UNIT-II: LITHOSPHERE AND LITHOSPHERIC DYNAMISM

3. Earth Composition and Internal Structure

3.1 Earth as A Monolith

In early times, for want of first-hand information about earth's interior, Earth was believed to be a **'Monolith'** – **A single massive solid rock or stone**. However, advances in Modern Science and better empirical studies clearly proved this **idea to be wrong.** In fact, Earth has a **layered internal structure**, with differing physico-chemical properties.

Earth has a layered structure. From the farthest edge of the atmosphere to the centre of the Earth, existing matter is **heterogeneous.** Atmospheric matter is the least dense. From the Earth's surface to the deeper interior, there are many **different zones**, each containing substances with different properties.

3.1.1 Evolution of Lithosphere

The earth was mostly in a volatile state during its **primordial stage**. Due to gradual increase in density the temperature inside has increased. As a result the material inside started **getting separated** depending on their densities. This allowed **heavier materials** (like iron) to **sink** towards the **centre of the earth** and the **lighter ones** to move towards the **surface**. With the passage of time, it cooled further and solidified and condensed into a smaller size. This later led to the development of the outer surface in the form of a crust. During the formation of the moon, due to the giant impact, the earth was further heated up. It is through the process of differentiation that the earth forming material got separated into different layers. Starting from the surface to the central parts, we have layers like the crust, mantle, outer core and inner core. From the crust to the core, the density of the material **increased.**

3.2 Source of Earth's Internal Structure

Understanding the basic structure of earth is very important to learn higher concepts well. Also, the origin of many phenomena like earthquakes, volcanoes, tsunami etc are linked with the structure of earth's interior.

Interior of the earth

It is not possible to know about the earth's interior by direct observations because of the huge size and the changing nature of its interior composition. It is an almost impossible distance for the humans to reach till the centre of the earth (The earth's radius is **6,371 km**). Two source of information about the strucrure of Earth:

1. Direct Sources: Through mining and drilling operations we have been able to observe the earth's interior directly only up to a depth of few kilometers. Direct source are as follows:

- Rocks from mining area
- Volcanic eruptions
- Deep Ocean Drilling Projects

2. Indirect Sources: The rapid increase in temperature below the earth's surface is mainly responsible for setting a limit to direct observations inside the earth.

- The rate of change of **temperature** and **pressure** from the surface towards the interior.
- Meteors
- Gravitation
- Magnetic sources
- Seismic Waves

3.2.1 The Crust

The Crust is the outermost, **rigid**, **brittle** and **rocky** layer upon which we live. It has two components, the Continental crust as well as the Oceanic crust. Crust is the least dense of the three layers, with relative density ranging from **2.7 to 3.0.**

Continental Crust is made up of lighter elements like **Silica and Aluminium (SiAL).** The Continental crust is less dense (2.7g/cm3) and predominantly made up of granitic rocks while the relatively denser **Oceanic crust** (3.0g/cm^3) is largely made up of basaltic rocks that contains minerals and substances like **silicon, magnesium (SiMa)** and **oxygen.**

The thickness of Crust varies from 7-9 km under the ocean to 25-70 km under the continents. As on digs into the crust, the temperature begins to **increase**, but it is not high enough to melt the rocks. So the crust remains a rigid, rocky solid.

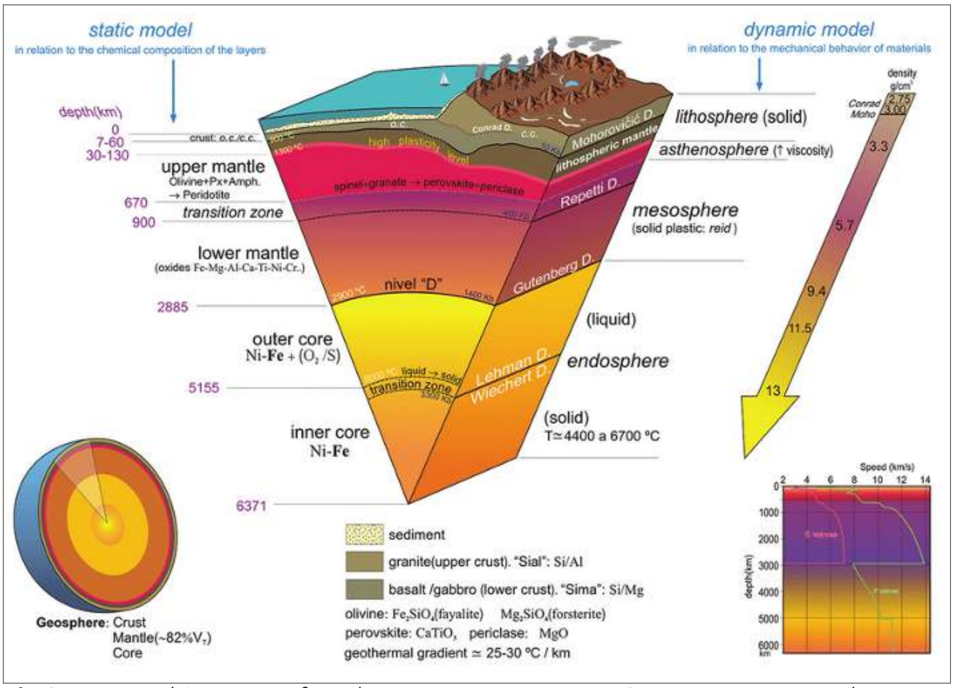


Fig.3.1: *Internal Structure of Earth* ***Source:*** *www.researchgate.net*

The crust ends at the **Mohorovicic discontinuity**, where the less dense Crustal Rocks begin to give way to more dense Mantle Rocks. However, the outer layer of Mantle, in contact with the crust, is in the same rigid, rocky physical state as the Crust. In fact, the solid crust along with the outer solid rocky part of the Mantle (generally upto the depth of 100km from the surface) is referred to as the Lithosphere.

Lithosphere

The outermost layer of Earth is called the **Lithosphere**. Since, Geography is the study of the outer layer of Earth, so the study of Lithosphere and its mineral composition acquires prime importance to a geographer.

3.2.2 The Mantle

Mantle refers to the most **voluminous inner layer** of Earth. The portion of the earth below crust and up to a depth of 2900 km is also known as **Mesosphere/Mantle**. 84% of the Earth's volume is contained in the Mantle.

As the temperature rises with depth, the upper mantle becomes so hot that it resembles hot plastic. This soft plastic layer in the upper mantle is called the **asthenosphere.** The hot plastic character of the asthenosphere and the convective heat cells facilitate the movement of lithospheric plates overlying this layer.

It is the main source of molten material (**magma**) that comes out of volcanic eruptions. Most common rock of the Mantle is **peridotite**, ultra-basic rock consisting of olivine which is a silicate of Magnesium or Iron.

Upper Mantle	Transition Zone	Mantle
● The **upper mantle** extends from the crust to a depth of about 410 kilometers. The **upper mantle** is mostly solid, but its more malleable regions contribute to tectonic activity. ● Two parts of the **upper mantle** are often recognized as distinct regions in **Earth's interior:** the **lithosphere** and the **asthenosphere**.	● From about 410 kilometers to 660 kilometers beneath Earth's surface, rocks undergo radical transformations. This is the mantle's transition zone. ● In the transition zone, rocks do not melt or disintegrate. Instead, their **crystalline structure** changes in important ways. Rocks become much, much more dense. ● The transition zone prevents large exchanges of material between the upper and lower mantle.	● The lower mantle extends from about 660 kilometers to about 2,700 kilometers beneath Earth's surface. The lower mantle is **hotter** and **denser** than the upper mantle and transition zone. ● The lower mantle is much less **ductile** than the upper mantle and transition zone. Although heat usually corresponds to softening rocks, intense pressure keeps the lower **mantle solid**.

The Mohorovicic discontinuity separates the Mantle from the Crust **(see Fig 3.1)** while the Mantle and the Core are separated by the **Guttenberg discontinuity**.

3.2.3 The Core

The Inner solid core also known as **Barysphere** having temperature up to **6000°c** goes up to a depth of **6371** km at the centre of the Earth.

Above the **Solid inner** core, there lies a **liquid outer** core which is predominently filled with molten **Iron** and **Nickel**. Despite having high temperature, Inner core is solid because pressure at such great depth is also high, which increases the melting point of the materials.

Inner core is having **relative density** around **13g/cm³** while outer core has a density of 10 g/cm³. Discontinuity between Mantle and Core is called **Guttenberg's Discontinuity (See Fig. 3.1)**.

Outer core

The outer core, which surrounds the inner core, is located between **2900 and 5100 km** below the planet's surface. Iron with nickel and traces of light metals make up the outer core. Although the outer core is similar in composition to the inner core, it is **liquid** because it is not under sufficient pressure to solidify. According to the **dynamo theory**, the Earth's magnetic field is generated by convection in the outer core, coupled with the **Coriolis effect**.

Recently, In Turkiye's (old name Turkey) Gaziantep province, the epicenter of the 7.8 magnitude earthquake struck

Inner core

The inner core extends from the center of the Earth to a depth of **5,100 km** below the surface. This layer is rigid because it can transmit shear waves (shear seismic waves). (**S-waves** are generated when **P-waves** collide with the outer boundary of the core and the inner boundary of the core.) **The rotation of the Earth's inner core** is slightly faster than that of the surface. The solid inner core is too hot to maintain a constant **magnetic field**. The core (inner and outer core) makes up only about **16%** of Earth's volume, but **33%** of its mass.

3.3 Earthquake

An earthquake is the shaking of the surface of the Earth, resulting from the sudden release of energy in the **Earth's lithosphere** that creates seismic waves. Earthquake is the form of energy of wave motion **transmitted** through the surface layer of the earth. It may be due to faulting, folding, plate movement, volcanic eruptions and anthropogenic factors like dams and reservoirs.

Earthquake are by far the most unpredictable and highly destructive of all the natural disasters. Minor earth tremors caused by gentle waves of vibration within the earth's crust occur every few minutes while Major earthquakes usually caused by movement along faults, can be very disastrous particularly in densely populated areas.

Focus and Epicenter	Richter scale	Mercalli scale
● The point within earth where faulting begins is the **focus**, or **hypocenter**. ● The point directly above the focus on the surface is the **epicenter**.	● Richter magnitude scale is the scale to measure the **magnitude of energy** released by an earthquake. ● This scale was devised by **Charles. F. Richter** in the year 1935. ● The number indicating magnitude ranges between **0 to 9.**	● The Mercalli intensity scale is a seismic scale used for measuring the **intensity** of an earthquake. ● It measures the effects of an earthquake. ● The number indicating intensity ranges between **1 to 12**.

3.3.1 Seismic waves

Seismic waves are caused by the **sudden movement** of materials within the Earth, such as slip along a fault during an earthquake. Volcanic eruptions, explosions, landslides, avalanches, and even rushing rivers can also cause seismic waves.

Main types of seismic waves

I. Body Waves

Faster, Higher Frequency

Traveling through the interior of the Earth, body waves arrive before the surface waves **emitted** by an earthquake. These waves are **higher frequency** than surface waves.

i. Primary waves (P-waves)

The first kind of body wave is the P wave or primary wave. It's the **fastest** kind of seismic wave, and the first to arrive at a seismic station. P waves can move **through solid rock and fluids**, like water or the liquid layers of the Earth. It squishes and stretches the rock it moves through just like sound waves compress and expand the air as they move through it.

ii. Secondary waves (S-waves)

The second type of body wave is the S wave or secondary wave, and are easy to remember because they're the second wave to arrive **after an earthquake.** An S wave is about 1.7 times **slower than P waves.** The biggest difference is that S waves can not move through **liquids**. Because S waves only move through **solids**, seismologists were led to conclude that the Earth's outer core is a liquid. S waves move rock particles up and down, or side-to-side, and are always perpendicular to the direction that the wave is traveling in (the direction of wave propagation).

II. Surface waves

Slower, Lower Frequency

Surface waves travel more slowly through Earth material at the planet's surface and are predominantly **lower frequency** than body waves. They are easily distinguished on a seismogram. **Shallow earthquakes** produce stronger surface waves; the strength of the surface waves are reduced in deeper earthquakes.

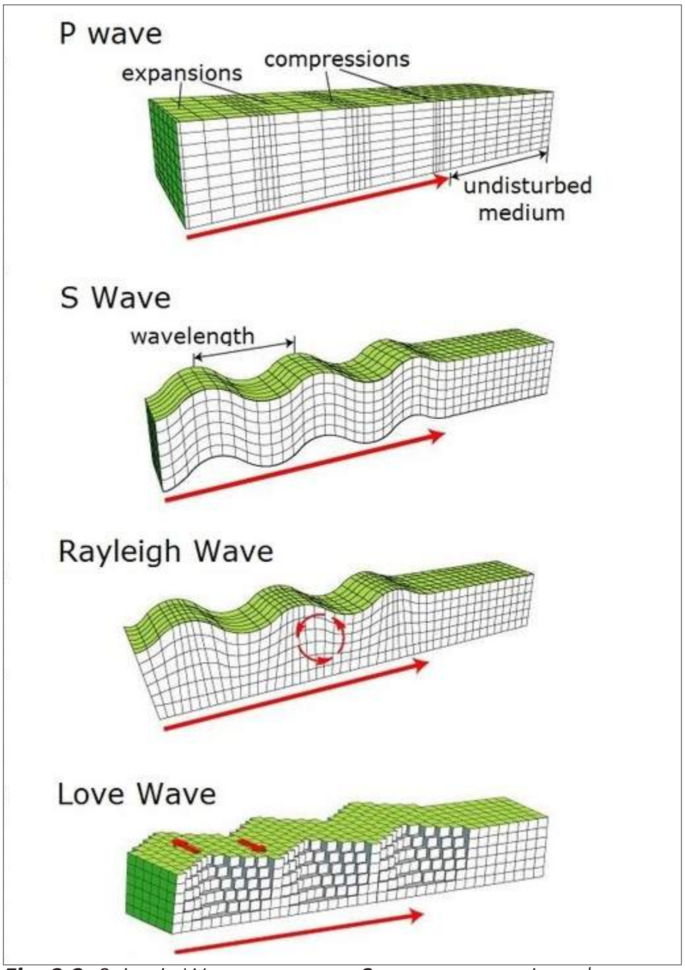


Fig. 3.2: *Seismic Waves* ***Source:*** *www.sciencelearn.org*

i. Love waves (L-waves)

One kind of surface wave is called a Love wave, named after British **mathematician A. E. H. Love,** who worked out the mathematical model for this wave type in **1911.** Love waves produce entirely **horizontal motion**. The amplitude is largest at the surface and diminishes with greater depth.

ii. Rayleigh waves

A Rayleigh wave rolls along the ground with a more complex motion than Love waves. Although Rayleigh waves **appear to roll like waves on an ocean,** the particle motion is opposite of ocean waves. Because it rolls, it moves the ground up and down, and forward and backward in the direction that the wave is moving. Most of the **shaking felt** from an earthquake is due to the Rayleigh wave, which can be much larger than the other waves. Like Love waves, the amplitude of the wave decreases dramatically with depth.

3.3.2 Shadow Zones

Seismic waves are recorded by **seismographs** in remote locations. Differences in wave arrival times, different wave paths than expected (due to refraction), and the absence of seismic waves in certain regions, called **shadow zone**, allow **mapping** of the Earth's interior. Changes in velocity with depth indicate changes in composition and density. That is, we can infer the density and composition of the Earth's interior by observing changes in its velocity (changes in density greatly change the speed of the waves). The **non-uniformity** of a wave with depth indicates a phase shift. That is, the changes in the direction of the waves, the emergence of shadow zones, different layers can be identified by observe.

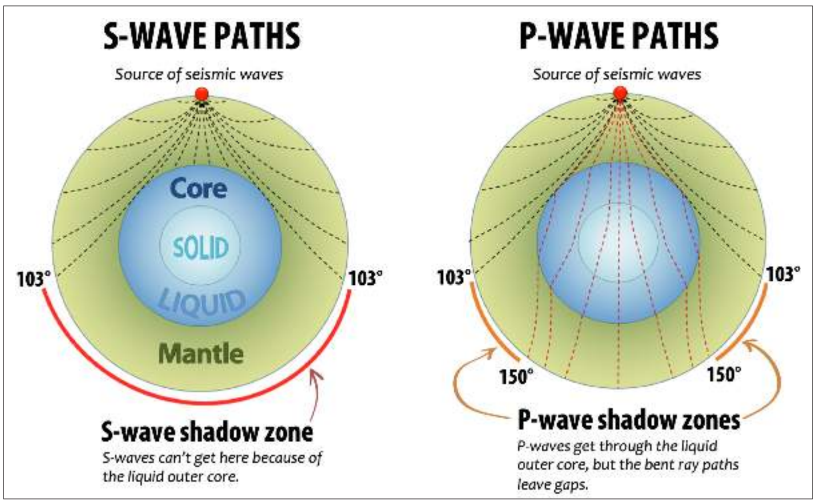


Fig. 3.3: *Shadow Zones* ***Source:*** *www.en.wikipedia.org*

3.4 Volcano and Its Types

A volcano is a place where gases, ashes and/or molten rock material – lava – escape to the ground. A volcano is called an **active volcano** such as **Andaman Islands** (***Barren Island) volcano in*** Andaman Sea, if the materials mentioned are being emitted or have been discharged in the recent past. Mantle is the layer below the solid crust. It has higher density than that of the Earth's crust. The mantle contains a **weaker zone** called **asthenosphere.** It is from this that the molten rock materials find their way to the Earth's surface. The material in the upper mantle portion is called **magma**. Once it starts moving towards the crust or it reaches the surface, it is referred to as **lava**. The material that reaches the ground includes lava flows, pyroclastic debris, volcanic bombs, ashes and dust and gases such as nitrogen compounds, sulphur compounds and minor amounts of chlorene, hydrogen and argon.

Volcanoes are classified on the basis of nature of eruption and the form developed at the surface. Major types of volcanoes are as follows

3.4.1 Shield Volcanoes

The shield volcanoes are the **largest** of all the volcanoes on the earth. These volcanoes are mostly made up of **basalt**, a type of lava that is **very fluid** when erupted. For this reason, these volcanoes are not steep. They become explosive if somehow water gets into the vent; otherwise, they are characterised by low-explosivity. The upcoming lava moves in the form of a fountain and throws out the cone at the top of the vent and develops into **cinder cone**. For example, Hawaiian Volcanoes.

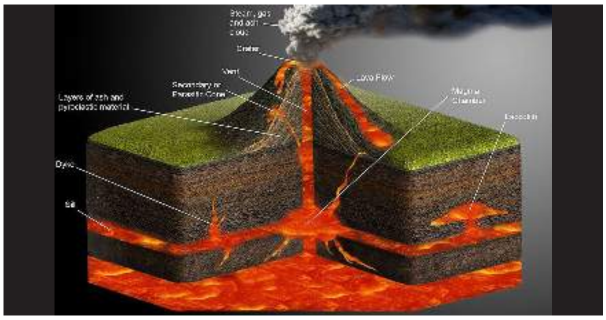


Fig.3.4: *Shield Volcano* **Source:** *www.pinterest.com*

3.4.2 Composite Volcanoes

These volcanoes are characterised by eruptions of **cooler and more viscous lavas than basalt.** These volcanoes often result in explosive eruptions. Along with lava, large quantities of **pyroclastic material and ashes** find their way to the ground. This material accumulates in the vicinity of the vent openings leading to formation of layers, and this makes the mounts appear as composite volcanoes. Famous **examples** of composite volcanoes include Mount Fuji in Japan, Mount Rainier and Mount St. Helens in Washington State, and Mayon Volcano in the Philippines.

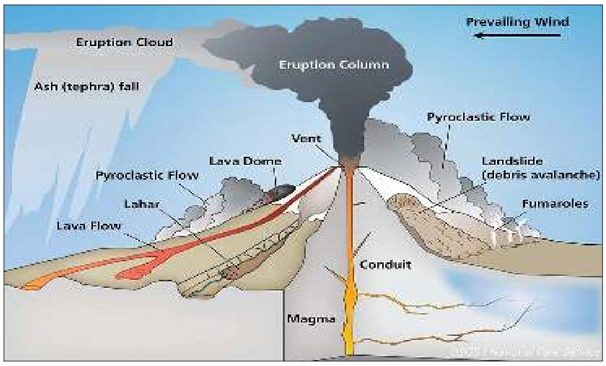


Fig.3.5: *Composite Volcano* **Source:** *www.nps.gov*

3.4.3 Caldera

These are the **most explosive** of the earth's volcanoes. They are usually so explosive that when they erupt, they tend to **collapse on themselves** rather than building any tall structure. The collapsed depressions are called **calderas**. Their explosiveness indicates that the magma chamber supplying the lava is not only huge but is also in **close vicinity**.

Example:- **Crater Lake** in oregon, USA.

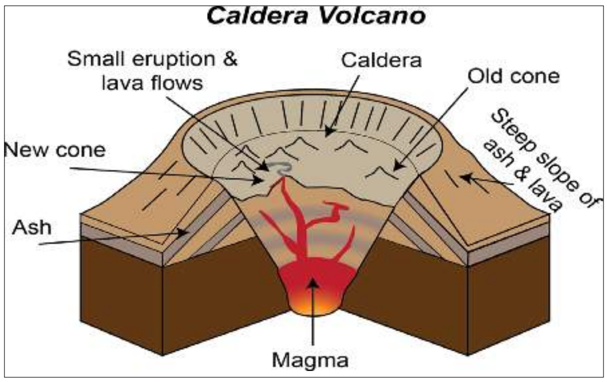


Fig.3.6: *Caldera Volcano* **Source:** *ds.iris.edu*

3.4.4 Mid-Ocean Ridge Volcanoes

These volcanoes occur in the oceanic areas. There is a system of mid-ocean ridges more than **70,000** km long that stretches through all the ocean basins. The central portion of this ridge experiences frequent eruptions.

3.5 Earth's Minerals: Origin, Classification and Rock Cycle

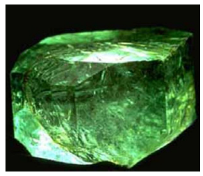
Earth was formed out of the **Solar Nebula**. It is a part of the **four Terrestrial Planets**, and is thus composed of the heavier and denser minerals of the solar system. As the Earth cooled, the Earth minerals arranged themselves in density layers, through the process of **Density Differentiation.** A better understanding of Earth's minerals can be obtained by studying the diferent layers and their characteristic minerals.

3.5.1 Minerals and Rocks

Minerals are the **"building blocks"** of rocks, and hence, of Earth. A mineral is a natural compound with a fixed chemical name and formula. There are around 5,000 known minerals and most of them contain silicon and oxygen atoms. But **only 10 minerals** are common and they are known as **ROCK BUILDING MINERALS.** Most common are **Feldspar** and **Quartz – SiO_2** (Most of Earth's crust is made up of these 2 minerals). Minerals usually exist in rocks as crystals.

Crustal Composition

- Only about 50 minerals are abundant. 98.5% of the crust is comprised of just 8 elements.

Properties of some of the most important minerals					
					
Feldspar	**Quartz**	**Pyroxene**	**Hornblende**	**Mica**	**Olivine**
I. Silicon and oxygen are the main elements of all types of feldspar. **II.** Sodium, potassium, calcium, aluminum, etc. exist in specific varieties of feldspar. **III.** Half of the Earth's crust is composed of feldspars (plagioclase (39%) and alkali feldspar (12%). **IV.** It is light cream to salmon pink in color. **V.** Feldspar is commonly used in the manufacture of ceramics and glass.	**I.** Quartz is one of the most important components of sand and granite. **II.** It is composed of silicon dioxide, a hard mineral practically insoluble in water. **III.** It is usually white or colourless. **IV.** It is used to make radios, radars, etc.	**I.** The common elements of pyroxene are calcium, aluminum, magnesium, iron and silicon. **II.** Approximately 10% of the earth's crust is made up of pyroxene. **III.** Pyroxene is commonly found in meteorites. **IV.** It is usually green or black in color.	**I.** Aluminium, calcium, silicon, iron and magnesium are the main elements of hornblende. **II.** They constitute 7% of the earth's crust. **III.** It is green or black in color and is often used in the gray cutting industry. **IV.** Hornblende is used for building construction.	**I.** It is composed of potassium, aluminum, magnesium, iron, silicon and other elements. **II.** It represents 4% of the earth's crust. **III.** Mica is usually found in igneous and metamorphic rocks. **IV.** Mica is commonly used in electronic instruments.	**I.** Magnesium, iron and silica are the main elements of olivine. **II.** Commonly found in green basalts. **III.** Peridot is often used in jewelry. **IV.** The transparent green variety is known as Peridot. It was used as a gem in ancient times in the east.

- **Oxygen** is (by far!) the most abundant element in the crust. –This reflects the importance of **silicate** (SiO_2-based) minerals. –As a large atom, oxygen occupies ~93% of crustal volume.

3.6 ROCKS

Rocks are Earth materials made from minerals. Minerals combine to form Rocks, so, rocks are nothing but **"Aggregate of Minerals".** Most rocks have more than one kind of mineral. Rock may be hard or soft and in varied colour is hard, soapstone is soft, Gabbro is black and quartzite can be milky white, Rocks do not have definite composition of minerals consequents.

Example: Granite (an aggregate of Feldspar; Quartz and Hornblende)

There are **three-types** of Rocks: Igneous, Sedimentary and Metamorphic

3.6.1 Igneous Rocks

Earth is mostly igneous rock. These type of rocks are made by solidification of **Magma** or **Lava**. (Magma – Subsurface melt. Lava – Melt at the surface).

Some Example: Gabbro, Diorite, Granite, Basalt, Andesite and Rhyolite.

Igneous rocks can be classified in several ways.

- **Extrusive:** (Volcanic) rocks are formed when magma is **ejected** to the earth's surface by flowing lava, and usually cools quickly to form small crystals and have invisible or very small grains.
- **Intrusive:** Rocks form when magma **solidifies** in the earth's crust below the surface. It usually cools slowly to form large crystals.
- **Plutonic:** Cool the most slowly of the three rocks. Plutonic igneous rocks are formed due to cooling of magmas very deep inside the earth. Since the rate of cooling of magmas is exceedingly slow because of high temperature prevailing there and hence there is sufficient time for the full development of large grains. Thus, the plutonic igneous rocks are very coarse-grained (Pegmatites) rocks. Granite is best representative example of this category

3.6.2 Sedimentary Rocks

Sediments are the building blocks of sedimentary rocks. Sediments are diverse, as are the rocks made from them.

These rocks are formed as a result of the successive **deposition** of sediments. These sediments can be fragments of pre existing rocks, which may be igneous, metamorphic, or older sedimentary rocks. The process by which sedimentary rocks are deposited continuously is called **Lithification**. It is also called **stratified** rock because it has a layered or layered structure by successive sediments.

Sedimentary Rocks are classified as

- **Clastic rocks:** Clastic rocks are formed from the accumulation of clastic rocks. Small fragments of rock are deposited by **mechanical weathering** and then lithified by compaction and cementation. Examples of clastic sedimentary rocks include sandstone, shale, siltstone, and breccia.
- **Chemical Sedimentary Rock:** Chemical Sedimentary Rock is formed when a water component evaporates leaving behind **dissolved minerals**. Sedimentary rocks of this kind are very common in arid lands, such as salt and gypsum deposits. Examples include rock salt, dolomite, chert, iron ore, flint, and some limestone.
- **Organic-sedimentary rock:** Organic-sedimentary rock is formed by depositing **animal** or **plant** remains (shells, bones, etc.). These animal and plant remain contain calcium minerals that accumulate on the seabed over time to form organic sedimentary rocks. Examples include rocks such as coal, some limestone, and some dolomite.

3.6.3 Metamorphic Rocks

Metamorphic – Changed from an original "parent." (Meta = Change; Morph = Form or shape.) Metamorphic change is slow and in the solid state.

Metamorphic rocks are formed by the conversion of pre existing rocks in a process known as metamorphism (meaning "change of shape"). The original rock or **"protolith"** is subjected to heat and pressure, which causes physical, chemical, and mineral changes to the rock. Protolith can be igneous, sedimentary, or may be pre-existing metamorphic rocks.

Metamorphic rocks form **within** the earth's crust. Changes in temperature and pressure conditions can lead to changes in the mineral complex of gemstones.

Metamorphic rocks eventually surface as a result of uplift and erosion of the overlying rocks.

- ✔ **Some examples** of metamorphic rocks are **gneiss, state, marble, schist** and **quartzite.**
- ✔ **Slate** and **quartzite** tiles are used in building construction.

3.6.4 Rock cycle

The rocky components of the earth's crust change slowly but continuously from one form to another, and the processes involved are summarized in the rock cycle (Figure 3.7).

The cycle of rock is driven by **two forces.**

(1) **Earth's internal heat engine,** which moves material around in the core and the mantle and leads to slow but important changes within the crust.

(2) The **Hydrological cycle** of water, ice, and surface air driven by the sun.

Earth's rocky cycles are still active because the Earth's core is hot enough to move the mantle, the atmosphere is relatively thick, and there is liquid water.

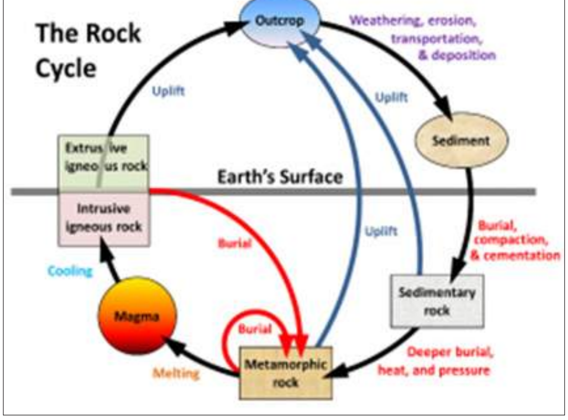


Fig.3.7: *Rock cycle* **Source:** *www.earthsci.org*

On some other planets or moons, such as the Moon, the rocky cycle is effectively dead because the core is no longer hot enough to cause mantle convection and there is no atmosphere or liquid water.

3.7 EARTH'S LITHOSPHERE : NATURE & COMPOSITION

Lithosphere: Geography deals with the study of Earth's surface and Lithosphere precisely forms that layer. A Geographer is more interested in the Lithosphere and its dynamism.

It is the rocky, solid, rigid and brittle outer layer of earth. It is however different from the Crust. In fact it includes the solid rocky part of both the crust as well as the outermost mantle. Lithosphere rests upon a relatively ductile and deformable layer of mantle called the **Asthenosphere**.

3.7.2 Lithosphere: The Plate tectonic theory based Composition

Earth's lithosphere is like an **eggshell** which has been cracked in a number of places. This outer rigid lithosphere consists of a mosaic of stable, rigid segments called **PLATES**. These plates may be large or small; oceanic or continental or partly oceanic and partly continental and their thickness varies from 80-100 kms in the oceans to over 100 kms (and in some regions may approach 400 kms.) in the continents.

For a particular lithospheric plate to be identified and named, its boundaries should all be active. In other words, there must be good evidence of present of recent relative motion between the plate and all its contiguous (adjoining) plates. Today, a fairly good consensus exists in the geologic community as to the number and name of the major plate, the nature of their boundaries, and their relative motions. Differences of interpretation persist in many boundary details. Also a few sections of certain Plate boundaries are of uncertain classification or location.

According to some Geologists there are only **TWELVE major Plates (6+6).** Of the twelve, **six** are of enormous extent - **THE GREAT PLATES** - whereas the remaining six range from intermediate in size to comparatively small. Geologists have identified and named a number of even smaller plates within the twelve major plates.

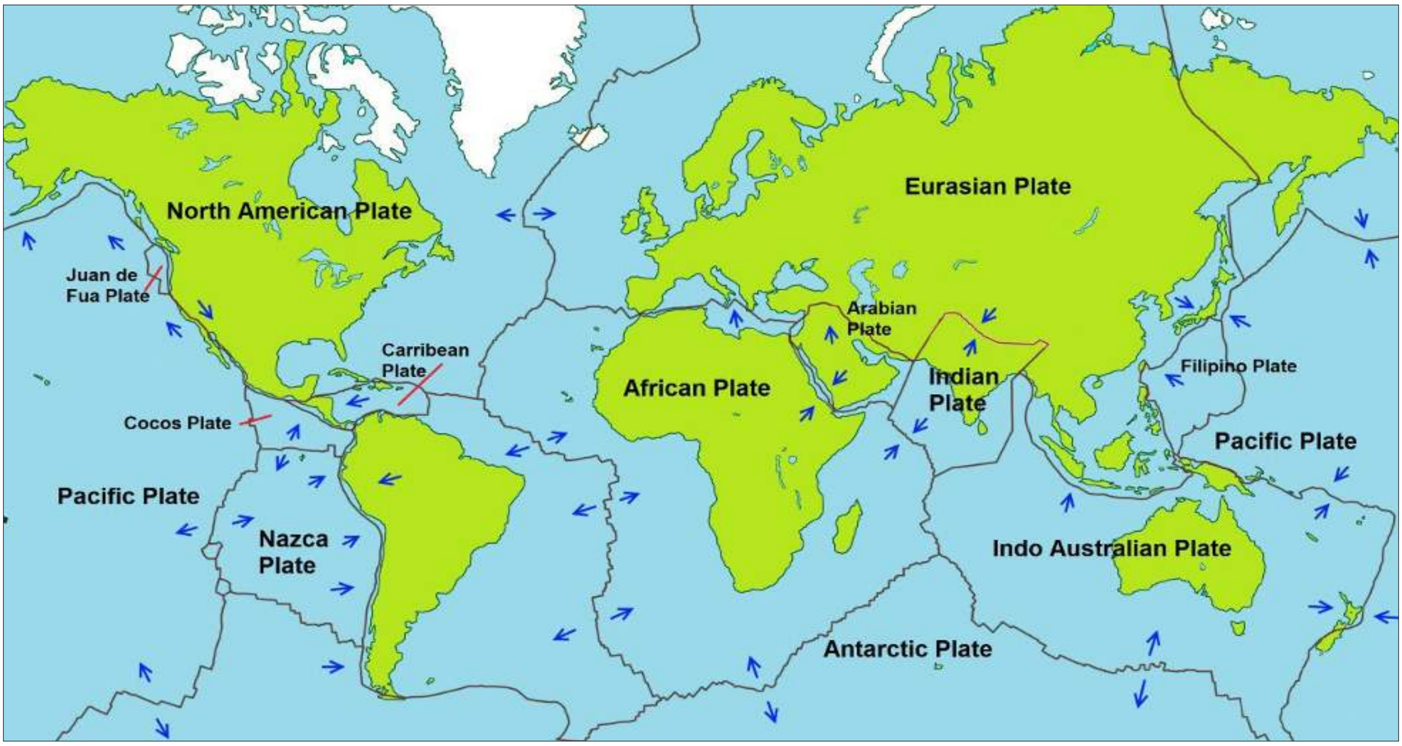


Fig.3.8: *Distribution of world's plates* ***Source:*** *www.savemyexams.co.uk*