets embedded in the soft asthenosphere of the continental plate and as a result, trenches are formed at the zone of subduction. There are mainly three ways of convergence: a) between an oceanic and continental plate, b) between two oceanic plates, and c) between two continental plates.
3. **Conservative or Lateral or Transform Plate Boundaries:** Where neither crust is created nor destroyed when the plates slide horizontally past one other is called transform plate boundaries. For example, San Andreas Fault along the western coast of USA.

Mechanisms of Plate Movement

Many ideas have been offered to explain the process of plate motion.

Convection current, slab pull, and ridge push are three types of probable mechanisms in plate tectonics. Let us now study these processes.

1. Convection Current

Convection current involves the whole mantle, which has a high level of radioactivity, resulting in a high level of heat concentration in the mantle. As the currents rise from below, they diverge and expand laterally over the plates' bottom edges. Because of mantle convection currents, the lithospheric plates float above the asthenosphere and move horizontally. Convection currents flow in either a clockwise or anticlockwise direction from the boundary of the mantle and core. The substantial heat flux along the mid-oceanic ridges provides evidence to this process. Convectional current is only observed in the Asthenosphere, where convection cells are believed to be smaller in size. If two neighbouring convection current cycles converge to a single direction, the two plates move towards each other. Where the convection currents have their movements in opposite directions, the plates floating over them also have a divergent motion relative to each other. In 1930, Holmes proposed the convection current theory, which acknowledges convection currents as the primary factor driving plate movement. Refer to Fig. 4.16, which illustrates the mechanism responsible for various plate movements. The other type of mantle convection involves jet like plumes are called mantle plume of low density materials from the core mantle boundary. When the plume reaches the lithosphere, it expands out laterally and advancing them in the radial flow direction. It is believed that mantle plumes caused the Pangaea to first break apart.

2. Slab Pull

Subduction occurs when the denser plate slips down the lighter plate at the convergent boundary. Slab pull is caused by the subducted section of the plate. This force is responsible for the majority of the overall forces operating on plate tectonics. Aside from that, the 'ridge push' force contributes nearly ten percent of the overall force for plate movement. Deep oceanic trenches are formed near the convergent plate boundary. The zone along which subduction occurs is known as **subduction zone** or **Benioff zone**.

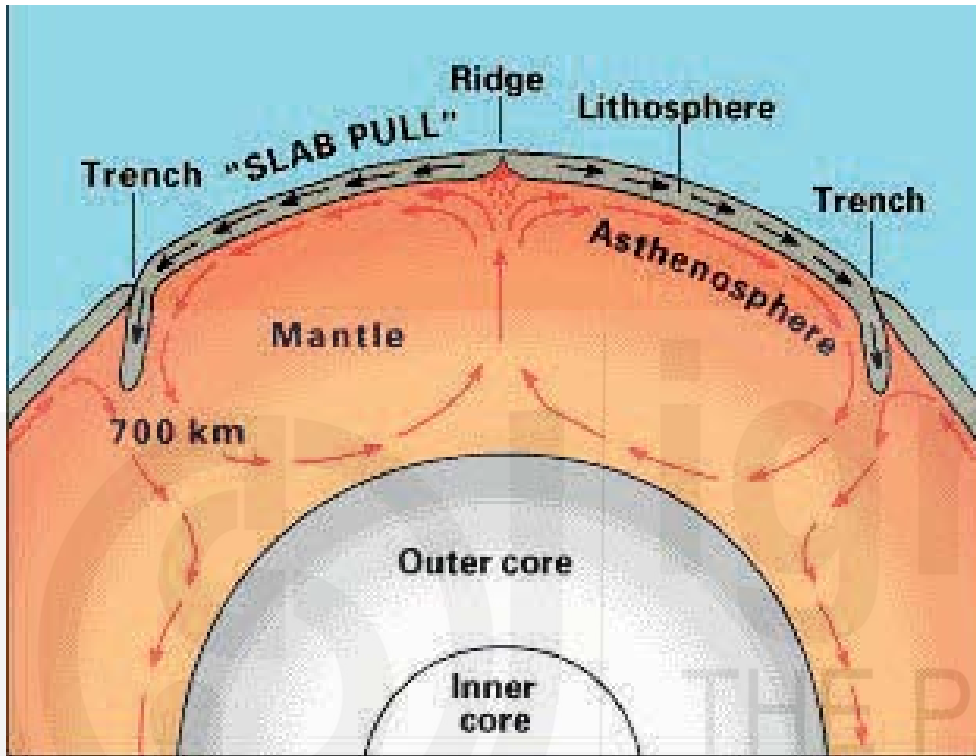


Fig. 4.16: Convection Current Movement in Interiors of the Earth.

(Source: <https://pubs.usgs.gov/gip/dynamic/unanswered.html>)

3. Ridge Push

'Ridge Push' is caused by magma erupting from the **mid-oceanic ridges**. Prior to the 1990s, this force was thought to be the primary contributor to the movement of the Earth's plates. Mid-oceanic ridges are known to rise thousands of metres above the ocean floor. These are formed along the divergent plate boundary. New magma rises up along the mid oceanic ridge to fill the gap between the two diverging plates and forms new ocean floor on both flanks of it. Along the mid-oceanic ridges, a new sea floor or oceanic plate is developed; it is very hot and thin, as well as considerably higher in elevation than the abyssal plains and trenches. The newly formed plate will slide down the slope and attempt to move towards the subduction zone, causing **sea floor spreading**. As the oceanic plate moves away from the spreading centre, its thickness and density increase, and the ridge push force rises towards the subduction zone.

In a nutshell, the Continental Drift Theory asserts that the continents are shifting, but plate tectonics asserts that not only the continents but also the sea floor are spreading. It appears that the consumption of old oceanic crust near subduction zones compensates for the production of fresh oceanic crust

at mid-oceanic ridges. As a result of this, the crustal block will drift away from the mid-oceanic ridges. Plate Tectonic Theory states that the lithospheric plate floating above the asthenosphere is in motion, not SIAL. Plate Tectonic Theory explained several processes for continent migration as well as the majority of the Earth's geo-tectonic properties.

SAQ 4

- a) Who proposed the Continental Drift theory? and what he called the landmass and watermass?
 - b) What are three types of plate boundaries in plate tectonics theory?
-

4.7 SUMMARY

In this unit, you have studied so far:

- Understanding the internal structure of Earth, sometimes known as the Earth's interior, is a difficult endeavour. Temperature, pressure, and density are three important factors in determining the Earth's basic structure.
- The upper and the thinnest layer of the interior of the Earth is the crust. Crust is made up of silica and alumina rocks. Oceanic Crust is high in density and Continental Crust is relatively low in density. The contract zone between the upper mantle and the crust is *Mohorovicic Discontinuity* where as the boundary between the upper crust and the lower crust is called the *Conard Discontinuity*.
- The mantle layer of the Earth's interior is above the core and just below the crust. It is made of iron and magnesium silicates. The boundary between the upper mantle and lower mantle is called *Repetti Discontinuity*.
- The core is mostly composed of nickel and iron which is in a fluid condition. The boundary between the core and mantle is termed as *Gutenberg Discontinuity*. The seismic studies revealed that the inner core is solid. The boundary between the outer core and inner core is called *Lehmann Discontinuity*.
- The concept of isostasy proposed Airy, Pratt, Hayford and Bowie, Joly, and Arthur Homes.
- Change in this eustatic sea level can be generated due to change in glaciation rate, spreading rates of the mid-oceanic ridges. Eustatic sea level is not relative to local surfaces, because relative sea level is dependent on many factors including tectonics, continental rise and subsidence.
- The continental drift theory was proposed by Wegner in 1912 explaining by the super continent Pangaea separated into different parts and the present shape and position of the continent is the result of the fragmentation.
- Also explained the plate tectonics theory.

4.8 TERMINAL QUESTIONS

1. Explain the internal structure of the Earth.
2. Discuss the concept of Airy and Pratt on isostasy.
3. Write a note on continental drift theory.
4. Discuss about plate tectonic theory.

4.9 ANSWERS

Self-Assessment Questions (SAQ)

1. a) The three important parameters are temperature, pressure and density.
b) At a depth of about 2,800 kilometres represents the boundary between the core and mantle.
c) The average density of the NIFE layer ranges between 9.5 and 14.5 g/cm³.
2. According to Airy, density is uniform with variable thickness, however Pratt hypothesised that height and density had an inverse connection and that density fluctuates with varying thickness
3. As sea level rises, dry land and wetlands can turn into open water because of low elevations.
4. a) Alfred Lothar Wegener. He proposed the name 'Pangaea' for landmass and panthalssa for watermass.
b) Three types of plate boundaries are divergent, convergent and transform.

Terminal Questions

1. Refer to Section 4.2.
2. Refer to Section 4.3.
3. Refer to Section 4.5.
4. Refer to Section 4.6.

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<https://pubs.usgs.gov/gip/dynamic/understanding.html>;
<https://pubs.usgs.gov/gip/dynamic/unanswered.html>

TECTONIC PROCESSES AND LANDFORMS-I

Structure

5.1	Introduction	5.5	Landforms Associated with
	Expected Learning Outcomes		Epeirogenic and Orogenic
5.2	Earth Movements		Movements
5.3	Epeirogeny/Epeirogenic	5.6	Summary
	Movements	5.7	Terminal Questions
5.4	Orogeny/Orogenic	5.8	Answers
	Movements	5.9	References and Suggested
			Further Reading

5.1 INTRODUCTION

The surface of the Earth is unstable and is changing constantly thus none of landforms are lasting. Various geomorphic processes have been at work on the landforms from prehistoric to the present, though differing degrees and intensities on multiple temporal scales. Overall, both internal and external forces have an impact on the Earth's crust and may have major and minor effects on the Earth. Radioactivity coming from the deep recesses of the Earth's crust or substratum and the resulting convection currents can be the primary causes of such internal forces.

Some of the processes may even cause the rocks to compress together, creating high relief features and mountain ranges. The exogenetic processes like weathering and erosion can also be seen on the surface of the Earth. The interior (endogenetic) forces drive the crust of the Earth and bring mobility (tectonism). The endogenetic and exogenetic forces together are responsible for modifying Earth materials and bring changes in the arrangement of the surface forms of the Earth which are known as landforms.

On the surface of the Earth, we frequently see a wide variety of topographical features, including mountains, valleys, plains, etc. Would you be interested in learning how they came to be? Did these features already existed when the Earth was forming, or did they gradually emerged? In this unit, we will examine the intricate interplay of the Earth's material with the tectonically and

climatically derived forces in order to discover the answers to these questions and try to understand the evolution of present landforms.

Expected Learning Outcomes

After studying this unit, you will be able to:

- Comprehend the tectonic processes and their role in the evolution of different landforms over the Earth's surface;
- Explain the epeirogenic and orogenic earth movements; and
- Describe the landforms associated with epeirogenic and orogenic movements.

5.2 EARTH MOVEMENTS

Earth movements are generally caused by two different types of forces. They are endogenetic and exogenetic.

A) Endogenetic/Endogenic/Hypogene

In Greek '*endo*' means *within* and '*genera*' means *origin*. Endogenetic forces are the pressure that originates inside the Earth's crust. It is also known as the internal forces. It leads to vertical and horizontal Earth movements which can give rise to various structural features on Earth's surface and result in subsidence, land upliftment, volcanism, faulting, folding, fracturing, earthquakes, etc. Understanding endogenetic forces and processes is important in geomorphological investigations. The results of these movements achieve greater significance and appreciation in some parts of the world, such as in the circum-Pacific belt and the young-fold mountain regions.

Significance of these forces also lies with the occurrence and distribution of the zones of vulcanicity and seismic activities. Moreover, the changes brought by the exogenic processes can be altered in those regions where endogenetic forces influences are stronger. Besides, endogenetic forces are thought to be primarily caused by the movement of the Earth's inner elements, however their exact origin is yet unknown. These forces are present in the Earth's deep interior, and researchers have mostly linked these to the Earth's varying inner thermal conditions, which may cause rocks to contract and expand and, in turn, produce endogenetic forces. These internal forces that operate from beneath the Earth's surface at a differential rate, frequently alter the Earth's topography through the process of creation, destruction, recreation, and maintenance of geomaterials (materials in the Earth crust). These forces cause a variety of vertical movement of the crust causing varying landforms such as mountains, ridges, plateaus, valleys, and plains, on the surface of the Earth. Additionally, volcanic eruptions and earthquakes are manifestations of endogenous forces which primarily result from abrupt movements from the Earth's interior.

Diastrophic forces, which function as vertical forces and typically come from deep within the Earth's interior. Diastrophic forces refer to forces produced by the movement of the solid components that make up the Earth's crust and interior. Diastrophism, also known as tectonism, is the term for the large-scale

natural deformation of the Earth's crust. It encompasses the varying responses which includes linear or horizontal movements and vertical subsidence and uplift of the lithosphere to tectonic stresses.

The diastrophic forces are usually leading to eustatic or isostatic or tectonic movements. The tectonic movements can be classified as either **orogenic** or **epeirogenic**, and these two are typically associated with the diastrophic forces. Moreover, non-isostatic or crustal bending within the mantle (known as epeirogenesis), earthquakes, folding (which is mountain building or orogenesis), faulting, metamorphism owing to heat flow, and vulcanism are some of the processes that emerge from within the Earth's crust.

B) Exogenetic Forces/Exogenic/Epigene

Exogenetic forces are primarily destructive and aim to alter the different relief features of the Earth's surface by smoothing, carving, and sculpturing them through a variety of processes. A detailed discussion on these forces is explained in the next Unit 6.

5.3 EPEIROGENY/EPEIROGENIC MOVEMENTS

Let us learn about the epeirogenic movements which are categorized under diastrophic forces. Epeirogenic movements are very broad and large-scale movements that spread throughout the continental platform or the stable block of land. G.K. Gilbert coined the term "epeirogeny" in 1890 by combining Greek words "epeiros" (mainland) and "genesis" (birth). Gilbert described epeirogeny as the process of building of continents, and the process of the construction of mountains. However, the scales of space and time for these two groups of processes are very different. The rate of cumulative uplift has surpassed erosional lowering in many regions of the Earth where very slow vertical crustal movements, measured in millimetres per year, have persisted since the late Cenozoic. Movement caused by epeirogenesis may be permanent or temporary. A thermal anomaly may experience brief elevation due to convecting anomalously heated mantle, which vanishes when convection decreases. When volcanic material is injected into the crust, there may be permanent uplift; a mantle plume is characterised by circular or elliptical structural uplift over a wide radius (tens to thousands of km).

Upliftment and Subsidence

Epeirogenic movements are those that are caused by radial forces and move vertically from the Earth's centre to its surface. Since it has a significant impact over a wide area, there is little surface deformation that is immediately apparent. They are characterised by broad, gradual, and widespread warping, as well as by enormous land areas subsiding, rising, emerging, and submerging. There is no visible bending or fracturing in the rocks as a result of these processes since they are so slow and extensive. This widespread regional tectonic movement, which does not include local deformation, can either be upliftment or subsidence. The continental masses are lifted through upliftment movement either the entire continent or a specific region. Additionally, it elevates the continents' coastal regions. Such type of upliftment is called emergence. The land near the seashore can slide

downward or subside below sea level, submerging it under the sea. This is commonly known as subsidence of the land area. The marine sedimentary rocks from the Palaeozoic, Mesozoic, and Cenozoic periods are present on all continents and are layered over older strata that have been severely degraded. The platform and coastal regions of peninsular India are typical locations for these movements, particularly recent vertical movements.

SAQ I

- a) What are endogenic forces?
 - b) What are processes that occurred as a result of epeirogenic movements?
-

5.4 OROGENY/OROGENIC MOVEMENTS

Orogeny specifically refers to the deformation induced during the development of mountains. Gilbert originally defined the orogeny (Greek *oros* meaning 'mountain' and *gens* meaning 'stemming from') as "displacement of the Earth's crust which produces mountain ridges". Great folded ranges of mountains are generated as a result of the strain and stress on the rocks. Orogenic movements are the ones, which work horizontally to the surface of the Earth like tangent to the surface of the Earth. Therefore they are also called tangential forces. It occurs mainly along the plate boundaries or plate margins that produce intense folding and faulting.

The horizontal forces mainly operate in three ways 1) in the same direction, denoting compressional or convergent forces, 2) in the opposite direction, which denotes tensional or divergent forces, and 3) the movements parallel to each other designated as shearing forces.

Let's understand the folding and faulting in the following sub-sections.

5.4.1 Folding

Compressional forces or **convergent forces** refer to two forces that act face to face or in the same direction. You may be aware that when compressional force is applied to rocks, they are pressed or squashed. Like this, compressional forces near convergent plate borders cause the rocks to be squeezed and crushed. Along the continental boundaries, compressional forces crush the overriding plate into a protracted series of folded mountain ranges. Because tectonic plates experience extremely high levels of lithostatic stress, any deformation on the tectonic scale is always subject to net compressive force. Besides the crustal bending associated to compressional forces is the process through which rocks in the crust are compelled to bend as a result of horizontal movement that is working in the same direction. It can be of two kinds:

Warping: Warping occurs when a sizable piece of the crust of the Earth bends. Down warping refers to the formation of a depression or basin as the crust bends downward, and up warping refers to the opposite process of uplifting.

Folding: All geologic processes by which the surfaces of rocks become curved during deformation are collectively referred to as **folding**. Folding refers to primarily slow, ductile behaviour of relatively soft and/or heated rocks because folds are permanent deformation structures with little or little loss of cohesion of the folded layer. Much of the early geologic research on folding processes concentrated on the deformation of stratified sediments, in addition to the descriptive, anatomical categories. The geometrical (layer thickness and spacing) and physical (viscosity and anisotropy) characteristics of the rocks are combined in various folding mechanisms.

Tangential compressive force from horizontal movement brought on by the endogenetic force originating deep below the Earth causes wave-like bends to form in the crustal rocks. These kinds of bends, where some parts are bent up and some down, are known as folds. Anticlines are formed by upfolded rock strata that have an arch like shape, whereas synclines are formed by down folded structures that have a trough-like shape. Sizes and shapes of the folds vary depending on the type of rock, the strength and direction of compressive forces. A few centimetres to several kilometres long, tight, or broad, symmetrical or asymmetrical folds can be found in several rock layers. The majority of mountain systems show folding to some extent. Before understanding the different types of folds, their characteristics, you need to know its geometry and associated terminology. Refer to Figure 5.1 for this purpose.

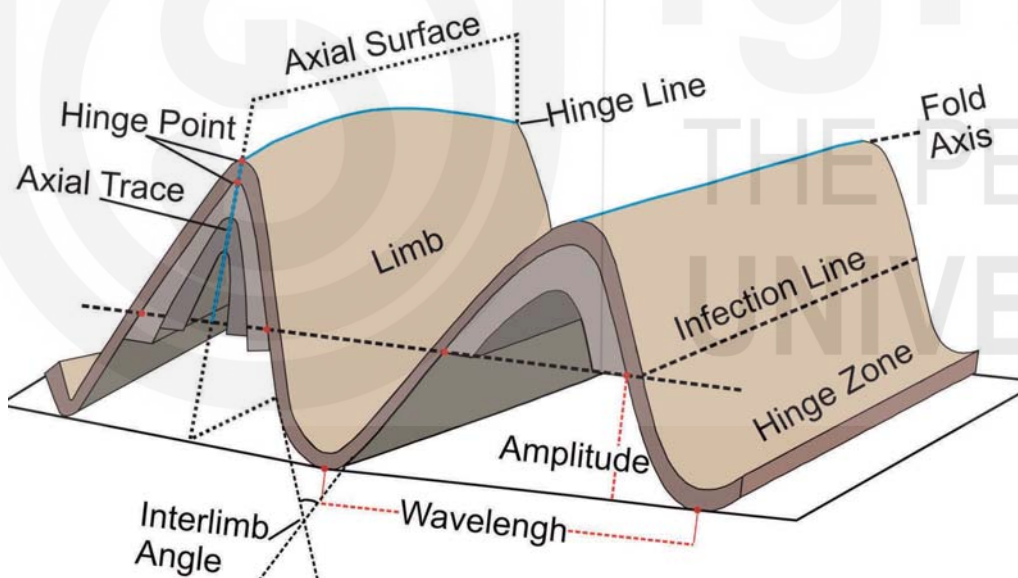


Fig. 5.1: Structure of Fold showing Anticlines and Synclines.

- a) **Fold Hinge:** It is ideal to study folds in sections that are perpendicular to the folded layers or perpendicular to the axial surface. In general, folds consist of a hinge joining two typically oppositely oriented limbs. Although the hinge may be sudden and sharp, it usually curves gradually, with a defined hinge zone. There is a wide range of hinge shapes, from the well-rounded hinges of concentric folds to the point hinges of kink bands and chevron folds (sharp and angular folds).
- b) **Fold Hinge Point:** The point at the fold's maximum degree of curvature is known as the fold hinge point. A hinge line connects hinge points in three dimensions.

- c) **Fold Axis:** The axis of fold is the imaginary straight line that runs along the crest of anticline or the trough of syncline between the limbs. The fold is said to plunge if the axis is inclined relative to the horizontal. The fold is described as symmetrical if the axial plane and axis are vertical and horizontal, respectively, whereas the fold is inclined if the axial plane is inclined.
- d) **Fold Axial Plane:** An imaginary plane called the fold axial plane divides a fold into two parts that are as similar as possible. Depending on the shape of the fold, it could be vertical, horizontal, or inclined.
- e) **Fold Limbs:** These are located on either side of the axial plane, are a fold's flanks. Middle limb refers to the limb that an anticline and its companion syncline share. The axis of fold, also known as the axial plane, is the line that cuts through the angle formed by the middle limb of the syncline or the middle two limbs of the anticline. These axial planes are referred to as the axis of anticline and the axis of syncline, respectively, based on the anticline and syncline.

Types of Folds

The position of certain structural fold elements, characteristics of the involved rocks (elasticity and rigidity), intensity and duration of the compressive forces (magnitude), type and nature of the tectonic forces that affect the rocks during the folding process and additional factors can all be used to classify folds. For instance, the type and degree of folding process are significantly influenced by the elasticity of the rocks. While hard and less elastic rocks are minimally folded, and the softer, more elastic rocks are subjected to strong folding. Differences in the properties of folds are also influenced by variations in the intensity and magnitude of compressive pressures. The inclinations of the two limbs of a simple fold are typically more or less equal, but they differ most often in the case of various folds. Thus, the folds can be classified into numerous categories as described below based on the inclination of the limbs in response to varying compression (Fig. 5.2).

- a) **Anticline:** An anticline is a fold that is convex upward, and its oldest rocks are in its core. Anticlines are also denoting the term for the folded rock beds. The rock strata of the two limbs dip in opposite directions in a simple fold.
- b) **Syncline:** A syncline is a fold that is concave upward, and its youngest rocks are in its core. Moreover, synclines are downfolded rock beds carried on by compressive stresses brought about by horizontal and or tangential forces. These are trough-like shapes with beds that incline together toward the centre.
- c) **Fan Fold:** Fan folds are large, broad folds made up of several tiny anticlines and synclines. When there are several minor anticlines and synclines included within one substantial anticline, these folded formations are referred to as **anticlinorium**. A folded structure is represented by the **synclinorium**, which has a large syncline and several minor anticlines and synclines. These structures are created as a result of differences in the compressive forces.

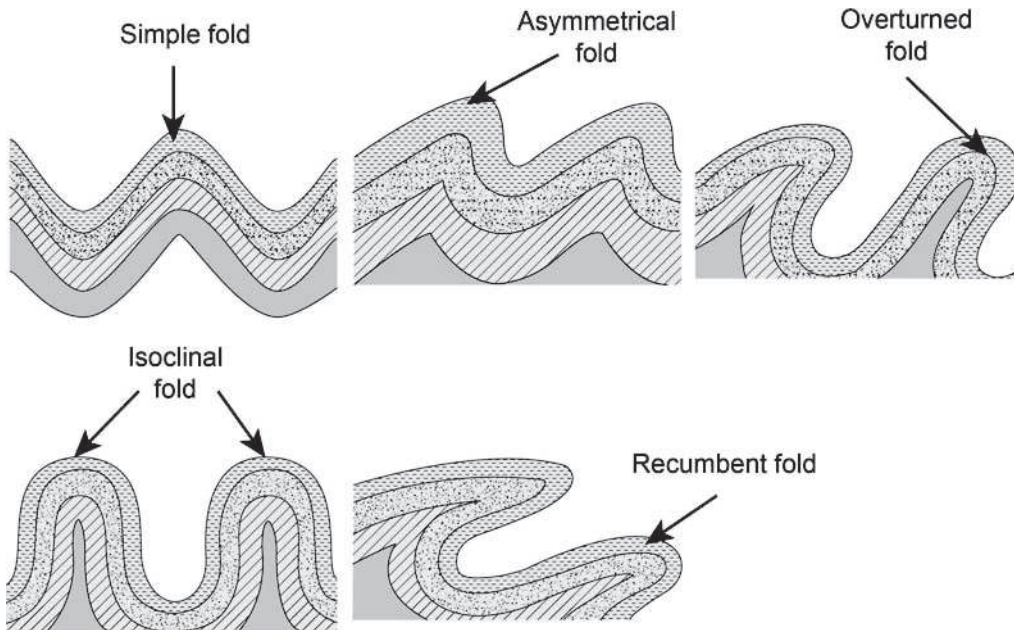


Fig. 5.2: Types of Folds- a) Simple b) Asymmetrical c) Overturned d) Isoclinal e) Recumbent.

- d) Symmetrical Fold:** Simple folds with evenly inclined limbs are symmetrical folds. When compressive forces operate frequently but with a low intensity, symmetrical folds are created. Symmetrical folds are extremely uncommon in nature. Furthermore, if the angle between the two limbs of the fold is greater than 90° but less than 180° , the symmetrical folds are referred to open folds. Due to the moderate nature of the compressive force, such open folds are created through wave-like folding. Besides, folds that have an acute angle between their two limbs are said to be closed folds. Such folds develop because of strong compressive strain.
- e) Asymmetrical Fold:** Uneven and irregular limbs that often incline at different angles define asymmetrical folds. While one limb is generally longer and inclined moderately and regularly, the other is relatively shorter and inclined steeply. As a result, both limbs are unequal in length and inclination.
- f) Monoclinical Fold:** One limb of a monoclinical fold will incline gradually with a regular slope while the other will incline steeply at a right angle with a nearly vertical slope. It should be noted that the production of monoclinical folds is attributed to vertical force and movement. Due to extreme folding, there is a strong potential that the limbs of such folds will separate. Faults arise as a result of the splitting of limbs. Monoclinical folds are thought to occur as a result of uneven horizontal compressive stresses emanating from both sides.
- g) Isoclinal Fold:** When compressive forces are so intense that both arms of the fold become parallel but not horizontal, isoclinal folds are created.
- h) Recumbent Fold:** When compressive forces are so intense that both folds limbs become parallel and horizontal, recumbent folds are created. Overthrust faults occur when pieces of rock migrate over the underlying rock on level surfaces with little inclination because of continued pressure.

rise in recumbent folds. The structure is an over thrust fold, and the shearing plane is a thrust plane.

- i) **Overtaken Fold:** Folds that have overturned are ones in which one fold's limb has been forced onto another fold by strong compressive pressures. In such folds, rarely are limbs horizontal.
- j) **Plunge Fold:** When the fold's axis tilts and creates a plunge angle-the angle between the axis and the horizontal plane-instead of being parallel to it, plunge folds are created.
- k) **Nappes:** These are the product of a folding process brought on by rapid horizontal movement and the compression that follows. A recumbent fold has two parallel, horizontal limbs. One of the recumbent folds moves forward and overcomes the Nappes because to an increase in the ongoing compressive force. Nappies are produced as a result of a complicated folding mechanism. Several examples of nappes are traceable in the folded mountains of the Himalayas.

SAQ 2

- a) What forces lead to folding?
 - b) Write any four types of folds.
-

5.4.2 Faulting and Thrusting

Tensional forces, also known as **divergent forces**, are forces acting on a rock in an opposite direction that cause the rock to fracture. Additionally, divergent forces are also used to describe these tensional tectonic events because they mostly take place near divergent plate borders, where oceanic plates are splitting apart, or continents are migrating apart. The rock is stretched by forces of tension acting horizontally but in opposing directions. When great tensional pressure is applied, the rock strata are split or fractured, causing fractures and cracks in the crust. The upward or downward displacement of rock along a crack from its starting position is referred to as **faulting**. There are also additional forces that are frequently referred to as shearing forces that act parallel to one another but in opposite directions, like how scissors move. Transform faults may result from these forces. Faults or fractures are produced by tensile and shear stresses. If one end is compressed, the other end can be in tension. It follows that folding and faulting often occur simultaneously.

Faulting occurs when the rock layers fractures and slides over one another. A fracture in the crustal rocks is referred to as a **joint** if there is no discernible movement of the rocks along the fracture. A fracture is a **fault** when there is discernible movement of the rocks along both sides of the fracture and parallel to it. Any fracture in the crustal rocks where the rocks are displaced along the fault plane is referred to as a fault. The fault plane is the direction along which the rock blocks are shifted.

The vertical displacement of rock blocks during fault formation may reach several hundred metres, and the horizontal displacement may reach several

kilometres. The surface trace or fault line can occasionally be followed along the ground for several kilometres when faults have a significant horizontal extent. It is essential to understand the geometry and related nomenclature of faults before understanding the various fault types and their features. The three angular measurements of dip, strike, and slip are explained in Fig. 5.3.

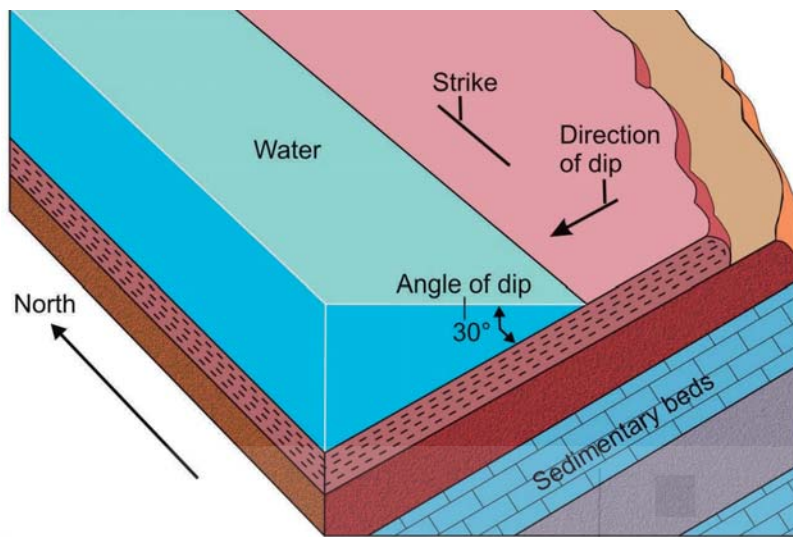


Fig. 5.3: Example of Measuring Strike and Dip.

- a) **Dip:** Faults can be vertical or horizontal in orientation in the Earth. The angle known as the dip indicates how steep the fault surface is. This angle is calculated from the surface of the Earth or a plane that is perpendicular to it. A horizontal fault has a zero-degree dip (0°), while a vertical fault has a 90° dip. In nutshell we can say that the dip is the maximum slope direction down an inclined surface as well as the angle it makes with a horizontal plane.
- b) **Strike:** The direction of a horizontal line drawn perpendicular to the dip determines the strike of a rock. The direction in which an inclined surface intersects a horizontal plane is known as the strike (e.g., intersection of a bedding plane with a water surface). Furthermore, it can be stated that the strike is an angle employed to define the orientation of the fault, measured in a clockwise direction from north. For instance, a strike of 0° or 180° signifies a fault oriented in a north-south direction, while 90° or 270° indicates an east-west orientation. To eliminate any ambiguity, it is essential to consistently specify the strike in a manner that, when you visualize the strike direction, the fault appears to dip to your right.
- c) **Slip:** The fault orientation is described by its dip and strike, but we also need to explain the fault's motion in one way or another. In other words, whatever direction did the fault move in relation to the other side? The slip is the term for the motion-descriptive parameter. The slip consists of two elements: direction and magnitude, which indicates how far the rocks moved. Typically, we separate the magnitude and direction. The distance between the two sides of the fault, which is typically a few centimetres for mild earthquakes and metres for large ones, is known as the magnitude of slip. On the fault surface, the direction of slip is measured and expressed as an angle, just as the strike and dip. The slide direction is specifically

the direction in which the hanging wall moved in relation to the footwall. The slip direction of a hanging wall is 0° when it moves to the right; 90° when it travels up; 180° when it moves to the left; and 270° or -90° when it moves down.

- d) **Fault Plane:** The fault plane is the plane along which tensional and compression forces acting vertically and horizontally shift rock blocks to create a fault. A fault plane can take any shape, including vertical, angled, horizontal, curved, and others. The two sides that represent the upper block and the lower block, respectively, are the up thrown side and the downthrown side. Fault dip is the angle formed between the fault plain and the horizontal plain.

Types of Faults

Geoscientists can better grasp how the tectonic plates move relative to one another by carefully studying faults. Faults are categorized based on the direction of slip along the fault and the dip, or angle of the fault with regard to the surface. The type of fault, such as a dip-fault or a strike-slip fault is determined by the direction in which the crustal blocks are moved. The four fundamental types of faults are categorised and are shown in Figure 5.4.

- a) **Normal Fault:** A normal fault is a dip-slip fault when the block above has slid downward in relation to the block below. Normal faults are those with mostly vertical movement. A normal fault dips steeply or almost vertically. Because the action is vertical, one side is lifted or up thrown in comparison to the other, which is downthrown. The extension of the crust's faulted beds is expressed by normal faulting. **Fault scarp** refers to a steep, wall-like slope, escarpment, or scarp created by a normal fault. A fault scarp can be several hundred metres tall or only a few metres high. They frequently reach lengths of 100 kilometres or more. Multiple, parallel sequences of faults are a common manifestation of normal defects. The tensional force pulling apart the crustal block in the opposite direction is the major cause of normal fault. Up thrust block is a horst; down dropped block is a graben or rift. The majority of them occur at diverging boundaries. These faults are "normal" not because they are the most typical type, but because they follow the gravitational pull of the fault plane. Normal faults include the East African Rift and the Sierra Nevada of California.
- b) **Reverse Fault:** A reverse (thrust) fault is a dip-slip fault in which the higher block travels up and over the lower block above the fault plane. It is also known as a compression fault because it develops when compression pressures cause the cracked blocks to travel in the opposite direction of one another. As a result, this kind of faulting frequently occurs in compression locations, such as those where plates are sub-ducting beneath one another. Furthermore, a reversal fault is frequently referred to as a thrust fault when the dip angle is shallow. The construction of a reverse fault, in which the hanging wall moves upward in relation to the footwall, is caused by the opposite displacement. We must keep in mind that fault scarps are created by normal and reverse faults at the edges of elevated or down drifting blocks. While normal faulting results in an

extension of the faulted area, the reverse fault shortens the affected area. In the case of a reverse fault, the movement that results from the up thrown block overriding the downthrown block at a relatively low angle will primarily be horizontal. Tens of kilometres of lateral movement are made by the rock slabs. Reverse faulting is frequently accompanied by slides. Subduction and continental zones frequently have thrust and reverse faults or we can say that they are typically found at the convergent boundaries.

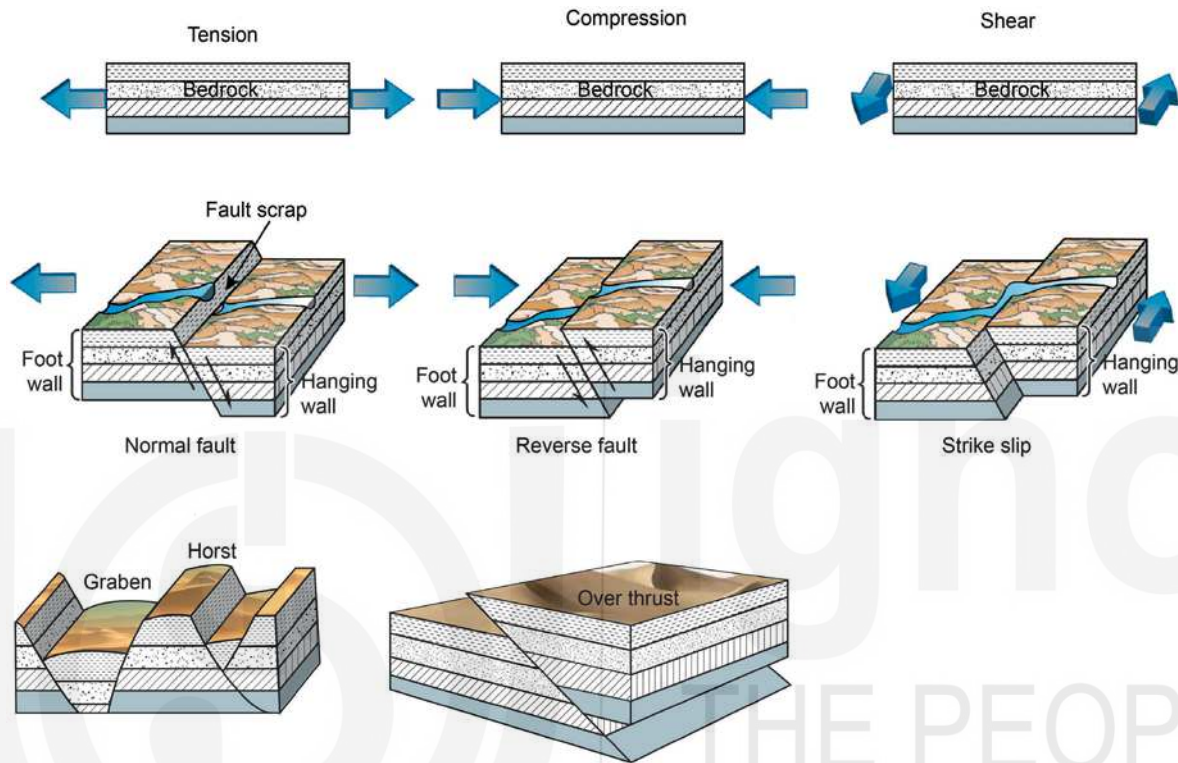


Fig. 5.4: Different Types of Faults.

- c) **Strike-Slip Fault:** A fault on which the two blocks move past one another is called a strike-slip fault. We can also describe that lateral or strike-slip faults form when rock blocks are moved horizontally along the fault plane due to horizontal movement in which no fault scarps are produced. These faults are extremely intricate. The surface can only be traced via a very tiny fault line. These also go by the names wrench faults, shear faults, transcurrent faults, and transform faults. The Alpine Fault in New Zealand, the Great Glen Fault in Scotland, and the Lorch-Alahama Fault or Alhama de Murica Fault in Spain are few noteworthy examples.
- d) **Oblique Fault:** Oblique-slip faults are defined as having both a component of dip-slip and a component of strike-slip movement. A fault must have both significant and quantifiable dip and strike components in order to be categorised as oblique because almost all faults will have some component of both dip-slip and strike-slip.

SAQ 3

What is a normal fault?

5.5 LANDFORMS ASSOCIATED WITH EPEIROGENIC AND OROGENIC MOVEMENTS

Sedimentary rocks are found throughout a relatively broad portion of the continent. These unaltered marine sedimentary rocks were deposited on top of the igneous and highly metamorphosed strata that make up the continental crust. These sedimentary strata resemble a platform and are divided by disconformities with minimal relief. Broad structural domes that cover the crust and basins with tectonic relief of a few hundred metres over distances of hundreds of kilometres are examples of erosional features.

Topographic basins are created in the core region when these epeirogenic domes are eroded. When compared to erosion, tectonic uplift occurs far more slowly and at lower pace. The sedimentary successions erected upon the continental shelves within the continent itself provide evidence of movements of higher size. One can see the many types of sedimentary deposits on the stable blocks of the continents. They may consist of aeolian deposits, lacustrine deposits, coal, evaporates, tillites, and arkoses made of elevated mountains that have degenerated over time. The interior of low, stable continental edges of the South African Karoo strata exhibit a succession of such protracted continuous deposits. Another illustration of a shallow basin with serpentine boundaries and land drowning is Lake Victoria and Lake Kyoga in East Africa.

The broad continental crust or shields are referred to as **cratons** or continental cratons. They are a collection of orogenic terrains that have been severely degraded and accreted. It has crystalline shields or platforms of old, thin sedimentary rocks that can be several centuries old. These rocks are monotonous, low height, and low relief. Without any sedimentary cover, around one-third of the sub aerial landscape has been eroded from old igneous and metamorphic rocks of the continental crust. They are exposed rocks that must have undergone metamorphosis or solidified from magma at depths of at least ten to twenty kilometres. For instance, the Canadian Shield's current relief persists as an unconformity beneath the Paleozoic and Mesozoic sedimentary strata that surround it. Landforms in the Australian Craton, which has unusually low relief and tectonic stability, are thought to be between 10 and 7 million years old. If Cratons are such large low-lying platforms of thin, old sedimentary rocks, then what tectonic processes could cause the epeirogenic uplift of other large continental areas.....? An elevation change occurs in Yellowstone National Park's western region and The Colorado Plateau. The Rhine Massif is rising at a rate of 0.35 mm annually. The Deccan Plateau in India has been rising since the Tertiary and Quaternary.

There are landforms associated with orogenic movement explained below in brief.

- a) **Mountains:** There is evidence that mountain ranges embedded within continents, such as the Himalaya Mountains and the Ural Mountains of Asia, formed close to plate borders. It is not necessary for vertical

movements in orogenic movements to be faster than broad, regional movements. However, they seem to be more continuous through time. Because of this, not all orogenic mountain belts are distributed randomly throughout the surface of the planet but rather follow certain recognisable patterns. Even though the orogenic belt and earthquake zone areas do not directly relate to one another, the circum-Pacific belt is linked to active volcanoes along subduction zones.

- b) **Island Arcs and Trenches:** There are subduction zones between two parts of the oceanic plates or lithosphere along thousands of kilometres of western Pacific borders in Indonesia and in the Caribbean Sea. The drowning plate flexes upward in a substantial outer swell seaward of the trench that it lowers into below the superimposing plate. The accumulated sediments, which are made up of deformed mudstone and sandstone, are scraped when the plate submerges and rubs against the inner trench wall. Such distorted sedimentary strata frequently rise above sea level to create frontal arcs of mountainous islands. Island arcs can be followed by volcanic arcs of andesitic composite cones. The buoyancy of the subducted plate caused the overlying plate to spread.
- c) **Cordilleran-Type Mountain Ranges:** Complex mountain ranges arise as oceanic lithosphere subducts beneath heavier continental lithosphere near converging plate boundaries of the cordilleran type, such as the Andes Mountains in South America. The accretionary prism of trench sediments, as well as faulting and uplift of continental crustal blocks, can result in narrow coastal ranges and an elongate longitudinal valley parallel to the coast on the continent's boundary. The volcanic peaks on a cordilleran type of mountain belt stand over a wide plateau and are made up of earlier sedimentary and metamorphic rocks that make up the axial component of the belt. The core mountain range thickens from intense compression, and isostatic adjustment causes the continental crust to raise it.
- d) **Collisional Mountain Belts:** When the island arc or another plate of continental lithosphere collides with the overlying plate of the subduction zone as a result of convergence and subduction, collisional mountain belts are formed. Due to their low density, continental rocks and island arcs are forced over one another to build large mountain ranges rather than sinking into the mantle. High mountain ranges with strongly deformed rocks of different lithologies, like the Himalayas or Alps, are suitable examples.
- e) **Extensional Mountains:** In a variety of tectonic environments, extensional and strike-slip plate motions create a fourth category of mountains. Because of its relative localization, rift valley development is regarded as a unique type of orogeny. The faulting that results in the creation of rift valleys along an extended swell or bulge is what defines continental disintegration. Some of the most intricate mountain ranges in the world are the result of strike-slip faults. Due to their connection to the San Andreas Fault, the Transverse Ranges in southern California share a common genesis.
- f) **Rift Valley (Horst and Graben):** Any extended trough created by the subsidence of a section of the Earth's crust between dip-slip or regular

faults is referred to as a rift valley. A fault of this type is a crack in the surface of the Earth where the rock material above the fault plane has moved lower in relation to the rock below the fault. In contrast to river and glacier valleys, which are created by erosional processes (exogenic forces), rift valleys are a form of tectonic valley (endogenic forces). When a block is moved downward between two normal faults, a graben or rift emerges. A horst is a small fault block that is elevated between two normal faults. Horsts are block-like plateaus or mountains with a flat top and steep, straight sides from a topographic perspective. A graben is a formation that resembles a valley or a trench and is surrounded by steep, parallel walls. The Shillong Plateau in India and the Rhine Graben (East African Rift Valley System) are the best examples.

SAQ 4

What are landforms associated with epeirogenic and orogenic movements?

5.6 SUMMARY

In this unit, you have studied so far.

- Earth movements are two different kinds of forces namely endogenetic and exogenetic. Endogenetic forces are primarily caused by the movement of the Earth's inner elements, however their exact origin is yet unknown. Exogenetic forces are primarily destructive and aim to alter the different relief features of the Earth's surface.
- Diastrophism is also called as tectonism. The diastrophic forces are usually leading to tectonic movements. The tectonic movements can be classified as epeirogenic and orogenic movements. These movements operate very slowly and their effects become perceptible after thousands and millions of years.
- Epeirogenic movements are those that are caused by radial forces and move vertically from the Earth's centre to its surface leading to vertical subsidence and uplift of the lithosphere to tectonic stresses.
- Orogenic movements are also called tangential forces that work horizontally to the surface of the Earth. It occurs mainly along the plate boundaries or plate margins that produce intense folding and faulting.
- Folding is referred to the surfaces of rocks curved during deformation by various earth's processes. The folds can be classified based on the inclination of the limbs in response to varying compression for example fan folds, symmetrical and asymmetrical folds, isoclinal, recumbent folds and so on.
- The upward or downward displacement of rock along a crack from its starting position is referred to as faulting. Faults are different types namely normal, reverse, strike-slip faults, and oblique faults.
- There are also additional forces that are frequently referred to as shearing forces and stresses acting under shearing forces work parallel to one another but in opposing directions.

- Landforms associated with epeirogenic and orogenic movements.

You will learn more about volcanism and earthquakes and their distribution and related landforms under Unit 6 on tectonic processes and landforms.

5.7 TERMINAL QUESTIONS

1. What are epeirogenic movements? Explain.
2. Explain different types of folds with neat sketch.
3. Describe various types of faults with diagram.
4. Explain landforms associated with orogenic movements.

5.8 ANSWERS

Self-Assessment Questions (SAQ)

1. a) Endogenetic forces originate from inside the Earth's crust. It is also known as the internal forces leading to vertical and horizontal Earth movements.
b) Land upliftment and subsidence.
2. a) Compressional forces or convergent forces are caused for folding in rocks.
b) Isoclinal, recumbent, symmetrical, and fan folds.
3. A normal fault is a dip-slip fault when the block above has slid downward in relation to the block below.
4. Cratons, basins, mountains, island arcs-trenches, etc.

Terminal Questions

1. Refer to Section 5.3.
2. Refer to Sub-Section 5.4.1.
3. Refer to Sub-Section 5.4.2.
4. Refer to Section 5.5.

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TECTONIC PROCESSES AND LANDFORMS-II

Structure

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6.1 INTRODUCTION

In Unit 5, you have studied about epeirogenic and orogenic forces that operate within the Earth's crust and are responsible for the upliftment and subsidence of the land as well as their folding and faulting. In this Unit, you will learn about volcano and earthquakes and their distribution and landforms produced by these processes. The most stunning manifestations of the dynamic processes of the Earth's interior are volcanism and earthquakes. The volcanoes and earthquakes played a major role in the evolution of the major landforms of the Earth. These processes are endogenetic in nature and operate in an abrupt manner and bring significant morphological changes on the surface of the Earth. These are known to be the destructive forces of the nature. The endogenetic forces occurring beneath the surface of the Earth very often change the Earth's topography through the process of creation, destruction, recreation, and maintenance of geomaterials (materials in the Earth crust). These forces produce various types of landforms on the Earth's surface in the form of mountains, ridges, plateaus, valleys, and plains, etc. In addition, volcanic activity and earthquakes are also considered as the outcome of the endogenetic forces of sudden nature. As the name suggests, the sudden forces arise due to abrupt movement of the materials within the interior of the Earth.

Section 6.2 explains you one of the important consequences of sudden forces leading to volcanoes. In this section, you will study the characteristics, types and distribution of volcanoes. Section 6.3 will discuss about the volcanic landforms. While studying earthquakes in Section 6.4, you will learn about the origin of earthquake, its characteristics and types of earthquake waves, magnitude and intensity of an earthquake and earthquake's impact.

Expected Learning Outcomes

After studying this unit, you should be able to:

- Explain about volcanism;
- Classify volcanoes and illustrate the distribution of volcanoes;
- Explain about an earthquake, its origin and their distribution; and
- Describe the magnitude, intensity and impact of an earthquake.

6.2 VOLCANISM

Let us first understand what volcanism is? **Volcanism** is the endogenetic process capable of bringing sudden and massive changes inside the crust or above the surface of the Earth by releasing a lot of lava, dust, gases and smoke. Simply, volcanism is the process through which solid, liquid, and gaseous substances escape from the interior of the Earth to the surface of the Earth. The terms "*vulcanicity*" and "*volcanism*" are used synonymously to describe the process by which gases and molten rock are either extruded (poured) or intruded (pushed) into the Earth's crust. Volcanism can be described by including the surface discharge of molten rock, pyroclastic fragments or hot water, steam and smokes.

6.2.1 Volcano

Let us now discuss about the nature and characteristics of a volcano. The term *volcano* is frequently used to describe mountains formed by volcanic activity. What exactly is a volcano in general? A **volcano** has a deep vent, or opening, usually circular or nearly circular in shape, through which heated materials consisting of gases, ash, water, liquid lava and molten rock are ejected from the Earth's interior to the surface of the Earth.

We will now study the structure and main features of a volcano. The size and shapes of the volcanoes vary but however, certain characteristics are common to the majority of the volcanoes. Refer to Figure 6.1 for understanding a volcano where different types of features formed during its eruption are shown. You may be surprised to learn that Oxygen (O), Silicon (Si), Aluminum (Al), Iron (Fe), Calcium (Ca), Sodium (Na), Potassium (K), and Magnesium (Mg), comprise almost 99% of the components constitute the magma. The most prevalent element in magma is oxygen, which accounts for slightly less than half of the total. Although mantle magma comprises of larger proportions of iron, magnesium, and calcium, they are still likely to be dominated by oxygen and silicon. All magmas include various proportions of the components like hydrogen, carbon, and sulphur, which are transformed

into gases like water vapour, carbon dioxide, and hydrogen sulphide when they cool.

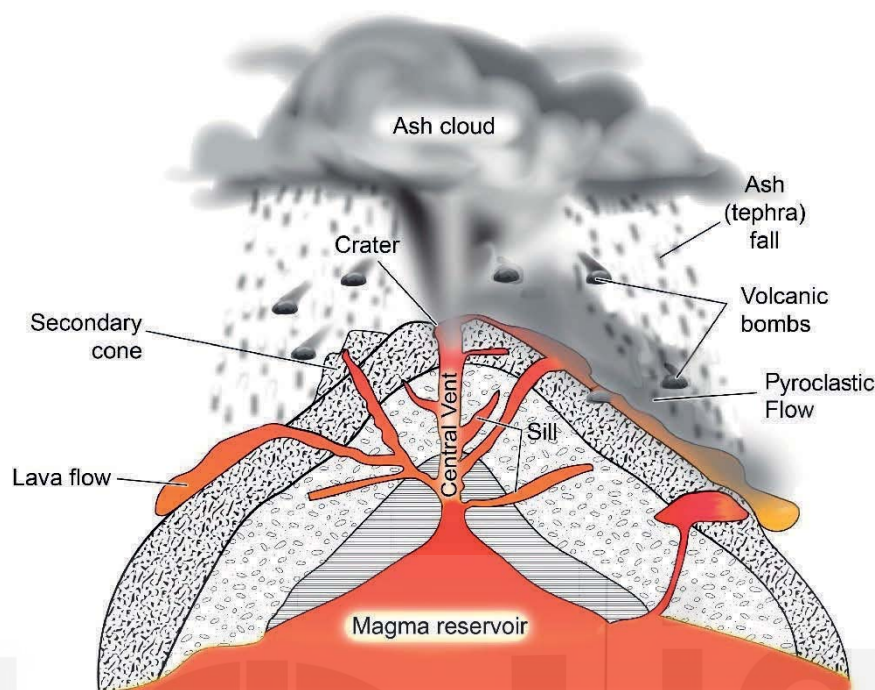


Fig. 6.1: A Volcano and its Features.

Characteristic Features Associated with a Volcano

Magma: A molten rock inside the Earth's crust is generally called as magma. It comprises of molten rocks, hot liquids, gases, water vapour, and clouds of dust. Magma remains under intense pressure and move towards the Earth's surface when it finds an outlet on the surface of the Earth.

Magma Chamber: A huge volume of liquid or molten rock found below the Earth's surface which becomes the source of supply of molten material to the volcano is known as a magma chamber. In such a chamber, the magma is under intense pressure that can eventually fracture the rock surrounding it and create a path for the magma to move upward.

Lava: The name given to the magma once it is emerged from a volcano's vent and reached to the surface of the Earth. The ejection of the heated materials from a volcano through the vent is called volcanic eruption.

Vent: Volcanic vent can be a main vent and/or a secondary vent, the route by which magma rises to the surface. In other words, the primary/main vent serves as the magma's main exit while secondary vents are smaller outlets through which it exits.

Crater: The crater, which is the volcano's entrance or opening to the Earth's surface, is formed as a funnel-shaped depression at the summit of the volcanic cone. It has usually the steep sided walls made up of hardened lava that surround the main vent. The base of the crater is connected with the interior of the Earth by volcanic pipe through which the lava rises to the top.

Volcanic Pipes/Conduits: Deep-origin volcanoes erupt violently and often create a subterranean geological structure known as volcanic pipes/conduits. The difference between a vent and a conduit is that a vent is an opening in the surface of the Earth through which volcanic materials can escape, whereas a conduit is an underground tube through which magma can transit.

Conical Hill: A *conical hill* is created when lava and other associated materials that have been released into the atmosphere gather near to the vent. In addition, on larger volcanoes, *secondary cones* grow up around secondary vents that emerge at the surface and also known as a parasitic cone. Smaller parasite volcanoes that feed from the same magma chamber as the primary volcano through secondary vents typically release volcanic gas known as fumaroles.

You must have understood some of the key features of a volcano.

Let us now study the types of volcanoes based on their eruption characteristics after answering the following questions.

SAQ I

- a) Describe volcanism.
 - b) What is a volcano?
 - c) What features are found in a volcano?
-

6.2.2 Classification of Volcanoes

Majority of volcanoes are not the traditionally soaring conical giants; instead, they come in a variety of sizes. Volcanoes often reflect the processes that shape them and so a wide set of features arise. This is because they have significantly different plumbing systems, magma kinds and supply rates, and eruption patterns. Accordingly, volcanoes can be classified broadly in to two categories a) based on frequency/periodicity of eruption and b) based on mode of eruption. Let us discuss one by one in detail.

(A) Based on Frequency or Periodicity of Volcanic Eruption

We can classify the volcanoes into three major types such as (1) active volcano (2) dormant volcano and (3) extinct volcano.

1) Active Volcano

A volcano, that has recently erupted or within the past few thousand years, is considered to be active. Simply we can describe that active volcanoes remain in continuous process that erupting periodically volcanic lava, gases, ash, and other materials. There are more active volcanoes identified in the world, although the number may be greatly underestimated because of a number of submarine volcanoes whose activity has not been seen and recorded. Active volcanoes frequently erupt and are typically found close to the Ring of Fire. For instance, Mount Stromboli, an active volcano, is referred to as the Mediterranean Lighthouse because it produces so many gas clouds. Barren Island in the Andaman and Nicobar Islands (India) erupted in the 1990s.

2) Dormant Volcano

A volcano that has historically erupted may be dormant right now and has been for hundreds of years is called as a dormant volcano. It is also called a sleeping volcano. Although it is not active right now, this volcano has previously been active and may do so again in the future. Volcanoes can be dormant for thousands of years before erupting again. This category includes events like the eruption of the Vesuvius volcano in 79 AD, which obliterated the Roman cities of Pompeii and Herculaneum. In 1631 AD, it erupted again, followed in the 19th century, eruption frequency had increased once more. The two well-known instances of dormant volcanoes are Mount Fuji in Japan and Mount Kilimanjaro in Tanzania, which is also the highest peak in Africa.

3) Extinct Volcano

A volcano that is no longer active and has no chance of being reactivated. If a volcano has not erupted in recorded history and is not likely to erupt in the near future, it is called extinct. The line between inactive and extinct is hazy. In the extinct kind, the crater is filled with water and often forms lakes. Although many of these are thought to be dormant, they could become active at any time because no one knows what is going on beneath the ground.

(B) Based on Mode of Volcanic Eruption

The volcanoes under the category are classified into two types as (1) **central** or **explosive eruption** and (2) **fissure** or **quiet eruption**. A volcano frequently exhibits a specific pattern of behaviour during an episode of activity. Some moderate eruptions only expel steam and other gases, but others silently expel large amounts of lava. The most spectacular eruptions are characterised by explosive explosions that send huge clouds of gas-laden debris into the atmosphere.

1) Volcanoes of Central or Explosive Eruption

Volcanoes of the central or explosive type erupt liquid lava, rock fragments, ash, and lapilli from a pipe-like central vent or mouth. The nature and intensity of core eruptions can vary depending on the amount of lava ejected because of the pressure of gases, and the viscosity of the lava. Considering that the lava is more viscous and has an acidic composition, the eruption will be especially powerful. The names of well-known volcanoes with similar characteristics are frequently used to describe these types of volcanic eruptions; as a result, the volcanoes of the central eruption type can be further classified into major types or terms like Icelandic, Hawaiian, Strombolian, Vulcanian, Vesuvian, and Pelean, among others. The major types of central eruption volcanoes are shown in Fig. 6.2.

(a) Icelandic Eruptions: Icelandic eruptions do not follow the conventional pattern of ash and lava erupting from a mountain summit; instead, vast quantities of extremely fluid lava pour from the Earth's cracks. Icelandic volcanoes spread their lava layers out horizontally into enormous sheets.

(b) Hawaiian Eruptions: These eruptions are known as Hawaiian type because they frequently happen on the Hawaiian Islands. This type of volcanoes has less explosive activity and erupts quietly due to less viscosity

of lava and non-violent nature of gases. These eruptions often do not produce large amounts of Tephra or pyroclastic material in the air, nor are they explosive or damaging. Instead, they create lava with low viscosity and low gas content that spreads across significant areas to form lava plateaus and shield volcanoes with a gentle slope. Examples of these eruptions include Krafla (1975–83) in Iceland and Kilauea (1959) on Hawaii Island.

(c) Strombolian eruptions: The most beautiful volcanic styles, often known as the "Lighthouse of the Mediterranean," were called after the volcano that created the island of Stromboli, part of the Lipari group of islands in the Mediterranean Sea. It has a comparatively mild explosion and, as the bubble explodes, ejects pumice, scoria, and bombs of hot materials that are made of liquid lava fragments. These explosions occur at regular, periodic intervals that might last anywhere between a few minutes and an hour.

(d) Vulcanian Eruptions: Vulcanian eruptions are more powerful and are called after eruptions on Volcano Island in the Aeolian Islands in the Mediterranean. More viscous magma is being produced by these eruptions, and the lava that forms as a result quickly solidifies and covers the crater opening in between two eruptions. This blockage makes it challenging for the erratic gases to emerge from the volcano's summit during the next eruption. As a result, the trapped gas in the underlying magma attempts to expand its space and subsequently, they force their way through the solidified vent under great pressure.

(e) Vesuvian Eruptions: Vesuvian eruptions, which take their name from Mount Vesuvius, entail enormous gas bursts that propel huge ash clouds into the atmosphere. This type of volcanic eruption has a very powerful explosion that is comparable to the Vulcanian and Strombolian explosions. The primary vent continues to build up powerful gases as the lava continues to come out with considerable force primarily from the lateral cracks. When a high pressure is built up, an explosion happens quickly, and the resulting ashes and gases create dense, mushroom-shaped clouds. These clouds have the capacity to soar higher in the sky.

(f) Krakatoan Eruptions: The Krakatoan eruptions get their name from the Krakatau volcano, which is situated in the Sunda Strait between Java and Sumatra. Krakatoa is situated in a region of intense volcanic and seismic activity where the Indian-Australian and Eurasian tectonic plates collide. Its explosive eruption in 1883 was one of the most catastrophic in history. Knowing that the lava from Mount Krakatoa was composed of rhyolite or dacite helps to explain the size of eruption. Since they are cooler and stickier than basalt, high pressure can build up inside them before it is released. These types of volcanoes typically have steep sides and usually erupt frequently and violently.

(g) Pelean Eruptions: The cataclysmic eruption of Mt. Pelee on Martinique Island in the Caribbean Sea prompted the naming of these eruptions. It is regarded as one of the worst volcanic occurrences of the 20th century. These are extremely explosive, eject highly viscous lava, and are characterised by hot, blazing clouds (termed *nuee ardente*, means glowing cloud).

(h) Plinian Eruptions: Massive vertical explosions that shoot gas, ash, and eject miles into the atmosphere characterise this kind of volcanic eruption. These eruptions are the most violent of the Vesuvian events. Such eruptions are triggered by highly viscous, gas-rich magmas. Similar to both Vulcanian and Strombolian eruptions, Plinian eruptions are distinguished by the presence of sustained eruptive columns rather than discrete explosive bursts. In some classifications, the word Krakatoan is used in place of Plinian is based on the Indonesian volcano Krakatau's explosion. Krakatoan, on the other hand, is incredibly violent and typically eliminates the volcanic cone's peak. This type of eruption was took place in New Zealand.

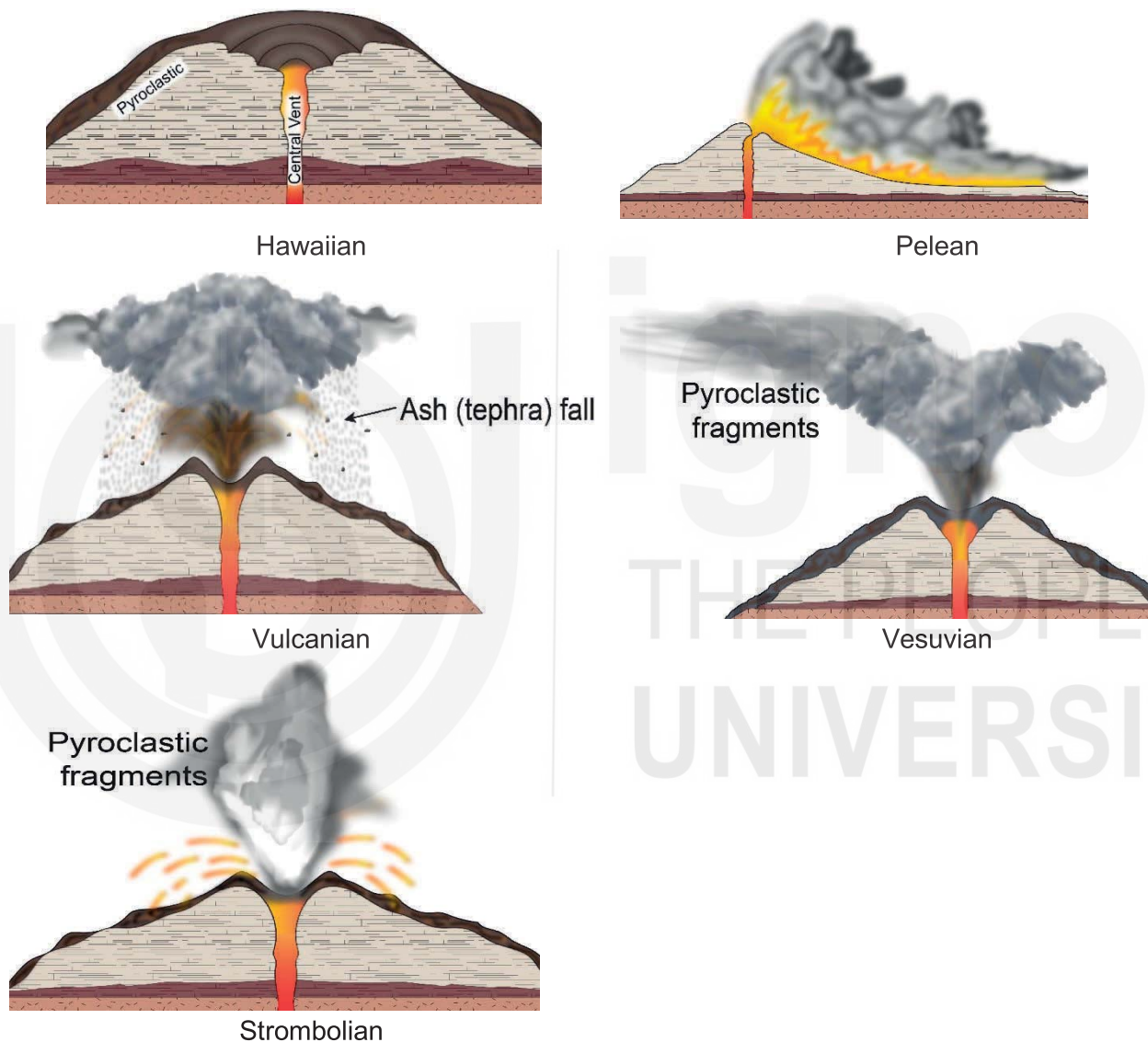


Fig. 6.2: Sketch of Central Eruption Type Volcanoes.

2) Volcanoes of Fissure or Quite Eruption

Fissure is a broad name for a crack in the Earth's crust that primarily forms during powerful earthquakes or related tectonic activity. Moreover, a fissure eruption is a volcanic eruption that originates from one or more fissures in the crust of the Earth. They do not usually explode, but they can spew forth a lot of lava quickly. Due to the basaltic composition of the lava and its extreme fluidity, the surrounding area frequently floods. A sheet of magma that erupts along the fault is frequently the starting point of fissure-fed eruptions. The

magma in the interior of the Earth cannot be reached directly by a conduit or central vent. So that it rapidly localises and forms several additional distinct vents along the fissure. For instance, a sequence of fissure-fed eruptions in a region near the Icelandic mountain Laki took place between June 1783 and February 1784. Approximately 14 cubic kilometer of basaltic lava ejected from a 25 km long fissure.

SAQ 2

- a) What is an extinct volcano?
 - b) Describe Hawaiian type volcanic eruption?
-

6.2.3 Global Distribution of Volcanoes

Do you know the volcanic activity has really helped us to know the degree of tectonic processes more qualitatively? Tell us what are the best indicators for identifying plate boundaries? Yes, the volcanic activity and earthquakes can give the idea. Athanasius Kircher created the first map illustrating the location of volcanoes on Earth in 1665. Additionally, Robert Mallet (1858) created the map illustrating the global distribution of both earthquakes and volcanic eruptions in a 'vast loop or circle round the Pacific', highlighting a significant geographic coincidence. When the locations of around 1500 terrestrial volcanoes with known or potential activity over the past 10,000 years are shown on a globe map, it is evident that the location or distribution of volcanoes on the surface of the Earth is not random (Fig. 6.3). It has been noted that volcanic activity is primarily concentrated within specific regions of the Earth's crust, predominantly occurring along the marginal parts of continents and in the littoral zones of oceans and seas. This information can be utilized to locate the edges of plates. Volcanic activity is mainly associated with plate boundaries.

a) Volcanoes along the Convergent Plate Margins

These boundaries are often associated with intense volcanism. As plates collide, heavier plates slide under lighter ones and melt as they move down into the hot mantle. The line of volcanoes that circles most of the Pacific Ocean is known as **Ring of Fire** or **Circum-Pacific Belt**. This zone is known to be the site of frequent volcanic eruptions where more than seventy five percent of the active and inactive volcanoes are located. It stretches from Tierra del Fuego, located at the southern tip of South America, extending northward along the Andes Mountains in South America, traversing Central America, following the Cascade Mountains in the Pacific Northwest of the United States and southwestern Canada, proceeding along the Aleutian Islands in Alaska, extending westward to the volcano-rich Kamchatka Peninsula, and reaching southward to encompass Japan and eastern China, the Philippine Islands, Indonesia, New Guinea, and New Zealand. In total, the Ring of Fire spans approximately 30,000 miles (48,280 km) in length and encircles an area of roughly 70 million square miles. Thus, the subduction-related volcanism is of two types:

- 1) **Ocean–Ocean Convergence:** It is described where oceanic lithosphere is subducted beneath oceanic lithosphere. The subsequent volcanism is expressed on the surface as chains of islands referred to as **Island Arcs**. Classic examples include the Caribbean Arc, Aleutian Arc, Kurile Kamachatka Arc, Japan, Philippines, South Sandwich Arc, Indonesian Arc, Marianas, Fiji, and Solomon Islands.
- 2) **Ocean–Continent Convergence:** Here the oceanic lithosphere is subducted beneath the continental lithosphere, resulting in the formation of volcanic chains close to the continental edge, commonly referred to as the continental margin arc. Notable instances include the Andes Mountains, Central American Volcanic Belt, Mexican Volcanic Belt, the Cascades, the part of the Aleutian arc on Continental crust, and the North Island of New Zealand.

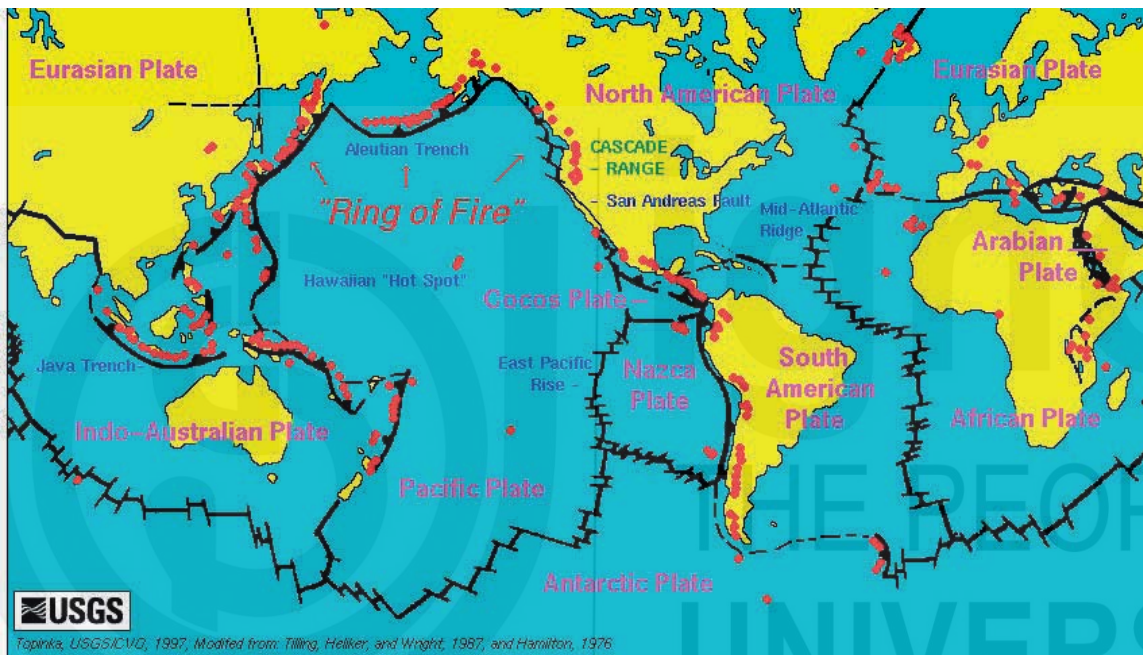


Fig. 6.3: The Volcanoes and Plate Margins.

(Source: <https://www.bgs.ac.uk/discovering-geology/earth%20hazards/volcanoes/how-volcanoes-form-2/>)

b) Divergent Plate Margins

The oceanic ridges or spreading centers are sites of active volcanism along diverging plate margin. However, most of this volcanism is submarine and Iceland, along the Mid-Atlantic Ridge is one of the only few places where an oceanic ridge reaches above sea level. Areas of plate divergence are not confined solely to oceanic settings; instead, they can extend into continental interiors. In these areas, one can observe phenomena such as the thinning of continental crust, the ascent and decompression of the Earth's mantle, the occurrence of active volcanism and eventually, the formation of new ocean basins. Volcanic ridges and their associated volcanic activity concentrated mainly in the Mid-Atlantic Ridge system, the East-Pacific Rise, the Carlsberg Ridge, and the ridges encircling the Antarctica Continent. Arc volcanism includes the Aleutian Islands, Kamchatka, the Kurile Islands, Japan, Philippines, Celebes, New Guinea, Solomon Islands, New Hebrides, New Zealand, and the Indian Ocean belt. It may represent early stages of

subduction zones. Volcanoes like Cotopaxi, Katmai, Fujiyama, etc. are located in this belt. Volcanic chains are straight line of volcanoes extended through the Andes of South America, Central America, Mexico, the Cascade Mountains of western U.S.A. Volcanic clusters are found in oceans and on continents, for example, the Galapagos, Canary Islands, Azores in the Atlantic, Mauritius in the Indian Ocean, and East African Rift Valley, etc.

c) Hot Spots

Volcanic activity arising from hotspots can be observed in both the Atlantic and Pacific Oceans. However, it is notably more pronounced in the Pacific Ocean's seabed due to the higher speed at which the tectonic plates move compared to those in the Atlantic. Consequently, the path of a hotspot is visibly marked by a linear sequence of islands and seamounts, for example, Hawaiian-Emperor-Seamount chain, Austral-Marshall-Gilbert chain, etc.

6.3 VOLCANIC LANDFORMS

As we understand landform is an Earth's surface feature that is part of the landscape. These are generally produced by the processes of erosion and deposition influenced by several natural factors like relief, slope, climate and vegetation as well as human factors. Different climatic environments produce different types of landforms.

Volcanic landscapes comprise a wide range of landforms that vary greatly in size, shape, composition, and eruptive history. Since magmatism on Earth is fundamentally basaltic, originating in the mantle, the character of volcanoes and resulting landforms is influenced by a variety of factors. These include tectonic environment, melt production and transport, and the nature of the lithosphere through which magma pass from source to surface. We can categorise volcanic landforms as **extrusive landforms** and **intrusive landforms** based on the kind of magma extruded on the Earth's surface or intruded into country rock.

6.3.1 Extrusive Landforms Associated with Volcanoes

The landforms produced from a volcano are determined by the materials of erupting magma. Their shapes are determined by the exclusivity of the eruptions and to the amount of water in the magma. Moreover, extrusive volcanic landforms can be grouped in to polygenetic volcanic landforms and monogenetic volcanic landforms based on the complexity of their eruptive history.

(1) Polygenetic Volcanoes

These are enormous volcanoes that have been constructed over at least tens of thousands of years and maybe millions of years old. They are defined as being located over a long-lived stable thermal anomaly in the crust. The polygenetic volcanoes are explained here:

- a) **Composite Volcanoes:** Strato-volcanoes/lava cones/composite cones/volcanic centres/compound/composite volcanoes are all terms used to refer to polygenetic volcanic landforms produced by repeated

eruptions from a single vent or migrating vents connected to a common magmatic system. Composite volcanoes eject highly viscous andesitic and rhyolitic lava, which doesn't travel as far from the volcanic vent as basaltic lavas. As a result, composite volcanoes tend to have smaller diameters compared to shield volcanoes. An exception to this pattern is Mt. Fuji in Japan, which erupts basaltic lava.

All tectonic regions have composite volcanoes, but subduction zones, particularly those within the Pacific Ring of Fire, are where they most frequently occur. The volcanic zones such as the East African Rift zone (including Mt. Kilimanjaro) and San Francisco Mountain in Arizona (USA) are assumed to be connected to continental rifting, they are less frequently observed. Large central volcanoes like Askja, Hekla, Torfajokull are found in Iceland on a divergent plate boundary. Other notable examples of strato- volcanoes include Mt. Fuji (Japan), Mt. St. Helens (USA), Cotopaxi (Ecuador), Popocatepeti (Mexico), Santa Mara and Fuego (Guatemala), Majon (Philippines), Haku-san and Iwate (Japan), Kliuchevskoi (Russia), Vsevid of (Alaska, USA), and Pilas, Las (Nicaragua).

- b) Shield Volcanoes:** These are large volcanic features with extensive summit areas and broad rounded shape. From a central summit vent, or from a collection of vents, numerous flows stream out in all directions, forming a broad, gently sloping cone with a flat, domical appearance, thus their name. Shield volcanoes are composed of fluid lava flows (non-explosive eruptions of low viscosity basaltic magma) that spread over long distances and large areas, occasionally exceeding 50 km in length. World's largest shield volcano-Mauna Loa located in Hawaii has a diameter of about 200 km with a summit height of 4,169 metres above sea level. Figure 6.4 represents the largest of all shield volcanoes of the Earth. The Auckland Field (New Zealand), Wrangell, Belknap, and Newberry in USA, Fernandina (Galapagos), and Prestahnukur (Central Iceland) are more notable instances of shield volcanoes.

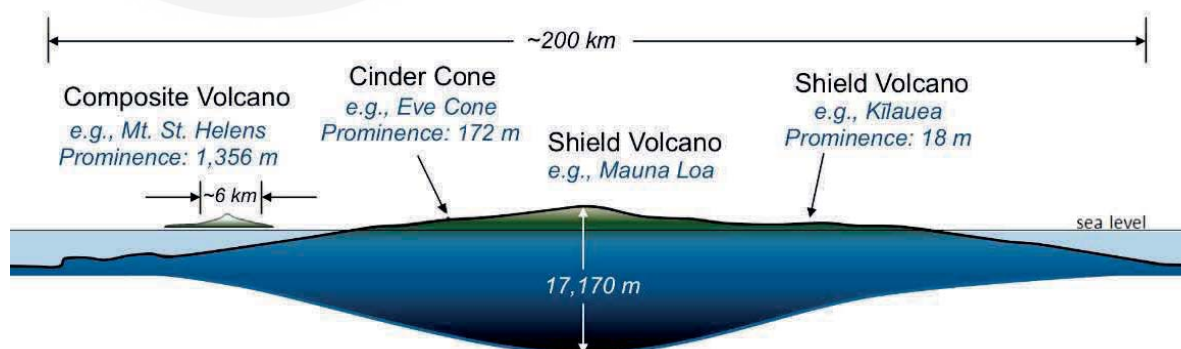


Fig. 6.4: Comparison of volcano sizes and shapes. Broad, rounded shield volcanoes are the largest, followed by cone-shaped composite volcanoes. Straight-sided cinder cones are the smallest, and barely visible in the scale of the diagram.

(Source: Karla Panchuk (2017) CC BY 4.0 modified after Steven Earle (2015) CC BY 4.0 <https://opentextbc.ca/geology/>)

- c) **Fissure Volcanoes (Lava Plateau or Flood Basalts):** Occasionally, very thin low viscosity magma escapes through cracks and fissures in the Earth's surface and flows across vast expanses of relatively flat terrain and create lava plateaus. Flood basalts are produced by large eruptions from long vents or fissures as opposed to isolated craters. These volcanoes last for centuries, perhaps even thousands, or even hundreds of thousands of years, unlike current volcanic outbursts. Their eruptions are frequently sporadic. For example, the Deccan Traps in India, Siberian Traps (Kamchatka, Russia), Banda Api (Indonesia), Pagan (Mariana Islands), Kuchinoerabu-jima and Komaga-take (Japan), and Krafla (Iceland) are some of the most notable examples of flood basalt eruptions.

(2) Monogenetic Volcanoes

These are those whose eruptive activity lasts only one episode. The duration of an episode can range from a single eruption lasting a few weeks to months to quasi-continuous activity lasting several years to decades.

Monogenetic volcanoes can further be divided into Mafic Monogenetic volcanoes and Cinder Volcanoes.

i) Mafic Monogenetic Volcanoes

Numerous small mafic volcanoes can be found all over the world in various tectonic settings; however they appear to favour extensional regimes in particular. They often appear as vents on the sides of bigger volcanoes (e.g. satellite scoria cones on the flanks of Mt Etna composite volcano, Italy) or as a component of a monogenetic volcanic field created by scattered volcanism (e.g., Auckland Volcanic Field, New Zealand). The following are the primary types of mafic minor volcanic landforms.

- a) **Scoria or Cinder Cones:** These represent the most prevalent and diminutive variety of volcanoes, typically standing at heights of under 300 meters. They can take the form of independent volcanoes within basaltic lava expanses or as subsidiary cones formed during eruptions along the flanks of shield volcanoes and stratovolcanoes. These cones are commonly associated with late-stage lava flows that are typically fed by lava fountains or erupted from the base of the cone. Examples are Par'cutin (Mexico) or Lava Butte (Oregon, USA).
- b) **Maar-diatremes:** Maars, which are by definition holes drilled into the pre-eruptive surface rather than structures rose above the ground. Maars typically fill with water and take the appearance of lakes. While diatremes are typically order of magnitude larger than the visible volcanic features. These are circular depressions with crater floors below the pre-eruptive surface and low rims of ejected debris surrounding them. If the eruption took place under strong winds, these rims can be asymmetrical (e.g., Cerro Colorado maar, Pinacate Volcanic Field, Mexico). These volcanoes are the result of violent eruptions that carved deep grooves in the local rock.

- c) **Tuff Rings and Tuff Cones:** Unlike Maars, which are built on the substrata rather than excavated into it? Tuff cones are smaller and have heavy deposits close to the vent that thin out fast, creating steeper slopes, as opposed to tuff rings, which have wide and flat characteristics, for example, Fort Rock (USA). Additionally, beneath tuff rings there is a shallow diatreme; diatremes are often missing beneath tuff cones.

ii) Cinder Volcanoes

The most prevalent type of volcano worldwide is a cinder cone. They resemble an idealised volcano because they are small, steep, conical hills-sized volcanoes made of pyroclastic pieces (tuff) and blobs of congealed lava ejected from a single vent (central vent), with a noticeable crater at the top. In general, cinder cones are found at the summit vents and flank vents of shield volcanoes and strato-volcanoes, and most have a bowl-shaped crater at their summits. For example, Wizard Island and the Newberry volcano in Oregon (USA), has more than 400 cinder cones on its flanks.

Due to the erosion prone unconsolidated pyroclastic materials, most cinder cones are short-lived landforms in terms of geologic time. Barren Island (India), Aso (Kyushu, Japan), Tolbachik (Kamchatka, Russia), Okmok (Alaska, USA), Michoacán-Guanajuato (Mexico), Cerro Negro (Nicaragua), Darwin and Santiago (Galapagos Islands), are just a few of the most notable examples of cinder volcanoes.

- a) **Lava Dome:** They are steep-sided, dome or spine-shaped masses of volcanic rock formed from viscous lavas that grow in or directly above a volcanic vent and are also known as volcanic domes. Depending on its shape, lava domes can be classified into different categories. Although lava domes are typically thick, steep extrusions, their morphologies can range from low-profile, round domes called Tortas to cylindrical spines called Peléean domes with substantial talus slopes. Merapi (Central Java), Unzen (Japan), Bezymianny (Kamchatka, Russia), Redoubt (Alaska, USA), St. Helens and Lassen Volcanic Center (Washington, USA), Ceboruco and El Chichón (Mexico), Santa María and Pululagua (Guatemala), Soufrière Hills (Montserrat, West Indies) are some of the examples.

- b) **Caldera Volcanoes:** The majority of calderas have enormous circular or oval depressions measuring more than one kilometre in diameter. These depressions were made when landforms internally collapsed after the massive release of magma from beneath the Earth. You need to understand here the distinction between a crater and a caldera. Craters are circular or elliptical depressions that are smaller than one kilometre in diameter, whereas calderas are those that are between one and one hundred kilometres in diameter. Both craters and calderas are created by the collapse or explosion of a volcano, but craters are created by the outward explosion of rocks and other volcanic materials, whilst calderas are created by the inward collapse of a volcano. When a caldera is filled with groundwater, precipitation, or melt water to form a lake within a crater, it is referred to as a Crater Lake. Toba (Sumatra), Banda Api (Indonesia), Taal and Pinatubo (Philippines), Mashu (Hokkaido, Japan), Akademica

Nauk (Central Kamchatka), Crater Lake (Oregon, USA), and Masaya (Nicaragua) are few examples of calderas. The West Eifel Volc Field (Germany), Ol Doinyo Lengai (Tanzania), Kelimutu (Indonesia), Maly Semiachik (Kamchatka), Douglas (USA, Alaska), Pinacate and Chichinautzin (Mexico), Telica and Las Pilas (Nicaragua), Cotopaxi (Ecuador), and Erebus (Antarctica) are some of the examples of Crater Lake type caldera. Others are also the Kilauea caldera on Kilauea, the Erta Al caldera in Ethiopia, the Summit caldera of Piton du la Fournaise on Reunion Island (Indian Ocean).

(3) Other Types of Extrusive Landforms

i) Volcanic Necks and Plugs

These are the solidified remnants of conduit and plumbing systems of volcanoes that are left after the majority of a volcano has been eroded away. They are created when a volcano stops erupting and is severely degraded; the exhumed plug emerges as an asymmetrical, columnar structure. In comparison to the surrounding rock formation, this columnar structure is more erosion-resistant. The Little Devils Postpile in Yosemite National Park, Ailsa Craig in Scotland, Kapsiki Peak in Cameroon, and Ship Rock in New Mexico are the examples of volcanic plugs.

ii) Non-Volcanic Craters (Cryptovolcanic)

The term "cryptovolcanic structure" refers to complexes with a roughly circular cross-section that resemble volcanic pipes (necks) on the surface but contain little to no volcanic material. Large meteorites, asteroids, and comets colliding with the earth to create impact craters leave behind similar destructive traces to volcanoes in the form of extreme disruption and localised rock melting. The Meteor Crater in Arizona (USA), the largest known crater with related meteorites, is a prime example of a non-volcanic crater.

iii) Geysers

Three essential components are needed for the formation of a geyser: a source of water, a heat source, and the right kind of subsurface water circulation system. Different features emerge when only two of these are present. For instance, a hot pool forms when there is a lot of water but little heat. A boiling hot spring arises when there is an abundance of water and heat but not the right kind of plumbing system. A typical example of a geyser is the Old Faithful Geyser in Wyoming's Yellowstone National Park which typically explodes once every one hour or so.

iv) Hot Springs (Thermal Springs)

They appear where hot water is naturally heated underground before rising to the surface. As it descends, the colder groundwater is heated by hot rock. Usually found along a fault zone, this hot water eventually rises to the surface.

v) Fumaroles

At the surface, volcanic gases are emitted (without accompanying any liquids or solids) through vents called fumaroles (or fumerole) or solfataras.

Fumaroles release combinations of steam and other gases since the majority of magmatic gas is water vapour. A typical gas coming from fumaroles is hydrogen sulphide (H_2S). Fumaroles generally maintain the temperatures ranging from 100 to 300°C. They frequently emit hydrogen sulphide, which combines with oxygen to form sulphur deposits known as **sofataras** in Italian. The most sofataras is found in Iceland.

6.3.2 Intrusive Landforms Associated with Volcanoes

Intrusions form where molten and mobile igneous materials cool and solidify without erupting through the Earth to form volcanoes. When they fill already existing niches in rocks, they are thought to be passive, and when they push a space for themselves, they are known to be active. Let us discuss intrusive landforms associated with volcanoes.

(1) Batholith and Lopolith

The bigger intrusions, which include batholiths, lopoliths, and stocks, have a surface exposure of more than 100 square kilometer and are approximately circular or oval in shape. A huge emplacement of igneous intrusive rock, also known as plutonic rock, that originates from cooled magma deep in the Earth's crust is known as a **batholith**. Felsic or intermediate rock types, such as granite, quartz, monzonite, or diorite, are usually the primary component of batholiths.

Lopoliths are massive, saucer-shaped, and layered intrusions of basic rocks that often have a gabbro-type composition. Lopoliths typically have feeder bodies in the shape of a dike or a funnel and are concordant with the intruded layers. The largest intrusive bodies of basic rocks are called **stocks or plugs**. They are dissonant and the magma chambers' solidified remnants. One stock in Hawaii is 1 km deep, 12 km wide, and 20 km long at the surface.

(2) Dyke and Sill

Dykes are discordant intrusions, which are typically 1 to 10 m wide, made mostly of dolerite, and that frequently occur in swarms (Fig. 6.5). A 24 km section of the Arran coast in Scotland has a swarm of 525 dykes, with an average dyke thickness of 3.5 m. A **sill** is specifically an intrusion of a tabular sheet of rock that has pushed through the joints of the layers of rocks, previous sedimentary rock layers, volcanic lava or tuff beds, or even along the foliation direction of metamorphic rock. The Karoo sediments in South Africa are covered with dolerite sills.

(3) Laccolith and Phacolith

Sills that have thickened to form domes are called **laccoliths**. Specifically, a laccolith, which is a type of pluton with a convex upper roof, nearly flat bottom, and a shape that resembles a dome in three dimensions.

Phacoliths are masses of volcanic rock in the shape of lenses that are intruded into folded sedimentary strata that are roughly concordant with one another and have its thickest areas along the axes of synclines or anticlines. They are elongated as opposed to laccoliths, which have a tendency to be circular in plan.

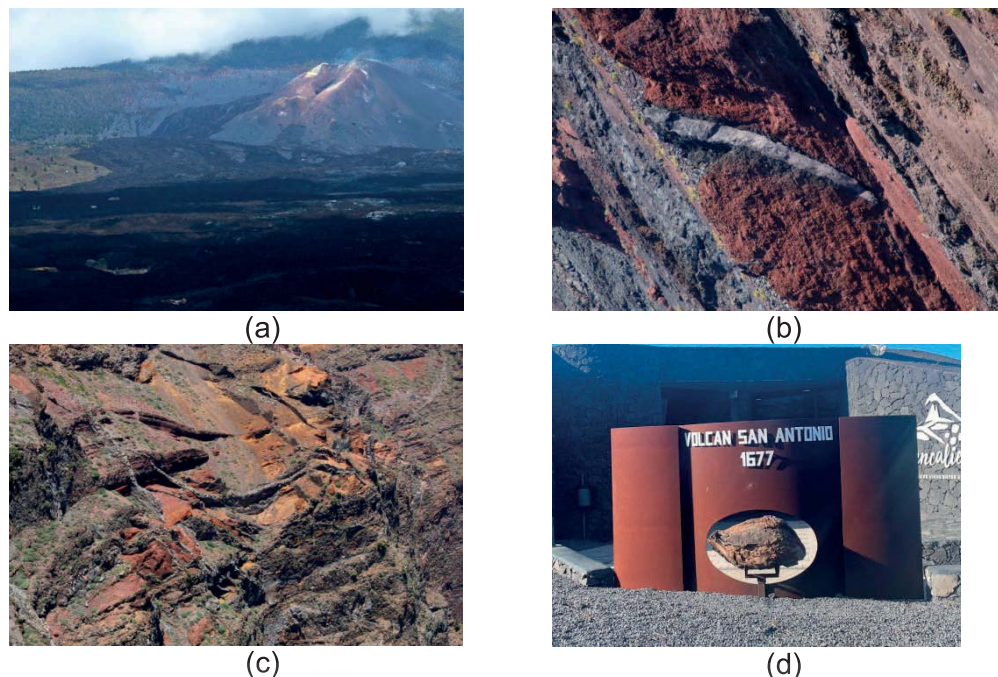


Fig. 6.5: Cumbre Vieja volcanic ridge, La Palma in the Canary Islands which is recently erupted in 2021; b) Volcanic Dyke; c) Signature of Volcanic Intrusive Landforms; and d) A Volcanic Bomb or Lava Bomb comes out during eruption of Volcan De San Antonio in La Palma, Canary Islands.

SAQ 3

- What are polygenetic volcanic landforms?
- What are Fumaroles?

6.4 EARTHQUAKE

In this section we will study about an earthquake, its origin, destructive effects on the landscape, and their distribution. Every year, as we all know, a large number of earthquakes occur across the world. Some last only a few seconds or minutes and can occur at any time of day or night and in any season. An **earthquake** may be described that it is the shaking induced by the rupture or breaking and subsequent movement of rocks beneath the Earth's surface. Simply said, an earthquake is the passage of vibrations through the Earth's crust caused by a sudden disturbance or movement of rocks. Volcanic eruptions or abrupt displacements of rocks in fault systems produce earthquakes. Earthquakes are classified into two types: volcanic and tectonic.

Volcanic earthquakes are triggered by volcanic activity. When magma is expelled from the volcanic system in the Earth's interior as a result of pressure changes underneath the volcano, an empty space is left to be filled. The flow of magma or other fluids within the volcano causes the tremors. It causes the surrounding rocks to fall to fill the space, resulting in an earthquake. Earthquakes, in general, accompany volcanic eruptions, and many strong Earthquakes induced volcanic eruptions. Tectonic earthquakes occur when the crust is subjected to strain, which causes the crust to break and shift during faulting activity. The largest

Earthquakes arise along the faults that form the border between down going and overriding tectonic plates. They typically form linear networks or systems, with branches leading from a main fault.

You may have realised by now that earthquakes originate many kilometres below the Earth's surface. The **focus** or **hypocenter** is the point on the Earth's surface situated vertically above the rock rupture or rapid shattering of rocks deep under the crust, and the **epicentre** is the point on the Earth's surface positioned vertically above the focus (Fig. 6.6). The focal depth, or distance from the epicentre, is an essential element in estimating the potential damage of an earthquake. The vibrations or seismic waves propagate up to the Earth's surface from this point of rupture or focus. The position of these two places is established by measuring seismic waves received at seismic stations.

You now know that seismic waves are released during an earthquake. Let us understand what these waves are and how we measure it? Seismograms are Seismographs that collect data about the nature and kinds of earthquake vibrations. It describes the many forms of tremors caused by the movement of rock layers. An earthquake produces body waves and surface waves.

Body waves are of two types, **P waves** or primary or compression waves, and **S waves**, or secondary or shear waves. The **P wave** is the quickest type of seismic wave to arrive at a seismic station and the first to be recorded on the Seismograph. P wave has the ability to travel through all three mediums- solid rock, liquids, and gases. P waves, like sound waves, are "push and pull" waves that push and pull the air in each particle vibrating to and fro in the direction of propagation. Compressional or longitudinal waves are another name for them.

The next type is **S wave**, which create vibrations at right angles to the wave's movement. These are termed as transverse or shear waves or secondary waves. It emerges only after the P waves have arrived. S waves can only pass through solid rock and move rock particles up and down or side-to-side perpendicular to the wave's travel direction. This indicates that fluids will not allow S waves to flow through. Because P and S waves pass through the Earth's body, thus they are referred to as body waves.

When body waves reach the Earth's surface, some of its energy is transformed into **surface waves**, which are classified into two categories as **Love waves** and **Rayleigh waves**. The **Love wave** is the fastest surface wave, moving on the ground horizontally from side to side. **Rayleigh waves** are significantly bigger than ordinary waves, and they move on the Earth up and down as well as side to side in the same direction as the wave. These are characterized by vertical motion of the ground surface, like waves on water. Surface waves, also known as L waves, have a lower frequency than body waves, which flow through the crust. Because of the complexities of their travels via crustal layers, they arrive after body waves and can pass through both land and water. Surface waves have greater amplitudes than body waves and so cause more damage and devastation.

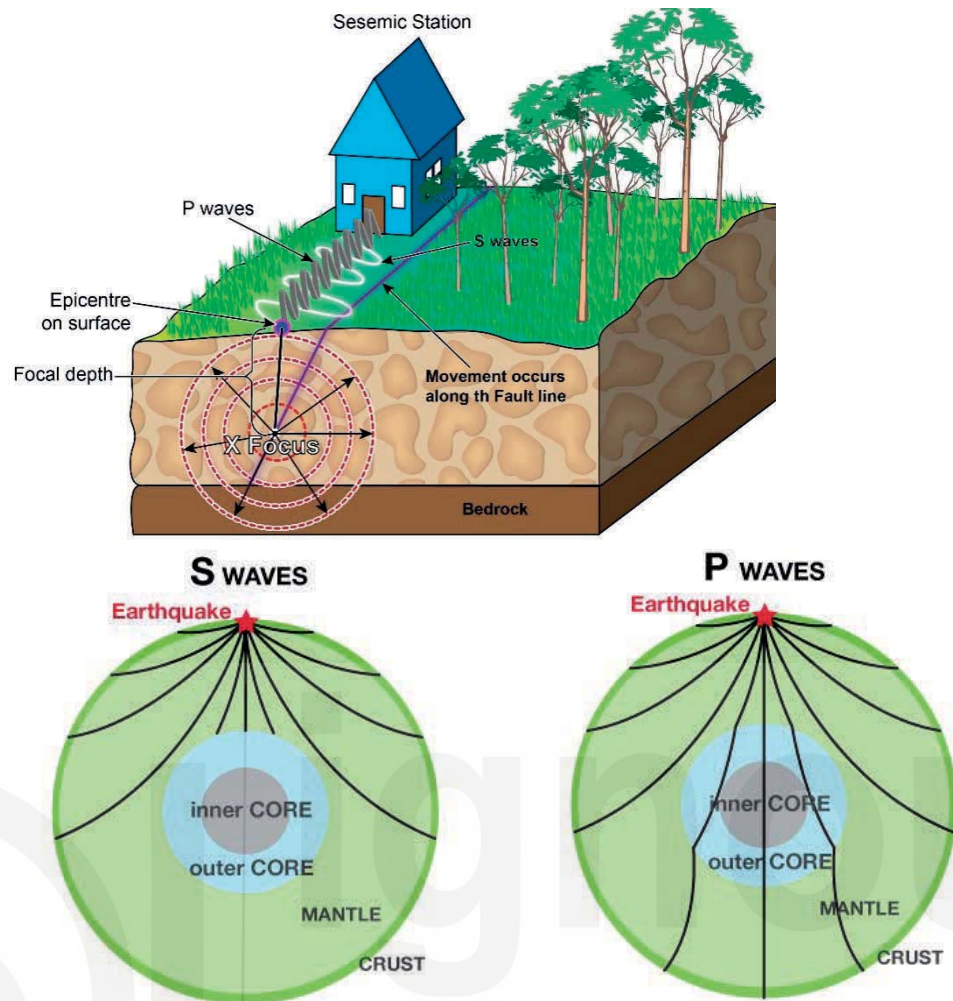


Fig. 6.6: a) Representation of an Earthquake and b) Possible Propagation of Seismic Waves.

(Source: <https://www.usgs.gov/programs/earthquake-hazards/earthquakes>).

6.4.1 Measuring an Earthquake

There are two primary methods for measuring earthquakes such as magnitude and intensity.

(1) Magnitude of an Earthquake

The magnitude of an Earthquake reflects the amount of energy generated by the Earthquake at its source. The scale was devised to record the earthquake energy in 1935 by Charles F. Richter, thus call it as Richter Scale (Table 6.1). This scale is based on the amplitude of seismic waves; the more powerful the Earthquake, the more powerful the seismic vibrations. It is made up of numbers ranging from less than 0 (negative values) to greater than 8.5. The logarithm to the base 10 of the amplitude recorded by a seismograph is used to calculate Richter magnitude, which asserts that a rise in magnitude equates to a factor of ten times increase in ground motion amplitude. A magnitude 6.0 earthquake, for example, generates ten times the shaking of a magnitude 5.0 earthquake. There is no lower or upper limit to the Richter scale. However, the biggest magnitude earthquakes observed so far have reached 8.9 on the Richter scale. Great Earthquakes have magnitudes of 8 or

above. Earthquakes of magnitudes ranging from 8 to 8.9 occur once a year on average throughout the entire world.

Table 6.1: Magnitude of an Earthquake on Richter Scale and its Effects.

Magnitude	Description	Earthquake Effects	Frequency of Occurrence (Estimated)
Less than 2.0	Micro	Micr-earthquakes, not felt, or felt rarely by sensitive people. Recorded by seismographs.	Continual/several million per year
2.0–2.9	Minor	Felt slightly by some people. No damage to buildings.	Over one million per year
3.0–3.9	Minor	Often felt by people, but very rarely causes damage. Shaking of indoor objects can be noticeable.	Over 100,000 per year
4.0–4.9	Light	Noticeable shaking of indoor objects and rattling noises. Felt by most people in the affected area. Slightly felt outside. Generally causes none to minimal damage. Moderate to significant damage very unlikely. Some objects may fall off shelves or be knocked over.	10,000 to 15,000 per year
5.0–5.9	Moderate	Can cause damage of varying severity to poorly constructed buildings. At most, none to slight damage to all other buildings. Felt by everyone.	1,000 to 1,500 per year
6.0–6.9	Strong	Damage to a moderate number of well-built structures in populated areas. Earthquake-resistant structures survive with slight to moderate damage. Poorly designed structures receive moderate to severe damage. Felt in wider areas; up to hundreds of miles/kilometers from the epicenter. Strong to violent shaking in epicentral area.	100 to 150 per year
7.0–7.9	Major	Causes damage to most buildings, some to partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Felt across great distances with major damage mostly limited to 250 km from epicenter.	10 to 20 per year
8.0–8.9	Great	Major damage to buildings, structures likely to be destroyed. Will cause moderate to heavy damage to sturdy or earthquake-resistant buildings. Damaging in large areas. Felt in extremely large regions.	One per year
9.0 and greater	Great	Near or at total destruction - severe damage or collapse to all buildings. Heavy damage and shaking extends to distant locations. Permanent changes in ground topography.	One per 10 to 50 years

(Source: Earthquake facts and statistics, United States Geological Survey.
<http://earthquake.usgs.gov/learn/topics/>)

(2) Earthquake Intensity

Another approach to analyse an earthquake's influence is to look at how individuals felt and how much damage was done. This is referred to as an **earthquake intensity**. Giuseppe Mercalli invented initially the scale in 1902

to study the strength of an earthquake. It was later updated in 1931 by Harry Wood and Frank Newmann. The modified Mercalli Scale (Table 6.2), which is composed of 12 ascending degrees of intensity spanning from Roman numeral I to XII, depicts the range of intensities ranging from unnoticeable shaking to devastating damage.

Table 6.2: The Modified Mercalli Intensity Scale.

Level of Intensity	Description/Damage
I (Not Felt)	Not felt except by a very few under especially favourable conditions.
II (Weak)	Felt only by a few persons at rest, especially on upper floors of buildings.
III (Weak)	Felt quite noticeably indoors, especially on upper floors of buildings but many people do not recognize it as an Earthquake; standing motor cars may rock slightly; vibrations similar to the passing of a truck.
IV (Light)	During the day felt indoors by many, outdoors by few; at night, some awakened; dishes, windows, doors disturbed; walls make cracking sound; sensation like heavy truck striking building; standing motor cars rocks noticeably.
V (Moderate)	Felt by nearly everyone; many awakened; some dishes, windows broken; unstable objects overturned; pendulum clocks may stop.
VI (Strong)	Felt by all, many frightened; some heavy furniture moves; few instances of fallen plaster; slight damage.
VII (Very Strong)	Everybody runs outdoor; damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII (Severe)	Slight damage in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse; great damage in poorly built structures; fall of chimneys, factory stacks, columns, monuments, walls; heavy furniture overturns.
IX (Violent)	Considerable damage in specially designed structures; well-designed frame structures thrown out of plumb; buildings shifted off foundations; ground cracks conspicuously.
X (Extreme)	Some well-built wooden structures gets destroyed; most masonry and frame structures destroys with foundations; damage to transportation network.
XI (Extreme)	Few structures remain standing; bridges destroys, fractures in ground; underground pipe lines disturbed; Earth slumps and land slips; great damage of transportation network.
XII (Extreme)	Total damage; waves seen on ground surfaces; lines of sight and level distorted; objects thrown upward into the air.

(Source: Earthquake facts and statistics, United States Geological Survey.
<http://earthquake.usgs.gov/learn/topics/>)

Earthquake intensity can be defined as it is a qualitative estimate of the actual shaking at a specific area during an earthquake, as established by the recorded impacts of the earthquake on people, furniture, buildings, and geological structures, among other things. Within the disturbed zone, the intensity varies from place to place. If it is a densely inhabited location, it can cause more casualties and massive potential damage, but it can only have a minor impact on isolated places with the same magnitude of earthquake shocks. Strong solid bedrock areas likely to undergo far less shaking than unconsolidated river or lake deposits.

6.4.2 Distribution of Earthquakes and Plate Tectonics

Plate tectonic theory has been accepted as the most possible explanation of causes of the earthquakes. You have already studied about the theory of plate tectonics in Unit 5. Figure 6.7 depicts the global distribution of earthquakes. The connections between earthquakes and plate boundaries are very obvious. As you know, the boundaries between the various plates are classified as spreading or divergent plate boundaries, convergent or destructive plate boundaries, and transform or conservative plate boundaries.

a) Earthquakes along Divergent Plate Boundaries

Earthquakes are widespread along divergent boundaries such as the mid-oceanic ridge and its branches where new lithosphere is created and spreads on either side of ridge. The shallow earthquakes stretch out mostly in the mid-Atlantic ridge, the East Pacific Rise, although they are limited to a narrow zone close to the ridge. Transform faults, such as the San Andreas Fault, are also prone to shallow earthquakes.

b) Earthquakes along Convergent Plate Boundaries

The majority of earthquakes, including shallow, moderate, and deep earthquakes, are located near convergent plate boundaries where oceanic plates are subducting. Strong pressures build up at the two plates' down slanting contact, and they are discharged by rapid fault slippages that result in large earthquakes. The best examples of such great plate boundary earthquakes are experienced in Japan, Alaska, Chile and other narrow zones close to oceanic trenches and volcanic arcs of the Circum-Pacific Zone.

Other example, the Cocos Plate is subducting beneath the North America and Caribbean Plates (ocean-continent convergence), while the North and South America Plates are subducting beneath the Caribbean Plate (ocean-ocean convergence)..? In both circumstances, the earthquakes become deeper as one moves farther from the trench.

c) Earthquakes along Transform Plate Boundaries

Transform boundaries are those where two plates just glide past each other without any collision. This mechanism happens along the transform faults. For example the San Andreas Fault forms the transform boundary between the American plate and the Pacific plate in California. Moderate to strong earthquakes are found to be occurring along this zone. The greatest earthquakes on transform boundaries are of the 8 magnitude. In fact, all of the

extremely big earthquakes (9 or above) occur along subduction barriers because a slightly dipping boundary has the potential for a wider rupture zone than a steep transform boundary.

Earthquakes also occur at scattered locations over the continental plate's far away from active plate boundaries. These are related to the Mediterranean and Trans-Asiatic earthquake belt extends along Alpine mountain system of Europe and North America, through Asia Minor and Himalayan system including Tibet and China.

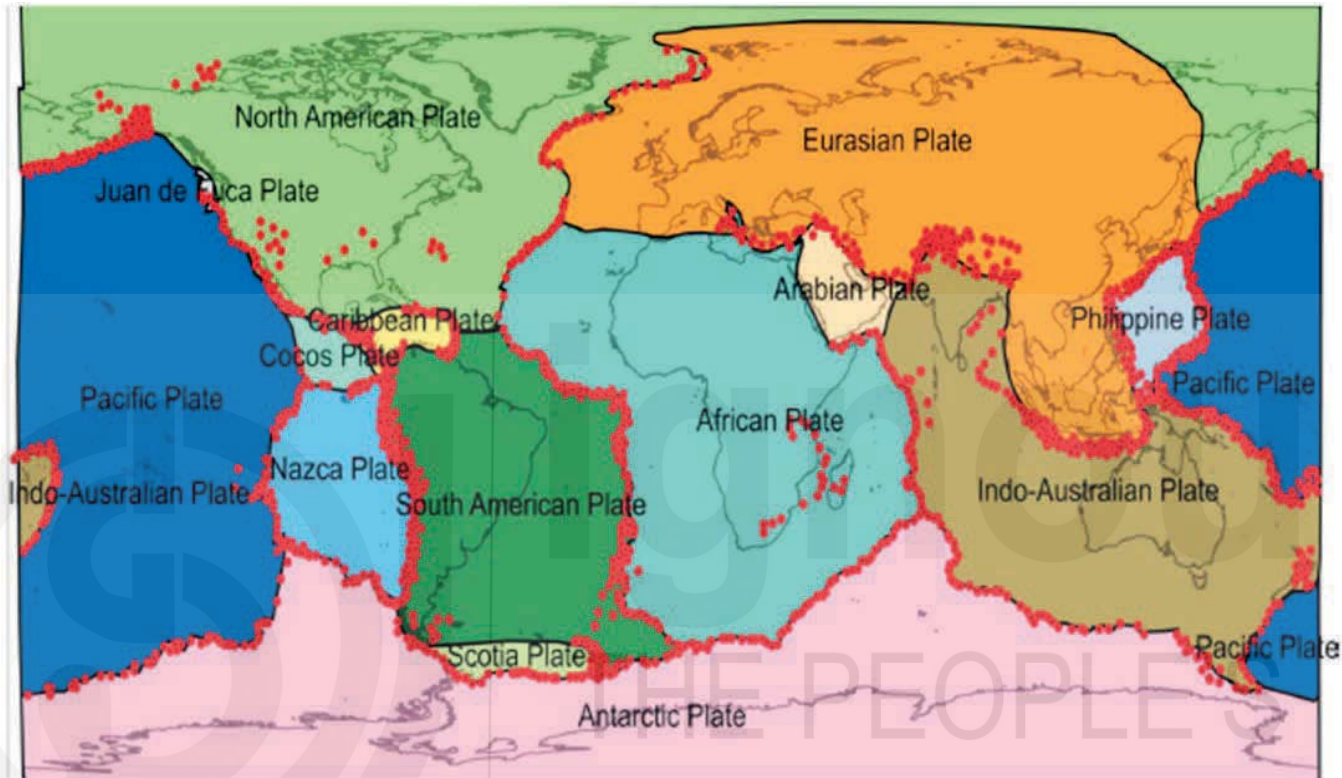


Fig. 6.7: Distribution of Volcanoes and Earthquakes along the Plate Boundaries.

6.4.3 Impact of An Earthquake

Earthquakes are known to cause structural damage to buildings, bridges, pipelines, transportation and communication network lines, landslides, tsunami and so on. The sorts of repercussions are heavily influenced by where the earthquake occurs: whether it is largely populated area, urban or rural, and, of course, the earthquake resistance infrastructure capacity. It is usual to find significantly severe earthquake damages in places underlain by soft sediments than in areas underlain by solid rock. The energy of higher frequency waves is absorbed by solid rock, but lower frequency waves pass through without being absorbed. However, soft sediments gradually absorb and amplify both waves. That is the reason, the significant damage is occurred where buildings construed in soft sediments, and multi-story and high-rise structures are more vulnerable to destruction than smaller structures.

Buildings and other infrastructure may be constructed to survive the majority of earthquakes, and this practice is becoming more common in earthquake-

prone areas. Government officials must enforce the construction code and undertake feasibility studies as builders do all they can to save money, including utilising improper materials in concrete and lowering the quantity of steel reinforcement, among other things (Fig. 6.8). You may find recent world earthquakes information from the following web link i.e. at http://www.earthquakes.bgs.ac.uk/earthquakes/recent_world_events.html; <https://www.worlddata.info/asia/india/earthquakes.php>.

Earthquake Risk in India

India accommodates the highest population in world. The haphazard growth of settlements and unscientific construction activities including multi-storied buildings, factories, shopping malls, etc. make this infrastructure vulnerable to earthquakes with a varying degree of risk. In recent years, the country has experienced several major earthquakes that have resulted in a significant number of deaths.



Fig. 6.8: Damage of Buildings by the Earthquake in Kathmandu Valley.

(Source: "Buildings Buckle" Photo by Binod Tiwari, CSUF Photos, licensed under CC BY-NC-SA 2.0)

Nearly 60% land area is under threat of moderate to severe seismic hazard (shaking of Intensity VII and above) (Fig. 6.9, BMTPC, 2006). The entire Himalayan belt is considered prone to great earthquakes of magnitude exceeding 8.0. The significant such earthquakes recorded were: 1897 Shillong (M8.7), 1905 Kangra (M8.0), 1934 Bihar-Nepal (M8.3), and 1950 Assam-Tibet (M8.6). Scientific publications have warned of the likelihood of the occurrence of very severe earthquakes in the Himalayan region, which could adversely affect the lives of several million people in India. The other prominent earthquakes are 1967 Koyana (M6.7) and 1993 Latur-Killari (M6.6) in Maharashtra, 2001 Bhuj (M7.7) in Gujarat affected human lives and property.

National Center for Seismology (NCS) works under Ministry of Earth Sciences is a Government of India organization that monitors and provides data on earthquakes in the country regularly. NCS maintains National Seismological

Network of more than 150 stations each having state of art equipment and spreading all across the country. Apart from earthquake monitoring, NCS is also actively involved in Seismic Hazard Microzonation and seismological research work. The major activities are including earthquake monitoring, operation and maintenance of national seismological network, maintenance of seismological data center and information services, seismic hazard microzonation related studies, aftershock/earthquake swarm monitoring/survey, understanding of earthquake processes, and public outreach.

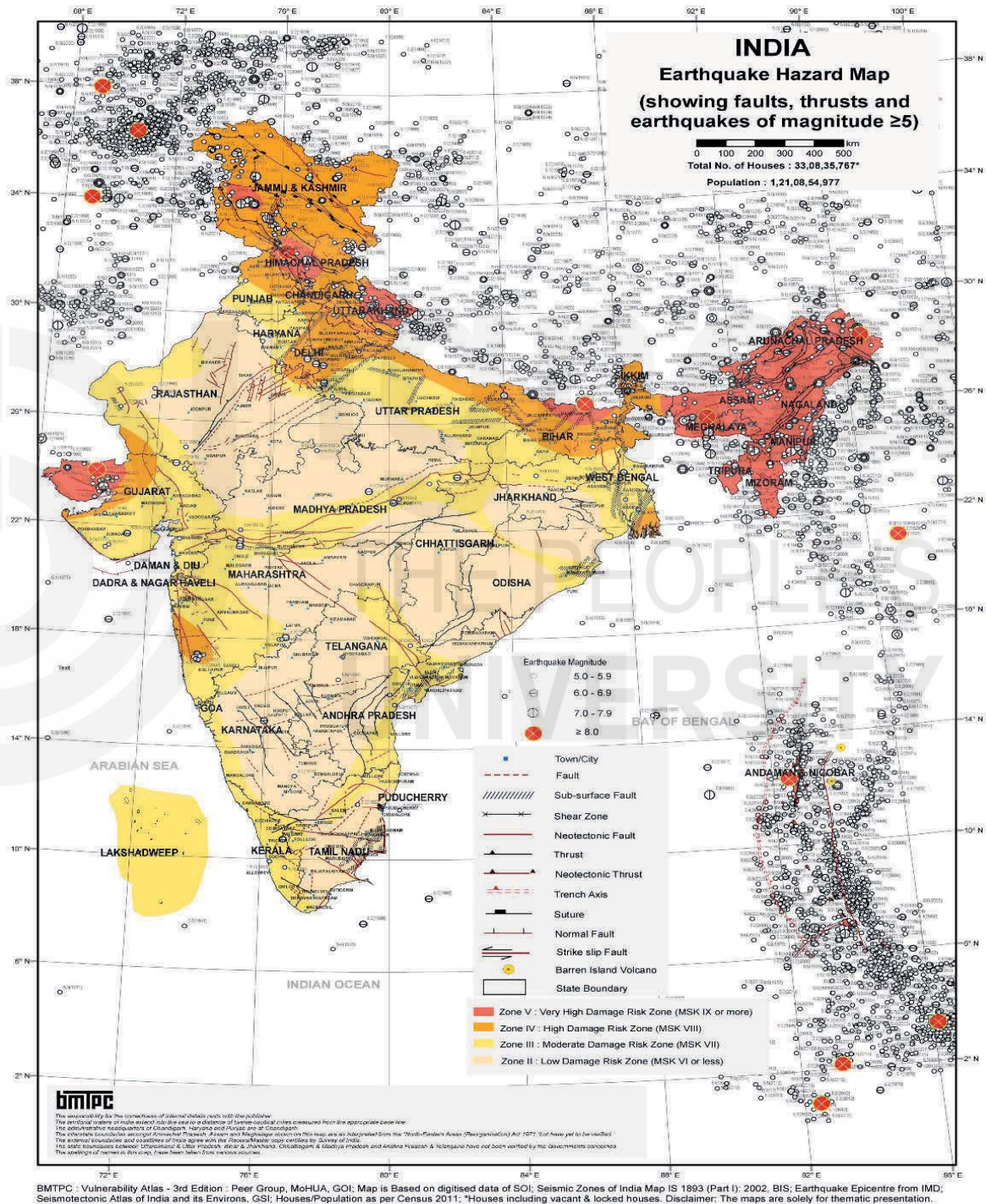


Fig. 6.9: Earthquake Hazard Map of India.

(Source: https://bmtpc.org/DataFiles/CMS/file/VAI2019/MAP/eqmap/EQ_JPG/EQ_INDIA.jpg, accessed on 07.06.2022)

For example, a brief report on earthquake is given below:

- Location - is about 409 km SSE of Kolkata, India and 418 km East of Puri, Odisha (Fig. 6.10).
- Epicentre - In Bay of Bengal at 19.13° N, 89.76° E and focal depth of 36 km at 08:32:57 IST on 05/12/2022.
- Magnitude - M: 5.1.
- Details - Within a 200-kilometer radius of the epicentre of today's earthquakes, there have been six earthquakes of magnitude 4.0 or more in the last ten years (2012-2022). The greatest magnitude of M:5.8 occurred on May 21, 2014, 195 kilometres southwest of today's event.
- Remarks - The earthquake occurred along 90 Degree East Ridge and closer to the subduction zone in which the Indian Oceanic Plate is being subducted beneath the Burma microplate.

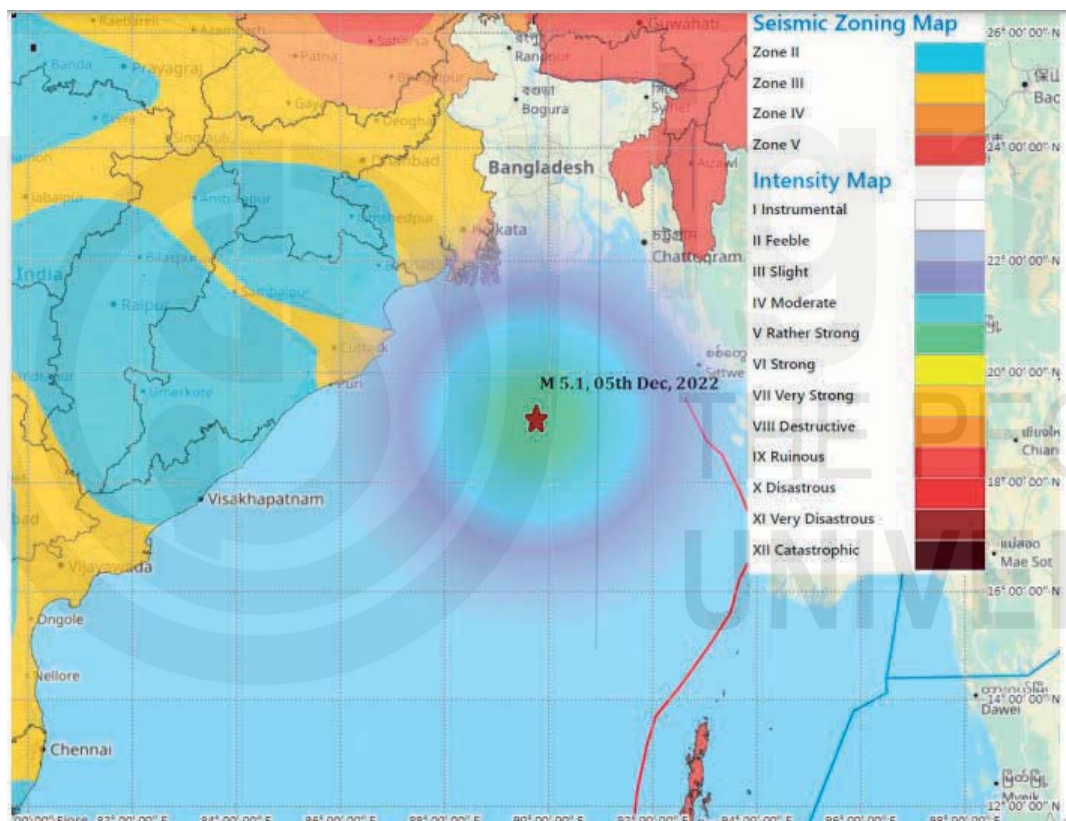


Fig. 6.10: Location of Earthquake Occurred on 05th December 2022.

(Source: <https://seismo.gov.in/>).

SAQ 4

- What is an earthquake?
- Describe the intensity of earthquake?
- Name the organisation, which monitors earthquakes and related impacts in India.

6.5 SUMMARY

In this unit, you have studied so far.

- The endogenetic forces which are responsible for the major relief features of the Earth's surface such as mountains, plateaus, plains, valleys, etc. Sudden movements result into sudden and rapid events such as earthquakes and volcanic eruptions which produce volcanic mountains and lava plateaus.
- Volcanism represents processes and features related to the movement and solidification of magma within the crust and on the surface.
- A volcano has a deep vent through which gases, ash, water, liquid lava and molten rock ejected to the surface of the Earth.
- Volcanoes can be classified in to two categories i.e. based on frequency/periodicity of eruption and based on mode of eruption.
- The volcanoes are three types such as active, dormant, and extinct based on frequency or periodicity of volcanic eruption.
- The volcanoes are classified into two types as central eruption and fissure eruption based on the mode of volcanic eruption.
- Volcanic landforms are extrusive landforms connected with volcanoes and intrusive landforms associated with volcanoes based on the kind of magma extruded on the Earth's surface or intruded into country rock.
- An earthquake is the shaking induced by the rupture or breaking and subsequent movement of rocks beneath the Earth's surface. There are two primary methods for measuring earthquakes such as magnitude and intensity.
- Earthquakes and volcanic activity are mainly associated with plate boundaries. Effects of earthquakes are enormous in terms of loss of life and property.

6.6 TERMINAL QUESTIONS

1. Explain various types of volcanoes?
2. Briefly describe various types of volcanic landforms.
3. Explain earthquake magnitude and intensity with examples.
4. Write a note on the impact of earthquakes.

6.7 ANSWERS

Self-Assessment Questions (SAQ)

1. a) Volcanism refers to a wide range of processes and phenomena, such as volcanoes, geysers, and fumaroles, which include the surface discharge of molten rock, pyroclastic pieces, or hot water and steam.

- b) A volcano is an opening or hole in the Earth's crust that allows lava, volcanic ash, and gases to escape.
 - c) Magma, magma chamber, lava, vent, crater, conduits, etc.
2. a) A volcano that is no longer active and has no prospect of reactivation.
- b) Hawaiian type of volcanoes has less explosive activity and erupts quietly due to less viscosity of lava and non-violent nature of gases.
3. a) Polygenetic volcanic landforms are volcanoes that have been formed over tens of thousands of years.
- b) Fumaroles or Solfataras are vents near the surface that produce volcanic gases.
4. a) An earthquake is a passage of vibrations through Earth's crust caused by sudden forces from beneath the ground.
- b) How the individuals felt and damage occurred due to earthquake refers to its intensity.
- c) National Centre for Seismology, Government of India.

Terminal Questions

1. Refer to Sub-Section 6.2.2.
2. Refer to Section 6.3.
3. Refer to Sub-Section 6.4.1.
4. Refer to Section 6.4.3.

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GLOSSARY

Anticline	: Anticlines are formed by upfolded rock strata that have an arch like shape.
Conard Discontinuity	: The boundary between the upper crust and the lower crust is called the Conard Discontinuity.
Continental Crust	: It is relatively low in density and is made up of different types of igneous, metamorphic and sedimentary rocks.
Continental Drift Theory	: Wegener proposed the idea of continental drift theory and he gave the name Pangaea to the whole landmass and Panthalassa to all the surrounded water-mass. The super-continent of Pangaea started separating during the carboniferous period and the present shape and position of the continent is the result of the fragmentation.
Core	: The Earth's interior layer. The core is mostly composed of nickel and iron which is in a fluid condition.
Crust	: The upper and the thinnest layer of the interior of the Earth is the crust. It is composed of different kinds of silica-rich rocks of different ages.
Endogenetic Forces	: These are forces that originate inside the Earth's crust. It leads to vertical and horizontal Earth movements which can give rise to various structural features on Earth's surface and result in subsidence, land upliftment, volcanism, earthquakes, faulting, folding, etc.
Faulting	: The upward or downward displacement of rock along a crack from its starting position is called faulting.
Folding	: Tangential compressive force from horizontal movement brought on by the endogenetic force originating deep below the Earth causes wave-like bends to form in the crustal rocks. These kinds of bends, where some parts are bent up and some down, are known as folds.
Gutenberg Discontinuity	: The depth represents the boundary between the core and mantle known as Gutenberg Discontinuity.
Isostasy	: The word is derived from the Greek word Isostasio meaning- a state of balance. American geologist Dutton was the first to use the term isostasy.
Landform	: It is a natural or human made feature on the surface of the Earth, for example, structural mountains, valleys, and pediplains.
Lehmann Discontinuity	: The boundary between the outer core and inner core is called Lehmann Discontinuity.
Mantle	: The mantle layer of the Earth's interior is above the core and just below the crust. The mantle is made of mostly dense iron and magnesium silicates and it is hot.
Mohorovicic or	: The contract zone between the upper mantle and the crust

Moho Discontinuity	is Mohorovicic or Moho Discontinuity.
NiFe	: The very last layer of the Earth's internal structure is the central core, also called Nife i.e. Nickel (Ni) and Ferrum/Iron (Fe).
Oceanic Crust	: It is high in density and is composed of magma that erupts underneath the ocean and cools down to form the oceanic crust.
Orogenic Movements	: These work horizontally to the surface of the Earth like tangent to the surface of the Earth, hence they are also called tangential forces.
Plate Tectonics Theory	: It explains that the Earth's lithosphere is broken into distinct plates which are floating horizontally on the asthenosphere. The lithospheric or the tectonic plates vary in size from minor plates to major plates, continental plates to oceanic plates and combination of both continental and oceanic plates. The movement of these plates causes the formation of various landforms of the Earth.
Repetti Discontinuity	: The boundary between the upper mantle and lower mantle is called Repetti Discontinuity. The rocks in the upper mantle are cool and brittle while the rocks in the lower mantle are hot and soft and flow instead of breaking.
SiAl	: The top layer, immediately under the continents, is composed of a rock layer consisting Silica (Si) and Aluminum (Al) elements.
SiMa	: The intermediate layer has a predominance of high density igneous rocks such as basalt and gabbro. Silicon (Si) and Magnesium (Ma) are principal elements in this layer rocks.
Syncline	: Synclines are formed by down folded structures that have a trough-like shape.
Terrain	: An assemblage of landforms are together called as terrain.
Topography	: The arrangement of landforms in a landscape is referred to as topography.
Volcanism	: It describes the process by which gases and molten rock are either extruded or intruded into the Earth's crust.
Volcano	: It has a deep vent, or opening, usually circular or nearly circular in shape, through which heated materials consisting of gases, ash, water, liquid lava and molten rock are ejected from the Earth's interior to the surface of the Earth.