General Knowledge Today

Prelims Geography-3: Plate Tectonics, Earthquake, Volcano, Tides

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Model Questions

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Plate Tectonics

Evidence of Continental Drift: Wegener's Continental Drift Hypothesis

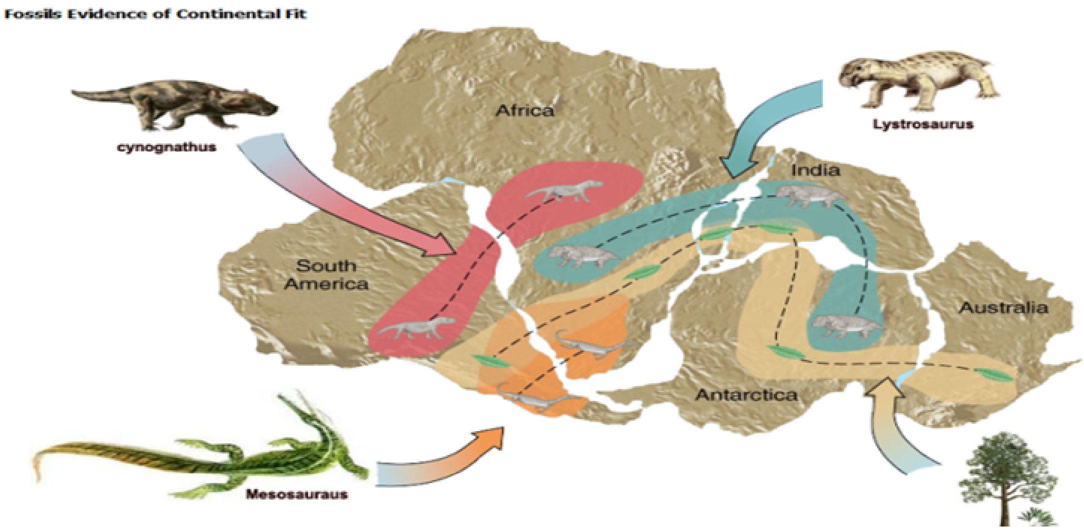
The Lithosphere is always in a state of work in progress. In 1912, a German geologist named **Alfred Wegener** came up with an outlandish theory known as **continental drift.** His theory was based upon the following clues.

Continental Fit

One of the first clues he had was that the continents were once joined once, by noting the jigsaw puzzle–like geometry of Africa's west coast and South America's east coast. This was called "**Continental Fit**".

Fossils

Fossils of Mesosaurus, a freshwater reptile, have only been found in Africa and South America. The fossil remains of Cynognathus, a land reptile, are found in South America and Africa. A **fern called Glossopteris** was found fossilized on all of the southern continents. Since these continents all have different climates now, Wegener proposed that they once all shared a similar climate as one landmass. The evidence of another land reptile, Lystrosaurus, was found in Africa, India, and Australia.



Coal Fields

He noticed the presence of coal fields in the temperate regions, while they could only be formed in the Tropical regions.

Glacial Flow

Wegener noticed that all over the southern hemisphere there are glacier deposits left over from millions of years ago. India, which is now located above the equator, shows signs of glaciers moving across it from the south. Since, it can not be explained without continental drift why would glaciers move toward India from the equator? The clue Wegener had was of a single giant ice sheet that moved outward from Antarctica.

Similarity in Rocks

The similarity in the rock structure on opposite sides of the Atlantic was another clue.

So, **Wegener** proposed that the present continents were once joined in a super continent named **Pangaea** and later the drifted apart. Wegener proposed that the **Pangaea** broke into continents and the new continents drove away themselves in two directions viz. Equatorward and Westward movements. He said that the movements towards the equators were because of the gravitational differential forces and force of buoyancy. The Westward movement occurred because of the tidal force of sun and moon.

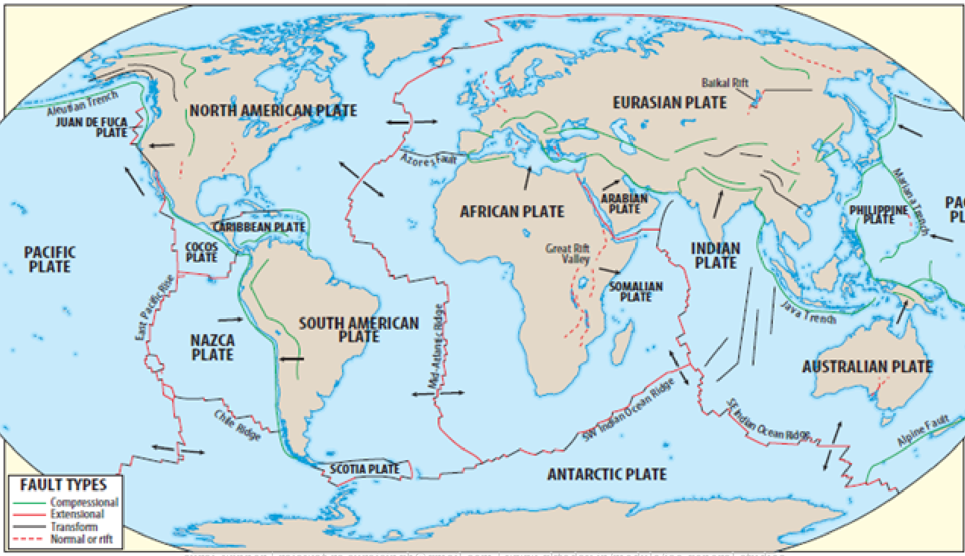
He proposed that the Pangaea began to separate into the **Gondwanaland** and **Angaraland** in the Carboniferous period and the space between the two was filled with water that was called **Tethys Sea**. Later the Gondwanaland disrupted during the Cretaceous period and with this, the Indian subcontinent (peninsula) , Madagaskar, Australia and Antarctica broke away from the Gondwanaland. Similarly the North America broke away from the **Angaraland** and drifted westward due to Tidal forces. He went on further proposing that South America broke way from Africa and moved westwards due to Tidal forces. This theory was interesting and thrilling but Wegener was unable to explain what the forces behind this drift were. So, the result was that **Alfred Wegener** was derided by the scientific community; his proposal was called "geopoetry". However, the later discoveries in deep-sea science led Wegener's basic proposition to be accepted as fact, and today a good deal is known about how the continental drift occurs.

Paleomagnetism

Earth has a magnetic field that causes a compass needle to always point toward the North magnetic pole. When the magnetic minerals cool down, the domains within the magnetic mineral take on an orientation parallel to any external magnetic field present at the time they cooled below this temperature. Using this, it can be determined what was the orientation of the magnetic field present at the time the rock containing the mineral cooled, and thus be able to determine the position of the magnetic pole at that time. Magnetite is the most common magnetic mineral in the Earth's crust. The studies showed that the magnetic pole had apparently moved through time. When similar measurements were made on rocks of various ages in North America, however, a different path of the magnetic pole was found. This would first imply that either the Earth has had more than one magnetic pole at various times in the past, which can not happen. The second implication is that the different continents have moved relative to each other over time. This led to the confirmation of the theory of continental drift.

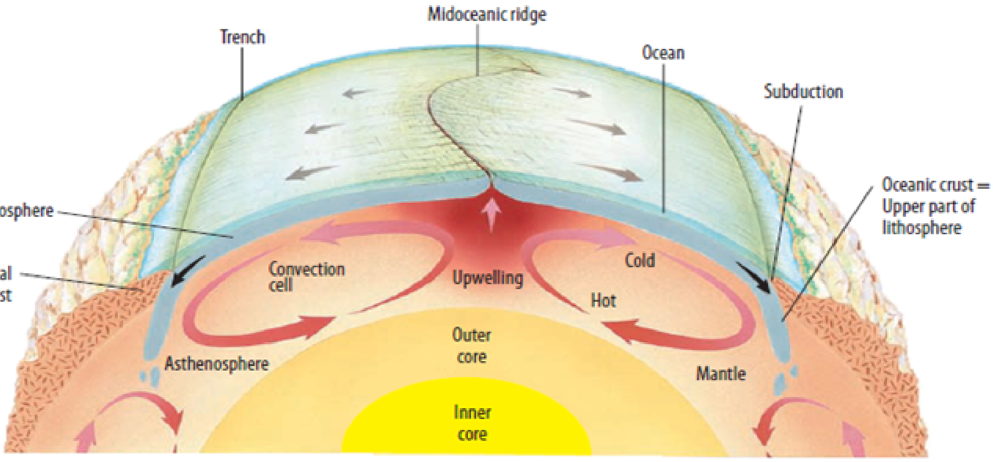
Plate Tectonics and Seafloor Spreading

Lithosphere is made up of about a dozen giant and several smaller sections called plates, and these move in various directions in processes known collectively as plate tectonics. The below graphics shows the plates and their general direction of Movement.



Earthquakes, volcanoes, and other geologic events are concentrated where plates *separate, collide, or slide past one another.* Where they separate, rifting produces **very low land elevations** (e.g. well below sea level at the Dead Sea of Israel and Jordan) or the emergence of new crust on the ocean floor (e.g. in the middle of the Atlantic Ocean).

The central item in the Plate Tectonics is the **Mid-Oceanic Ridge**. *The mid-ocean ridges of the world are connected and form a single global mid-oceanic ridge system that is part of every ocean, making the mid-oceanic ridge system the longest mountain range in the world.* The continuous mountain range is 65,000 km (40,400 mi) long and the total length of the oceanic ridge system is 80,000 km (49,700 mi) long.



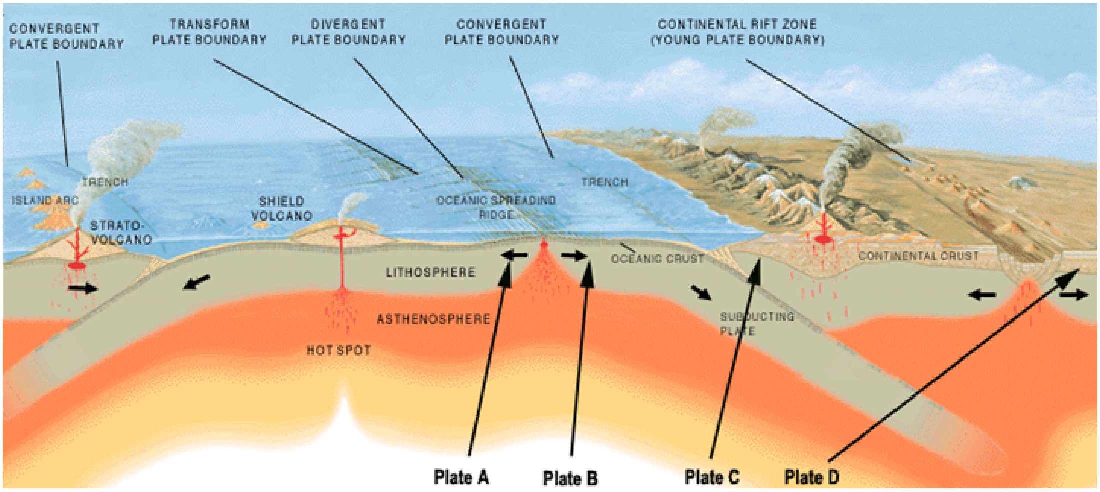
When the ocean floors such as Mid-Atlantic Ridge and the East Pacific Rise, new lithosphere is "born" as molten material rises from the earth's mantle and cools into solid rock. Plate tectonics are often explained by the useful analogy of a "conveyor belt" in constant motion. On either side of the long, roughly continuous ridges, the two young plates move away from one another, carrying islands with them; this process is called **seafloor spreading.**

Seafloor spreading has few impacts on us, but when the earth's plates collide, there is cause for great concern: tectonic forces are among the planet's greatest natural hazards. The seismic activity (seismic refers to earth vibrations, mainly earthquakes) that causes earthquakes and tsunamis (tidal waves) and the volcanism (movement of molten earth material) of volcanoes and related features are the most dangerous tectonic forces.

Subduction

We have already studied that the *Oceanic lithosphere is thinner and denser*, whereas *continental lithosphere is thicker and lighter.* Both of these crustal plates float on the plastic asthenosphere. We can visualize this as two blocks of wood floating in water, where a thicker block rides higher above the water surface than a thinner block. This implies that the *thicker continental surfaces rise higher above the ocean floors.*

In the below graphics, there are four plates viz. A, B, C and D. Plate A and B are pulling apart along their common boundary, which lies along the axis of a midoceanic ridge. When they pull apart, it creates a gap in the crust that is filled by magma rising from the mantle beneath. At greater depth under the rift, magma solidifies into plutonic rocks. The boundary between the plates A and B is called a **spreading boundary**.



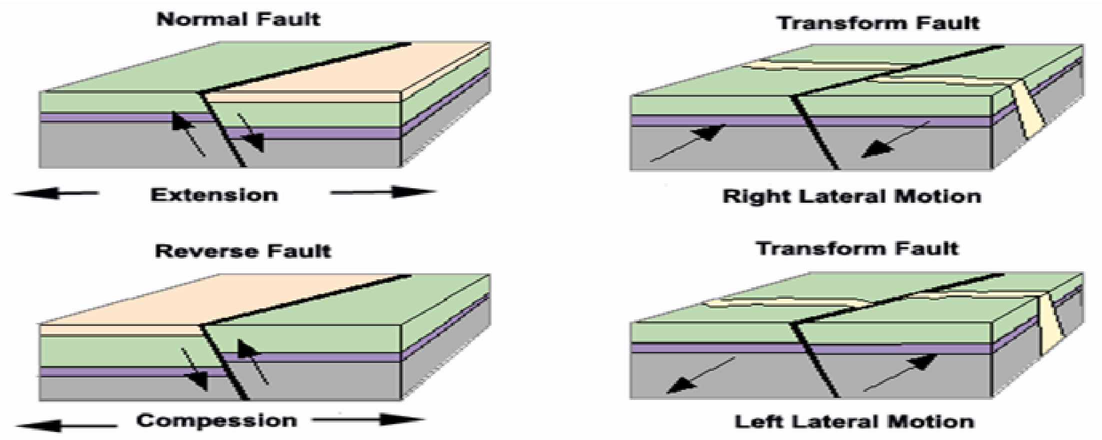
In the right, we see that the oceanic lithosphere of plate B is moving toward the continental lithosphere of plate C. Where these two plates collide, they form a **converging boundary**. Here, since the oceanic plate is comparatively thin and dense, in contrast to the thick, buoyant continental plate, the oceanic lithosphere bends down and plunges into the asthenosphere. *The process in which one plate is carried beneath another is called subduction*. The descending lithosphere is melted again as it dives into the earth's mantle along a deep linear feature called trench (such as the Mariana Trench off Japan). Subduction is another stage along the "conveyor belt" process that will eventually see this material recycled as newborn lithospheric crust. This subduction process releases enormous amounts of energy. The great stress of one plate pushing beneath another is released in the form of an earthquake. The world's largest recorded earthquakes—registering 9.5 (Chile, 1960), 9.2 (United States, 1964), and 9.1 (Indonesia, 2004), respectively, on the Richter scale, which measures the strength of the earthquake at its source—*struck along these subduction zones*. This sudden displacement of a section of oceanic lithosphere is also what triggers a tsunami and the attendant loss of life and property such a powerful wave can cause. Further, the Volcanism generally occurs at places near the subduction zones.

Movement of Plates – Faulting

In some other places, the lithospheric plates **grind and slide along one another.** The processes of rock crowding together or pulling apart along these **fracture lines** is known as **faulting. The** movement along various kinds of faults causes earthquakes, the emergence of new landforms, and other consequences. They are of the following types:

- Normal – tension in the crust (a 'pulling apart")
- Reverse – Compression in crust (a 'pushing in')

- Reverse Thrust Fault
- Transform



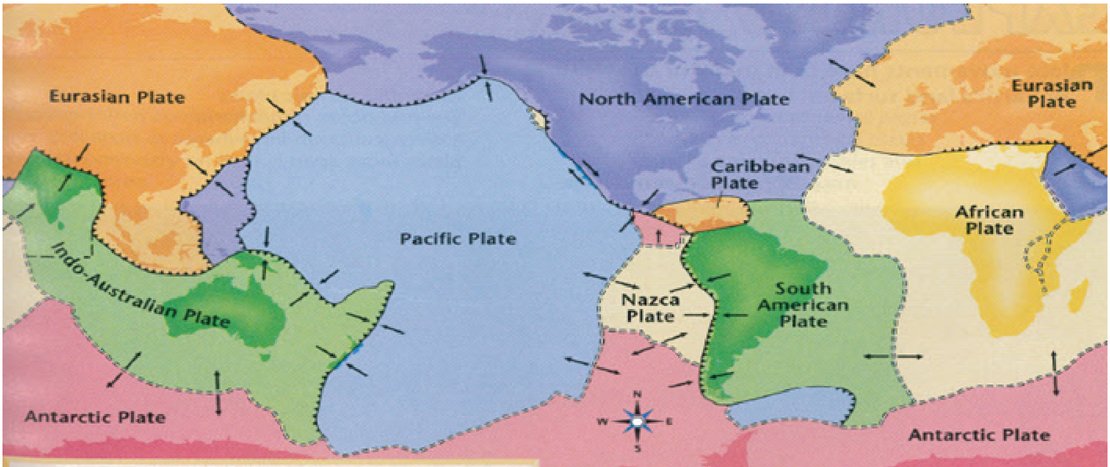
Subduction is responsible for high rates of volcanism, earthquakes, and mountain building. When the large pieces of material on the subducting plate are pressed into the overriding plate, it results in the Orogeny or Mountain formation. These areas are subject to many earthquakes.

Faulting Versus Folding

Please note that *both faulting of the Rocks and folding of the Rocks* play role in creation of the Earthquake, however, the role of later is also dependent upon the former. Earthquakes usually occur where Earth's crust has cracks and is weak. The cracks through which these vibrations pass are called Faults. The movement of rocks along these faults cause earthquakes. As a result of the earthquake, the rocks on the surface of earth change from their earlier position. Their up and down bending into elevations and hollows is called folding of rocks. When the folding continues for a long time, the beds of the rocks can no longer bear the pressure of the force. They break and the rocks may be thrown up on one side and down on the other, thus resulting in Faulting.

The Lithospheric Plates System and Plate Boundaries

The Earth's surface is composed of six major lithospheric plates' viz. Pacific, American, Eurasian, African, Austral-Indian, and Antarctic. Apart from those, there are some lesser plates and sub plates also. The below graphics shows these Lithospheric Plates.



Global System of Lithosphetric Plates

Some important notable observations about these plates are as follows:

- American plate includes most of the continental lithosphere of North and South America.
- Most part of the Eurasian plate is continental lithosphere, but it is fringed on the west and north by a belt of oceanic lithosphere.

- *African Plate is also known as the Nubia Plate*. It is a mix of continental and oceanic lithosphere.
- The great Pacific plate occupies much of the Pacific Ocean basin and consists *almost entirely of oceanic lithosphere.*
- The Antarctic plate is almost completely enclosed by a spreading plate boundary. This means that the other plates are moving away from the pole. The continent of Antarctica forms a central core of continental lithosphere completely surrounded by oceanic lithosphere.
- The *Austral-Indian plate is mostly oceanic lithosphere but contains two cores of continental lithosphere– Australia and peninsular India.* The recent studies show that they may be different parts of two different plates.

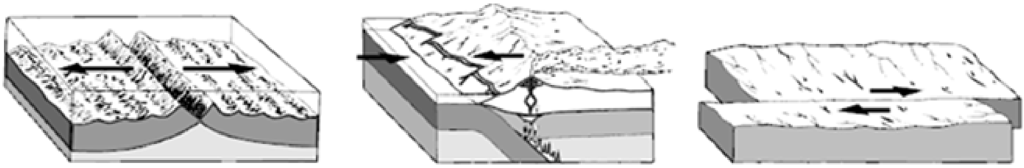
Plate Boundaries

The above discussed Lithospheric Plates are composed of lithosphere, about 100 km thick, that "float" on the plastic asthenosphere. While the continents do indeed appear to drift, they do so only because they are part of larger plates that float and move horizontally on the upper mantle asthenosphere. The plate boundaries can be identified ***because they are zones along which maximum earthquakes occur***. Plate interiors have much fewer earthquakes.

There are three types of plate boundaries:

- Convergent Plate Boundaries: where plates move toward each other.
- Divergent Plate boundaries: where plates move away from each other.

- Transform Plate Boundaries: where plates slide past one another.

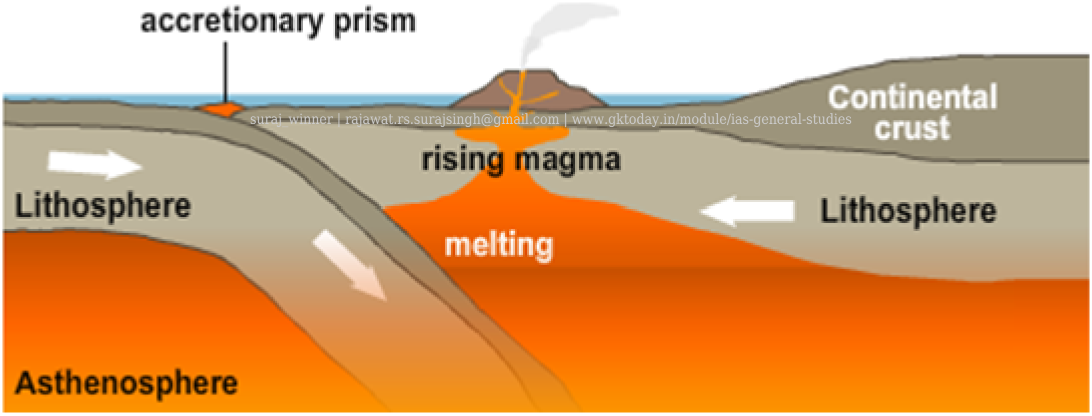


Convergent Plate Boundaries

The convergent plate boundaries are also responsible for nearly ***75% of Earth's volcanoes***. There are following types of Convergent Boundaries:

Ocean-Ocean Convergent Plate Boundary

When two oceanic plates meet and collide against each other, the denser of the two plates is pulled under the other and is subducted. It descends into the asthenosphere, or upper mantle, where it will lead to the generation of new magma. Such boundary would be called an Ocean-ocean convergent plate boundary.



Please note that when one oceanic plate is subducted under the other, the resulting new magma is less dense than the surrounding rock. Therefore it easily rises and erupts on the seafloor, ultimately building a volcano or a volcanic island in the sea. Areas of ocean-ocean convergence are characterized by ocean trenches, seafloor volcanoes, and volcanic islands.

Island Volcanic Arc

At ocean-ocean convergent boundaries, the resulting body of many volcanoes is called an island volcanic arc. An island volcanic arc may include islands that develop in the sea from the build-up of volcanic rocks. Thus, Island volcanic arcs are a chain of islands and mountains that form on the overriding or non-subducting oceanic plate. *Examples of such arcs are Japan, the Philippines, the Tonga Islands, the Aleutian Islands, and the West Indies Islands etc. All of them have developed parallel to the direction of subduction.*

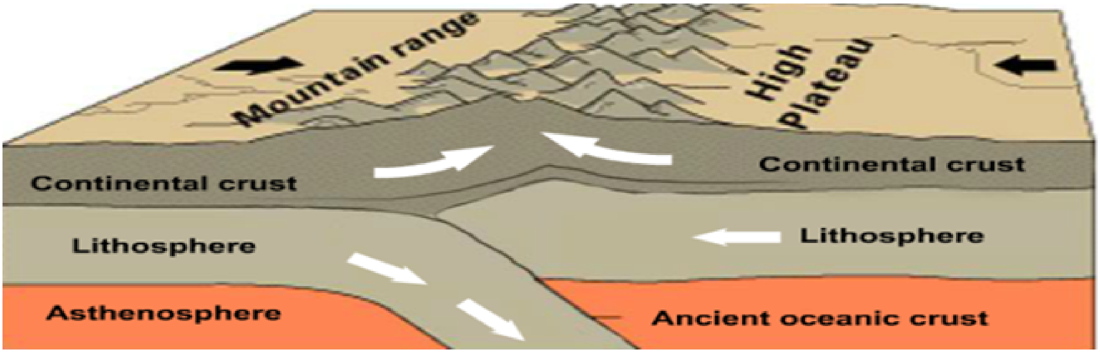
Ocean-Continental Convergent Boundary

Convergence of an oceanic plate with a continental plate is similar to ocean-ocean convergence and often results in the volcanic. *When an oceanic plate collides with a continental plate, the oceanic plate is always pulled under and subducted because it is denser than the continental plate.* When the oceanic plate is subducted under the continental plate, it leads to the generation of new magma, which upwells and forms volcanoes on the non-subducting plate, or the continental plate. Thus Volcanoes are common on Ocean-Continent Boundary also. At ocean-continent boundaries, the resulting body of volcanoes is called a continental volcanic arc. Continental volcanic arcs are chains of volcanoes found on the margin of the continent above a subduction zone at ocean-continent boundaries. *The most visible example is Andes Mountains off the west coast of the U.S.*

Here we should also note that Pacific Ring of Fire, where subduction is taking place at numerous trenches that border the continental shores, has 450 volcanoes, more than 75% of all the volcanoes on Earth. This makes plate convergence responsible for nearly all volcanic activity on Earth.

Continent-Continent Boundary

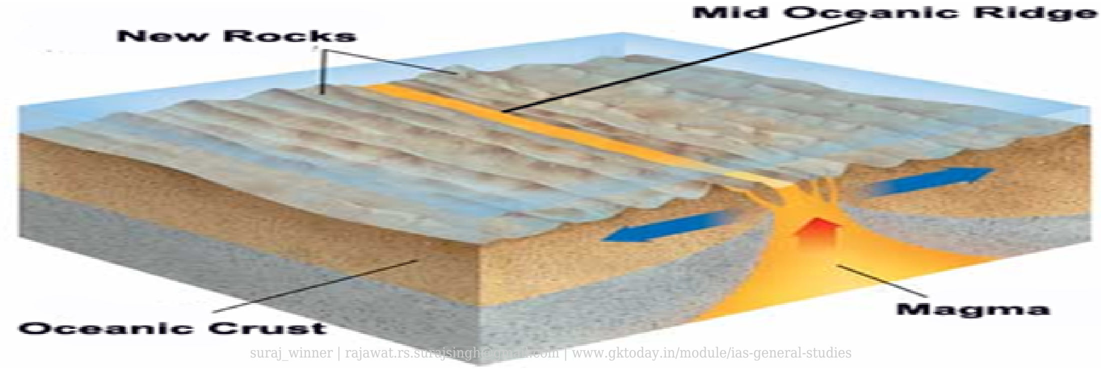
When the continent and continent converge, the crust at both the sides is too light and buoyant to be subducted, so neither plate is subducted in continent-continent convergent boundary. Both continental masses press against the other, and both become compressed and ultimately fused into a single block with a **folded mountain belt forming between them**.



- This is the type of activity is responsible for forming the Himalayas, and is still going on. The Himalayas are still growing, as we all know.
- Please note that due to intense pressure between the colliding plates, metamorphic rocks formation is common at such boundaries.
- Please also note that Volcanoes are not common at Continent-continent convergent boundaries because there is no subduction of plates. Subduction is prerequisite for formation of the new magma.

Divergent Plate Boundaries

The Continental Drift Theory says that all the continents were once joined together in one giant supercontinent called Pangaea. Because of plate tectonics, Pangaea broke apart and the continents began their slow migration to their present locations. The Atlantic Ocean opened up in between North America and the west coasts of Europe and Africa. The agent for causing this is the Mid-Atlantic Ridge, a divergent plate boundary, where two plates are rifting and moving away from each other. Thus, divergent plate boundaries are places of extension stress, where the crust is being extended, thinned, and rifted.



In the convergent plate boundaries are the **destructive plate boundaries** where the crustal material is consumed at the subduction zones. However, the divergent plate boundaries are ***constructive boundaries because it leads to formation of new Lithosphere***. The creation of the new crustal material takes place at mid-ocean ridges, where the oceanic crust is rifted open and magma wells up to fill the opening. The magma then hardens to form the igneous rocks that make up the oceanic crust. This is the mechanism which forms maximum amount of rock material on earth.

Comparison: Divergent and Convergent Plate Boundaries

Kindly note & remember the following points:

Convergent Boundaries	Divergent Boundaries
Explosive Volcanoes	Quite, Non explosive volcanoes
High Silicic Magma: The magma comes from the subduction of lithospheric crust so it has more of silicate.	High Basaltic Magma: Oceanic crust is created at the mid-oceanic ridges; it forms from up welling magma that cools and solidifies to igneous rock. Most of this is Basaltic.
Stratovolcanoes	Shield Volcanoes
Consumption of the Ocean Floor	Creation of Ocean Floor

Convergent Boundaries	Divergent Boundaries
Shallow, Intermediate as well as Deep Focus Earthquakes	Shallow Focus earthquakes only

Continental Rift Zones

Please note that the divergent plate boundaries can also develop on the continents, and here, we name them as Continental Rift Zones. Most of the features of Oceanic Divergent boundaries are valid for them also such as *thinned crust; normal faults; shallow earthquakes; basaltic volcanoes etc.*

While the Continental Rift Zones develop, the earth is stretched and thinned, leading to development of a small body of water. When the rifting keeps continuing, the body of water grows bigger to form a juvenile ocean. After millions of years of rifting, the body of water becomes a mature ocean with two separate continents on each side. Red Sea and Gulf of Aden is the best example of this phenomenon.

Transform Plate Boundary

Transform plate boundaries are places where two plates are sliding past each other. At these boundaries, the plates are neither compression nor extension stress, but are under shear stress. Then there is neither creation nor consumption of the lithospheric material. So, the transform plate boundaries are basically faults and nothing else.

The transform plate boundaries can cause horizontal displacement of hundreds of kilometers of land on the continents which results in several types of landscapes such as ridges and troughs. In oceans, transform plate boundaries are part of fracture zones. *Earthquakes are most common at transform plate boundaries. Volcanoes rarely develop at transform plate boundaries because transform boundaries do not allow for the upwelling or new creation of magma.*

Earthquakes & Seismic Waves

In Earthquake, there is a sudden release of energy in the **Earth's crust**, which leads to a series of motions because of the waves created due to this energy (called seismic waves) released. These seismic waves originate in a limited region and spread in all directions.

Types of Earthquakes

Earthquakes can be generated by a number of sources, most of which are result of natural tectonic processes, usually caused by the interaction between two lithospheric plates. Other quakes can be generated by volcanoes as magma is injected into the Earth's crust. For example, earthquakes in the island of Hawaii are generally volcanic earthquakes. Rest of the Earthquakes are artificially generated by nuclear test explosions. Thus, there are several types of Earthquakes such as:

- **Tectonic Earthquakes:** Tectonic Earthquakes are most common and generated due to folding, faulting plate movement.

- **Volcanic Earthquakes:** Earthquake associated with volcanic activity are called volcanic earthquake. These are confined to areas of volcanoes and pacific ring of fire is best example of these types of earthquakes.
- **Collapse Earthquakes:** They are evident in the areas of intense mining activity, sometimes as the roofs of underground mines collapse causing minor tremors.
- **Explosion earthquakes:** This is a minor shock due to the explosion of the nuclear devices.
- **Reservoir Induced Earthquakes:** Large reservoirs may induce the seismic activity because of large mass of the water. They are called reservoir induced earthquakes

Foreshocks, Mainshocks and Aftershocks

The Earthquakes come in three forms of clusters called foreshocks, mainshocks, and aftershocks. Foreshocks are quakes that occur before a larger one in the same location; around a quarter of all mainshocks happen within an hour of their foreshock. Mainshocks and aftershocks are better known. Mainshocks are of the highest magnitude. Aftershocks are smaller quakes that occur in the same general geographic area for days-and even years-after the larger, mainshock event.

Hypocentre and Epicentre

The point, where earthquakes are generated first, is called focus or hypocenter. A hypocenter is

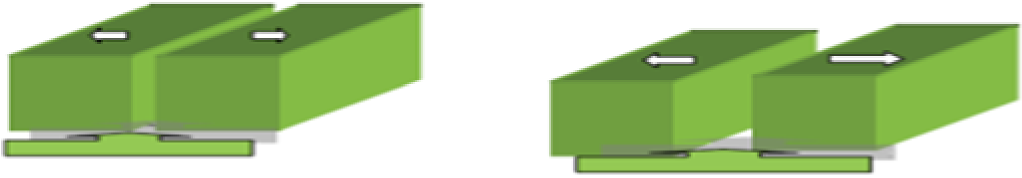
below the surface, where the first rock displaces and creates the fault. Epicentre is the point on the Earth's surface that is directly above the hypocenter or focus**.** This is the point where the shock waves reach the surface. Earthquakes originate at depths ranging from about 5 to 700 kilometers. Nearly *9o percent of all earthquakes occur at depths of less than 100 km. Shallower is the depth, more destructive an earthquake is.*

Mechanism of Tectonic Earthquakes

Theory of plate tectonics explains that earth's crust is formed by a number of large plates that move very slowly in various directions on the earth's surface. These plates are 60-200 km thick and float on top of a more fluid zone, much in the way that icebergs float on top of the ocean. Most earthquakes occur near a boundary between two plates. As one plate pushes past or moves over another, great stresses build up in the rock along the edges of the plates because friction prevents them from sliding past each other. Subsequently, the stresses become great enough so that the rocks can rupture. The edges of the plates slip a short distance in different directions, causing an earthquake. Greater the stresses, greater is the resulting earthquake. The movements are of three kinds

Divergent:

In divergent movements the plates move apart from each other. This is most common type of movement in mid-oceanic zones.



Convergent

In convergent movements the plates move towards each other and the border overlap. This is most common type of movement in subduction zones where the dense oceanic plates collide and slide beneath the continental plates.

Transformational

In this type of movement the plates move in opposite side, on parallel. Some earthquakes are caused by the movement of lave beneath the surface of the earth during volcanic activity.

Earthquake Belts

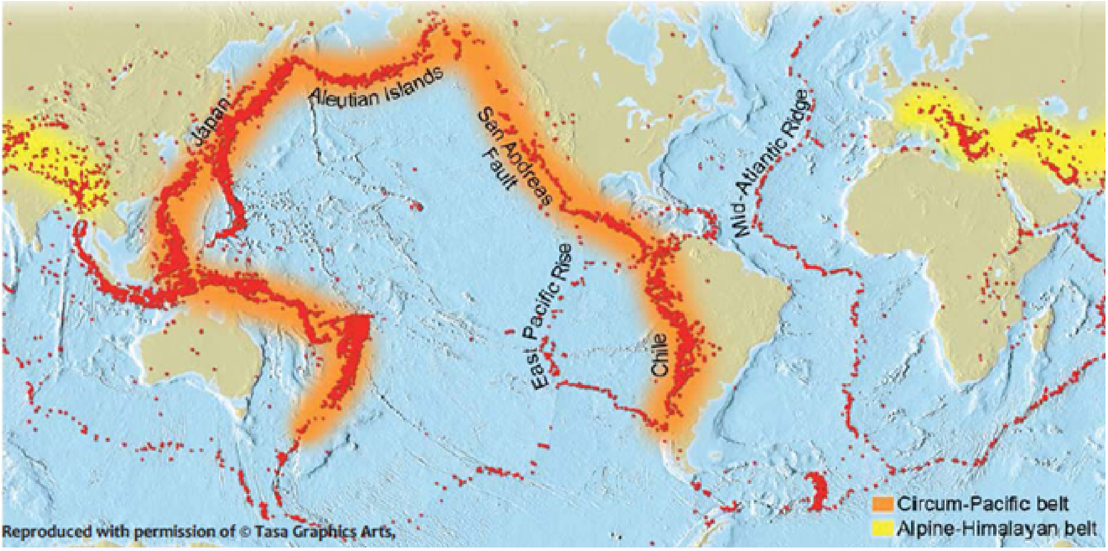
There are two major belts of earthquakes in the world. They are as follows:

Circum-Pacific Belt

This belt is along a path surrounding the Pacific Ocean This zone included the regions of great seismic activity such as Japan, the Philippines, and Chile. This path coincides with the "Pacific Ring of Fire".

Alpine-Himalayan Belt

Another major concentration of strong seismic activity runs through the mountainous regions that flank the Mediterranean Sea and extends through Iran and on past the Himalayan Mountains. This zone of frequent and destructive earthquakes is referred to as the Alpine-Himalayan belt.



Earthquake Magnitude and Earthquake Intensity

Earthquake Magnitude and **Earthquake Intensity** are two terms often misunderstood. Earthquake magnitude is a measure of the size of the earthquake reflecting the elastic energy released by the earthquake. It is referred by a certain real number on the Richter scale (such as magnitude 6.5 earthquake).

On the other hand, earthquake intensity indicates the **extent of shaking** experienced at a given location due to a particular earthquake. It is referred by a Roman numeral (such as VIII on MSK scale). Intensity of shaking at a location depends not only on the magnitude of the earthquake, but also *on the distance of the site from the earthquake source and the geology / geography of the area*. We note here that the ***Isoseismals** are the contours of equal earthquake intensity*. The area that suffers strong shaking and significant damage during an earthquake is termed as ***meizoseismal region.***

Richter Magnitude Scale

The concept of **earthquake magnitude** was first developed by Richter and hence the term "Richter scale". The value of magnitude is obtained on the basis of recordings of earthquake ground motion on seismographs.

Richter magnitude scale is a base-10 logarithmic scale obtained by calculating the logarithm of the shaking amplitude of the largest displacement from zero on **Wood-Anderson torsion** seismometer. It was developed in 1935 by Charles Richter in partnership with Beno Gutenberg, both of the California Institute of Technology.

Since in this scale, Earthquake magnitude is measured on a log scale, a small difference in earthquake recording on the instruments leads to a much smaller error in the magnitude. An increase of 1 in the

Richter magnitude, there is a tenfold **increase in the size of the waves also known as shaking amplitude**. The Richter scale 5.0 is 10 times more shaking amplitude of 4.0. But there is a huge difference in energy. The energy release of an earthquake denotes the destructive power. It scales with $^3/_2$ power of the shaking amplitude. A difference in magnitude of 1.0 is equivalent to a factor of 31.6. This is shown by the following equation:

$$(10^{1.0})^{\frac{3}{2}} = 31.6$$

A difference in magnitude of 2.0 is equivalent to a Factor of 1000. It is shown below:

$$(10^{2.0})^{\frac{3}{2}} = \frac{100^3}{100^2} = \frac{1000000}{10000} = 1000$$

With increase in magnitude by 1.0, the energy released by the earthquake goes up by a factor of about 31.6. Thus, a magnitude 8.0 earthquake releases about 31 times the energy released by a magnitude 7.0 earthquake, or about 1000 times the energy released by a magnitude 6.0 earthquake. There are no upper or lower bounds on earthquake magnitude. In fact, magnitude of a very small

earthquake can be a negative number also. Usually, earthquakes of magnitude greater than 5.0 cause strong enough ground motion to be potentially damaging to structures. Earthquakes of magnitude greater than 8.0 are often termed as great earthquakes

Following table shows the exponential increase in earthquake energy on Richter scale:

Richter Approximate Magnitude	Approximate TNT for Seismic Energy Yield
1.0	474 g (1.05 lb)
2.0	15.0 kg (33.1 lb)
3.0	474 kg (1050 lb)
4.0	15.0 metric tons
5.0	474 metric tons
6.0	15.0 kilotons
7.0	474 kilotons
8.0	15.0 megatons
9.0	474 megatons
10.0	15.0 gigatons

Examples of the most devastating Earthquake recorded are Indian Ocean Earthquake 2004, which caused the 2004 Indian Ocean Tsunami and the **Valdivia earthquake** (Chile), 1960. The Indian

Ocean Earthquake was of 9.3 intensity in Richter scale while the **Valdivia earthquake of Chile was 9.5**. An earthquake of 10.0 on Richter scale has never been recorded by Humankind. The 2010, Haiti Earthquake was 7.0 on the Richter scale. The undersea megathrust earthquake off the coast of Japan that occurred on 11 March 2011 was **9.0** on Moment Magnitude Scale.

Moment Magnitude Scale

The Richter scale is denoted by $\mathbf{M_L}$. This scale was replaced in 1970s by the new Moment magnitude scale which is denoted as $\mathbf{M_w}$. The scale is almost same and media uses the same term "Richter Scale" for the new MMS also. This is because medium earthquakes such as 5.0 are equal on both the scales. The Richter scale was based on the ground motion measured by a particular type of seismometer at a distance of 100 kilometers from the earthquake, and Richter scale has a highest measurable magnitude. The large earthquakes have a similar magnitude of around 7.0 on Richter scale. The Richter scale measurement is also unreliable for measurements taken at a distance of more than about 600 kilometers from the earthquake's epicenter. This problem is solved by the MMS (Moment magnitude scale). The Moment magnitude scale does not uses the ground motion, but used the physical properties of the Earthquake such as seismic moment. The scale was introduced by Thomas C. Hanks and Hiroo Kanamori in 1979. The US Geological survey uses the Moment magnitude scale for all large earthquakes. Drawback: Moment magnitude scale deviates at the low scale Earthquakes.

Shindo Scale

Shindo scale is also known as Japan Meteorological Agency (JMA) seismic intensity scale. It is used in Japan and Taiwan to measure the intensity of earthquakes. It is measured in units of Shindo which literally means degree of shaking. Unlike the moment magnitude scale, which measures the energy released by the earthquake, the JMA scale describes the degree of shaking at a point on the Earth's surface. Thus it is similar to Mercalli intensity scale. The Shindo Scale ranges between Shindo-0 to Shindo-7. Shindo-0 quake is not felt by most people, while Shindo-7 is most devastating earthquake. However, note that same earthquake has different Shindo numbers at different places. For example, 2011 Great Earthquake of Japan registered Shindo-7 at Kurihara, Miyagi Prefecture, while Shindo-6 at Fukushima, Ibaraki and Tochigi and Shindo-7 in Tokyo.

Medvedev-Sponheuer-Karnik scale (MSK-64)

Prior to the development of ground motion recording instruments, earthquakes were studied by recording the description of shaking intensity. This lead to the development of intensity scales which describe the effects of earthquake motion in qualitative terms. An intensity scale usually provides ten or **twelve grades of intensity** starting with most feeble vibrations and going upto most violent (i.e., total destruction). The most commonly used intensity scales are: Modified Mercalli (MM) Intensity Scale and the Medvedev-Sponhener-Karnik (MSK) Intensity Scale. Both these scales are quite similar except that the MSK scale is more specific in its description of the earthquake effects. Medvedev-Sponheuer-Karnik scale denoted by MSK or MSK-64, is a macro seismic intensity scale which is used to evaluate the severity of ground shaking on the basis of observed effects in an area of the earthquake occurrence. It was proposed by Sergei Medvedev (USSR), Wilhelm Sponheuer (East Germany), and Vft Karnfk (Czechoslovakia) in 1964.

MSK-64 is used in India, Israel, Russia, and throughout the Commonwealth of Independent States. In India the *seismic zoning has been done on the basis of this scale*. This scale has 12 intensity degrees expressed in Roman numerals, which are shown in the below graphics.

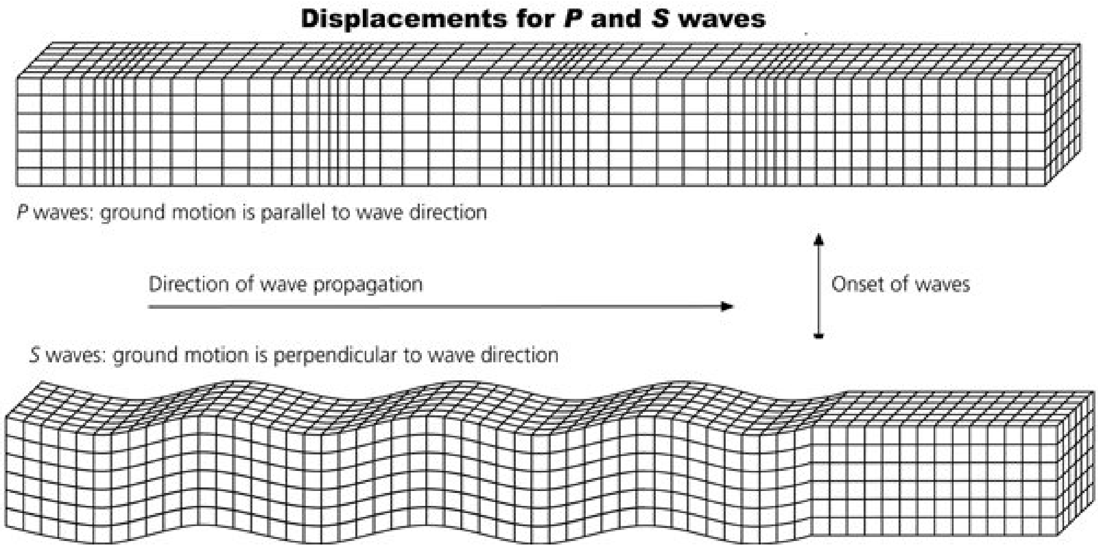
	MSK 64 Scale
	Not perceivable
II	Hardly perceivable
III	Weak
IV	Largely Observed
V	Fairly Strong
VI	Strong
VII	Very Strong
VIII	Damaging
IX	Destructive
X	Devastating
XI	Catastrophic

Seismic Waves

The waves generated by the earthquake are called Seismic waves. The study of earthquake and seismic waves is called Seismology and the researchers are called Seismologists. Seismic waves are divided into two broad categories viz. Body Waves and Surface Waves.

Body waves

In Body waves the speed decreases with increasing density of rock and increases with increasing rock elasticity. Rock elasticity increases faster than density with depth. There are two kinds of body waves viz. P-waves and S-waves.



Primary Waves or P-waves

The **Primary waves** or **Push waves** are *longitudinal / compression* waves that vibrate parallel to the direction of wave movement. They have shortest wavelength, fastest speed {5-7 km/s} and can travel through *solid, liquid and gas. They travel fast in denser, solid materials.*

Secondary waves or S-waves

Secondary waves or **Sheer waves** or **shock waves** are *transverse waves* which create vibrations perpendicular to the direction of wave movement. The S waves only travel through solids because liquids and gases have no sheer strength.

They have a medium wavelength and cause vibrations at right angles to the direction of propagation of waves. Their velocity is 3 to 4 km per second.

Surface Waves

Surface waves are of two types viz. Rayleigh Waves and Love waves

Rayleigh Waves or L-waves

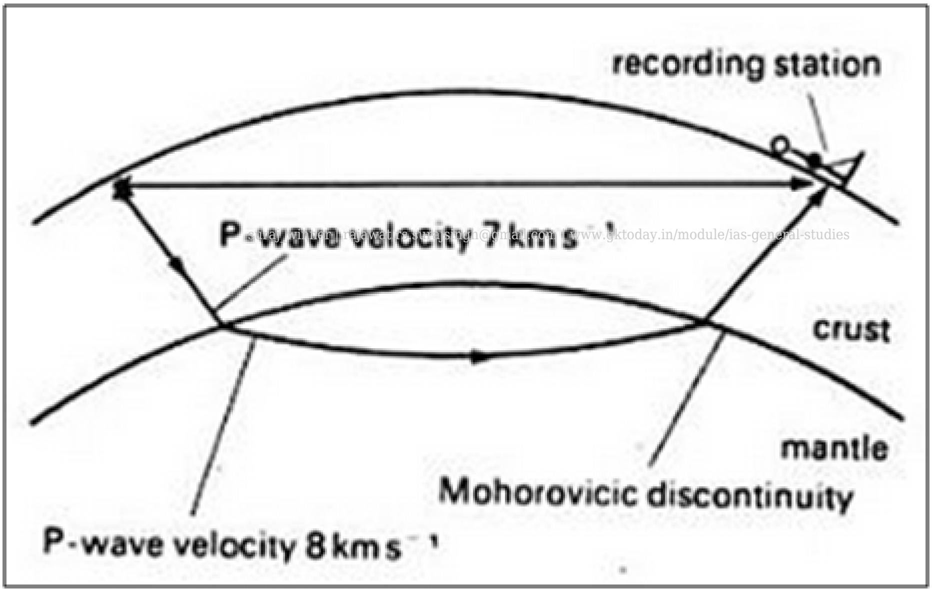
L Waves or Surface Waves travel near the earth's surface and within a depth of 30-32 kilometers from the surface. These are also called Rayleigh waves after Lord Rayleigh who first described these waves. Behave like water waves with elliptical motion of material in wave. Generally slower than Love waves.

Love waves

Love waves make the ground vibrate at right angles to the direction of waves . They are a variety of S-waves where the particles of an elastic medium vibrate transversely to the direction of wave propagation, with no vertical components. Involve shear motion in a horizontal plane. Most destructive kind of seismic wave.

How Seismic waves help in defining Earth's interior?

The speed of the **seismic waves varies with the composition of the medium**. In earth crust their speed is around 2-8 kilometers per second, while in mantle the speed is up to 13 kilometer per second, because mantle is denser. In his observations, Mohorovičić found that when the focus of the Earthquake is not too deep, some waves are propagated along the surface and remains in the crust, while other *set enters the mantle, speeds up and reaches the seismometer first.* This means that for a seismograph stations located at about 150 Kilometers from a shallow focus earthquake epicentre received those waves first which came from beneath the ground via mantle. This was enough to conclude that there is something below earth crust which has a greater density and varied composition. It was later called Mohorovičić discontinuity or simply Moho.



The above finding led to determine that mantle is denser than crust and is viscous, semi-molten material. P-wave velocities are much slower in the outer core than in the deep mantle while S-waves do not travel at all in the liquid portion of the outer core.

Role of Seismic waves in determination of Epicentre

To determine the location of an earthquake, the following two things of info are required:

- Recorded seismograph of the earthquake from **at least three seismographic** stations at different distances from the epicentre of the quake.
- Time it takes for P-waves and S-waves to travel through the Earth and arrive at a seismographic station.

As we know that the P waves reach the to the seismographs first at a station, the difference between the time of P waves and S waves is called S-P Interval. **<u>The S-P interval increases with increasing distance from the epicentre</u>**. At each station a circle on a map can be drawn which has a radius equal to the distance from the epicenter.

Earthquake Shadow Zone

Seismic waves recorded at increasing distances from an earthquake indicate that seismic velocities gradually increase with depth in the mantle. However, at arc distances of between about 105° and 140° no P waves are recorded. Furthermore, no S waves are record beyond about 105°. This is called Shadow zone.

Earthquakes in India

India has a very ***high frequency of great earthquakes*** (magnitude greater than 8.0) ***in comparison to the moderate earthquakes*** (magnitude 6.0 to 7.0). For example, during 1897 to 1950, India was hit by four great earthquakes. However, since 1950, only moderate size earthquakes have occurred in India which should be no reason to assume that the truly great earthquakes are a thing of the past.

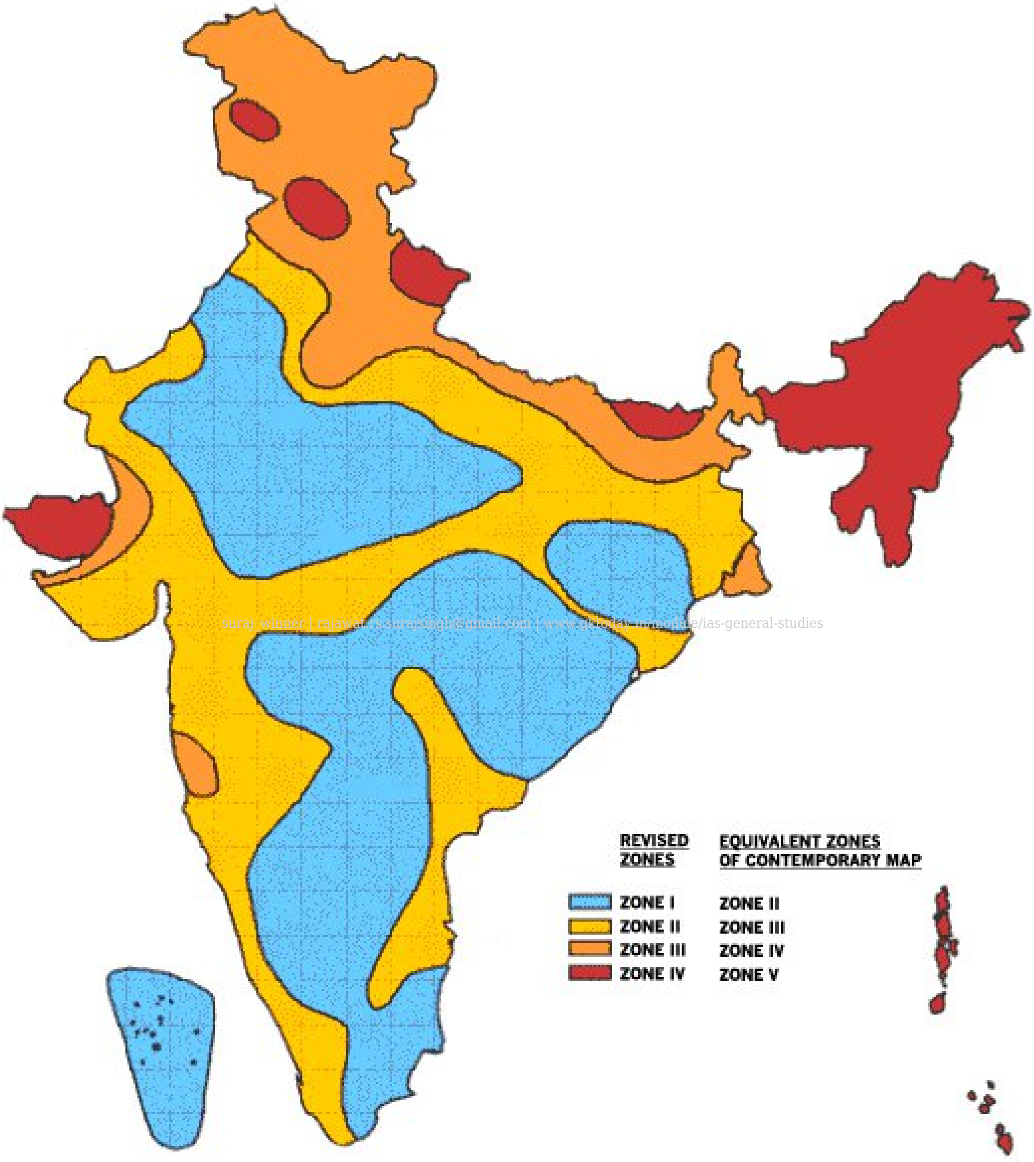
The reasons of high magnitude earthquakes in India are hidden in the tectonic setting of India. India is currently penetrating into Asia at a rate of approximately 45 mm/year and ***rotating slowly anticlockwise***. This rotation and translation results in left-lateral transform slip in Baluchistan at approximately 42 mm/year and right-lateral slip relative to Asia in the Indo-Burman ranges at 55 mm/year. At the same time, deformation within Asia reduces India's convergence with Tibet to approximately 18 mm/year. Since Tibet is extending east-west, there Is a convergence across the Himalaya that results in the development of potential slip available to drive large thrust earthquakes beneath the Himalaya at roughly 1.8 m/century.

Seismic Zoning of India

Indian subcontinent has a long history of devastating earthquakes, partially due to the fact that India is driving into Asia at a rate of approximately 47 mm/year. More than 50% area of Indian Subcontinent is vulnerable to earthquakes. According to the IS 1893:2002 (It is the latest code of Bureau of Indian Standards (BIS) which lays down the criteria of for earthquake resistant design of structures), India has been divided into four seismic zones viz. Zone-II, -III, -IV and -V unlike its previous version which consisted of five zones for the country. After some revisions in the previous zoning, Zone I was altogether removed.

This zoning has been done on the basis of MSK-64 scale and a IS code Zone factor has been assigned by the BIS to each of them. The zone factor of 0.36 is indicative of effective (zero period) peak horizontal ground acceleration of 0.36 g (36% of gravity) that may be generated during MCE level earthquake in this zone. They are presented in the following table with IS code.

Seismic Zoning of India		
MSK-64	Seismic Zone	Zone Factor
VI. Strong	Zone II This region is liable to MSK VI or less and is classified as the Low Damage Risk Zone	0.10
VII. Very Strong	Zone III The Andaman and Nicobar Islands, parts of Kashmir, Western Himalayas fall under this zone. This zone is classified as Moderate Damage Risk Zone which is liable to MSK VII.	0.16
VIII. Damaging	Zone IV This zone is called High Damage Risk Zone anc covers Indogangetic Basin, Delhi, Jammu and Bihar	0.24
IX. Destructive	Zone V Zone 5 covers areas with the highest risk zone that suffers earthquakes with intensity of IX and greater. It includes Kashmir, Punjab, Western and central Himalayas, North East India and Rann of Katch	0.36



Some Great Indian Earthquakes

India has suffered some of the greatest earthquakes in the world with magnitude exceeding 8.0. For instance, in a short span of about 50 years, four such earthquakes occurred: Assam earthquake of 1897 (magnitude 8.7), Kangra earthquake of 1905 (magnitude 8.6), Bihar-Nepal earthquake of 1934 (magnitude 8.4) and the Assam-Tibet earthquake of 1950 (magnitude 8.7).

Katch Earthquake of 1819

This 8.3 magnitude earthquake took place on the west coast of India and caused ground motion which was perceptible as far as Calcutta. It created a fault scarp of about 16 mile long and about 10 foot high which was later named as "Allah Bund".

Assam earthquake of 1897

This 8.7 magnitude earthquake caused severe damage in an area of about 500 km radius and caused extensive surface distortions in the area. The earthquake caused extensive liquefaction in the alluviated plains of Brahmaputra.

Bihar – Nepal Earthquake Of 1934

This 8.4 magnitude earthquake caused wide-spread damage in the northern Bihar and in Nepal. Due to extensive liquefaction, most buildings tilted and slumped bodily into the ground in an area of about 300 km long and of irregular width. This area was termed as the "slump belt".

Koyna Earthquake Of 1967

This 6.5 magnitude earthquake occurred close to 103 metre concrete gravity dam at Koyna. Prior to this earthquake, the area used to be considered aseismic. However, after the construction of dam and filling up of reservoir in 1962, the seismic activity increased significantly.

The main shock of December 10, 1967 caused widespread damage, killing about 200 persons and injuring more than 1500 persons. This was an example of the reservoir-induced seismicity in India.

The dam, designed keeping in mind the possible seismic activity, performed quite well with only nominal damage to the dam. This earthquake lead to the revision of Indian seismic zone map wherein the area around Koyna was brought in zone IV from zone I, and seismic zone for Bombay was upgraded from zone I to zone III.

Uttarkashi Earthquake Of 1991

This 6.6 magnitude earthquake shook the districts of Uttarkashi, Tehri, and Chamoli of current Uttarakhand.

Killari (Latur) earthquake of 1993

This was a magnitude 6.4 earthquake that shook the area near village Killari in Latur district killing about 8,000 persons. Until this earthquake the area was considered non-seismic and placed in the lowest seismic zone (zone I) by the Indian code (IS:1893-1984).

The affected area did not have any modern towns, modern buildings or major industries. In some of the villages more than 30% of the population was killed. This earthquake will be known for outstanding rescue, relief and rehabilitation.

Jabalpur Earthquake Of 1997

This magnitude 6.0 earthquake is only example of such earthquakes which occurred close to a major Indian city in recent times.

2004 Indian Ocean earthquake and tsunami

The 2004 Indian Ocean earthquake was an undersea megathrust earthquake with an epicentre off the west coast of Sumatra, Indonesia, and it is known as Sumatra–Andaman earthquake or 2004 Indian Ocean tsunami or South Asian tsunami, Indonesian tsunami, and the Boxing Day tsunami. It killed 230,000 people in fourteen countries, and inundating coastal communities with waves up to 30 meters.

Impact of Earthquakes – Liquefaction

Earthquakes can cause soil liquefaction where loosely packed, water-logged sediments come loose from the intense shaking of the earthquake. The liquefaction is more prominent in areas such as river valleys, river plains and deltas. The randomly bunched together soil particles have spaces have formed between them. These spaces, called pores, can be filled with water or air. The pressure of the material in the spaces holds the particles apart and stabilizing the soil in its present configuration.

The effect of a seismic wave on granular soil and pore pressure is that it increases the water pressure and forces the particles apart as well as disrupts the contact point of the particles themselves. At this point in time the soil will flow like a liquid. The end product is the collapse of the particles so that there is less space between them. The water that was in that space is then forced upward. Liquefaction should have the following conditions for it to take place:

- Water table is less deep
- The soil has pore spaces
- The intensity of shaking in that area is viii or greater

The impacts of the Liquefaction are as follows:

The underlying layer of water rich sand compacts and sends a column of water and fine sand up and out onto the surface. This phenomenon is called Differential Compaction. At the same time, **depth of lakes, ponds, borrow areas, and other depressions becomes lower,** because the sand is pushed through the ground. The buildings sink into the ground after the earthquake.

Volcanoes & Volcanism

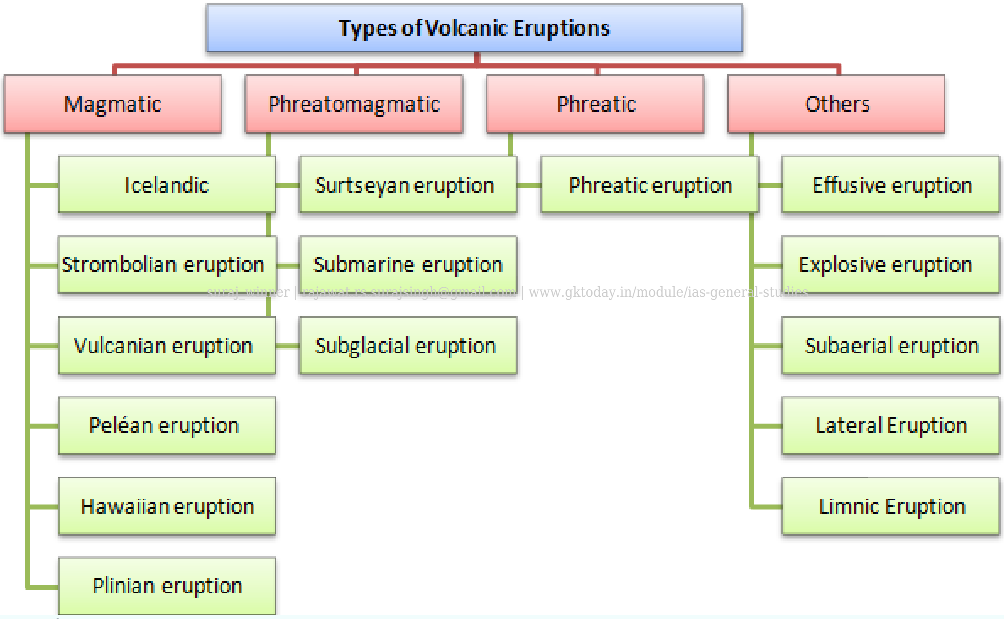
Introduction to Volcanoes

A volcano is simply an opening in the Earth's surface in which eruptions of dust, gas, and magma occur; they form on land and on the ocean floor. The driving force behind eruptions is pressure from deep beneath the Earth's surface as hot, molten rock up wells from the mantle. The results of this activity are a number of geological features, including the build-up of debris that forms a mound or cone, which we commonly imagine when talking about a volcano.

> *Vulcan* is Greek God of beneficial and hindering fire. Vulcanization is another term derived from the name of Vulcan God. Vulcanization is adding sulfur or other curatives

to rubber or other polymers to make them more durable. The rubber so produced is called Vulcanite or ebonite. Vulcano is the name of an island near Sicily, the largest island in the Mediterranean Sea and an autonomous region of Italy.

An opening or vent through which the magma, molten rocks, ashes, gases and other volatiles erupt on the surface of Earth is called a Volcano. The most known types of Volcanoes are conical mountains which spit law and poisonous gases. But there are other types of Volcanoes. The Volcanoes can be divided in the basis of **Type of Eruption**, **Material erupted** & **Periodicity of eruption**.



Types of Volcanoes by Volcanic Eruption

There are three major categories of the volcanic eruptions. The **magmatic eruptions** involve the decompression of gas within the magma. This decompression of the gas propels it outward. In **Phretomagmatic** eruptions involves compression of the gas within the magma. Another is **Phreatic eruption** which involves superheating of steam via contact with Magma. In Phreatic eruption, there is no magmatic release and they cause the granulation of the rocks. Apart from this there are other types of eruptions which sometimes don't seem to be Volcanic Eruptions. The following graphic shows this classification.

Magmatic Eruptions

When Magma, the mixture of rocks, volatiles and solids erupts in a fissure, it is called magmatic eruption.

Pheratic Eruptions

These eruptions usually occur with extremely loud explosions. The explosions are mostly accompanied by carbon dioxide or hydrogen sulfide gas emissions which prove fatal to the organisms around. This eruption is also known as steam-blast eruption and most common example is 1979 explosion in the Java Island, which killed more than 100 people.

Other Types of Eruptions

Effusive eruption causes the lava to flow on ground slowly, and it travels slowly away from the site of eruption. Sub aerial eruptions occur on the surface in contrast with the submarine or subglacial eruption. Limnic Eruptions occur below the bed of lakes and is called Lake Overturn. The gases (mostly CO_2) suddenly erupt from the bed of the lake making the water and environment poisonous killing animals. The lake tsunamis are caused by Limnic disruptions sometimes. **Lake Monoun & Lake Nyos in Cameroon** have suffered this kind of eruptions in near past.

Types of Volcanoes by Periodicity of Eruption

There are three kinds of Volcanoes on the basis of frequency of eruption viz. Active, Dormant and Extinct.

Active volcanoes

Active Volcanoes erupt frequently and mostly located around Ring of Fire. The Mount Stromboli is an active volcano and it produces so much of Gas clouds that it is called Light house of Mediterranean. Other examples are Eyjafjallajökull in island, which erupted in 2010, Mount St. Helens located in Washington USA, Mt. Etna located in Sicily.

Dormant Volcano

Dormant Volcanoes are those who are not extinct but not erupted in recent history. Mount Kilimanjaro, located in Tanzania which is also the highest mountain in Africa is known to be a dormant Volcano. **The dormant volcanoes may erupt in future.**

Extinct Volcano

Extinct or inactive volcanoes have not worked in distant geological past. In most cases the crater of the Volcano is filled with water making it a lake.

Some Notable Terms Related to Volcanoes

Tephra

Materials of all types and sizes that are erupted from a crater or volcanic vent and deposited from the air. The Tephra is all the volcanic material such as Ash, Plumes, Volcanic Bombs, Volcanic Blocks, lapilli etc.

Volcanic Bomb

Pieces of Viscous lava often 2.5 inch size are ejected from the volcanoes. They are viscous rounded shaped half semisolid pieces called Volcanic Bombs. They are either round or spindle shaped or ribbon shaped. Sometimes referred to as Volcanic Blocks, however, Volcanic blocks are thought almost same size, are solid. The smaller particles less than 2.5 inch are called **Lapilli.** The pieces of rocks that erupt violently are also called ballistic fragments.

Lapilli

Lapilli mean "little stones." These are round to angular rock fragments, measuring $^{1/10}$ inch to 2 $^{1/2}$ inches in diameter, which may be ejected in either a solid or molten state.

Volcanic Ash

The Ash from the Volcanoes is hard and abrasive type which is made up of rock particles, minetals and Volcanic glass fragments. The cloud made by the Volcanic Ash is called Ash Cloud. When this ash falls on the ground, it is called Volcanic Ash Fall. The clouds are called Avalanches sometimes.

Pillow lava

Interconnected, sack-like bodies of lava formed underwater.

Pyroclastic Rocks

It is the fragmented (clastic) rock material formed by a volcanic explosion or ejection from a volcanic vent.

Cinder Cone

A cone shape hill of volcanic fragments that accumulate around and downwind from a volcanic vent is a cinder cone. There is usually a bowl-shaped crater at the top. As the gas-filled lava erupts into the air, the lava fragments and forms cinders.

Repose

The time lag between the volcanic eruptions is called repose.

Volcanic Explosivity Index

Volcanic Explosivity Index is a scale that measures the Volume of Volcanic Products, Height of Plume and other observations to decide which volcano is more explosive. Highest Magnitude is 8.

Other Important Trivia

- There are more than 1500 active Volcanoes in the word.
- The Crater Lake in Oregaon USA was formed when a Volcano lost its top in eruption thousands of years ago.
- *The Volcanic Ash is mostly acidic.*
- The Olympus Mons is the tallest known Volcano on Planet Mars.
- Italy's Stromboli Volcano is erupting for more than 2500 years.
- The Mount St. Helense had erupted in 1980, which caused the ash travel across entire US.
- The 1883 eruption of Indonesia's Krakota eruption was so loud that blasts were heared 3000 miles away.
- Mauna Kea in Hawaii is the tallest Volcano on earth. The meaning of its name is White Mountain as it is snow capped. Its height is 4205 meter from Sea Level; however, if it measured from its oceanic base, it is the higher than mount Everest (over 10000 meters).

Pacific Ring of Fire

Pacific Ring of Fire is a horse-shoe shaped 40,000 kilometer area with 75% of Earth's active and dormant volcanoes. It is the area with large number of Volcanic Eruptions and Earth quakes. The most active Volcanoes are located in Chile, Mexico, United States, Canada, Russian Far East, Japan, Philippines, Indonesia, New Zealand, & Antarctica.

Basics of Magma

Magma is a mixture of molten or semi-molten rock, volatiles and solids. Besides molten rock it may contain suspended crystals and dissolved gases. The two most abundant elements in earth's crust and mantle are oxygen and silicon which combine to make Silica i.e SiO_2.

Types of Magma

The classification of the Magmas is done primarily on the basis **of Silica content**. On this basis there are four types of Magmas as mentioned below:

Magma Type	Silica Content	Fe-Mg Content	Temperature	Eruption	Viscosity
Ultramafic or Picritic	Less than 45%	8-32%	High up to 1500°C	Gentle	Low
Mafic or Basaltic	Around 50%	Less than 10%	Up to 1300°C	Gentle	Low

Magma Type	Silica Content	Fe-Mg Content	Temperature	Eruption	Viscosity
Andesitic	Around 60%	Around 3%	Up to 1000°C	Explosive	Medium
Felsic / Rhyolitic	Around 70%	Around 2%	Below 900°C	Explosive	High

From the above table we may note down the following observations:

- Increasing silica content is the basis of classifying the Magma from Picritic to Felsic.
- Increasing Silica content implies a lower temperature of the Magma.
- Increasing silica content implies an explosive eruption behaviour of Magma
- Increasing silica content implies an increasing viscosity of Magma.

Magma often collects in magma chambers that may feed a volcano or turn into a pluton. Magma is capable of intrusion into adjacent rocks, giving rise to **Sills and Dikes,** and extrusion onto the surface as lava, and explosive ejection as Tephra to form **pyroclastic rocks**. The Tephra is all the volcanic material such as Ash, Plumes, Volcanic Bombs, Volcanic Blocks, lapilli etc.

Gases in Magma

The gases are dissolved in magma at high pressure beneath the layers. The gas forms a separate vapor phase when pressure is decreased as magma rises toward the surface of the Earth; very much similar to the carbonated beverages which are bottled at high pressure. Gas gives magmas their explosive character, because volume of gas expands as pressure is reduced. The composition of the gases in magma is:

- Mostly H_2O (water vapour) & some CO_2 (carbon dioxide)
- Minor amounts of Sulphur, Chlorine, and Fluorine gases

The amount of gas in magma is also related to the chemical composition of the magma. Rhyolitic magmas usually have higher gas contents than basaltic magmas. That is also the reason that the Rhyolitic Magma is more explosive than the Basaltic Magma.

Formation of Magma

Outer core is the ONLY part of earth which is liquid, but ***outer core is NOT the source of Magma****, because it does not have the right chemical composition.* For instance, *the outer core is mostly Iron, but magmas are silicate liquids*. Magma originates in the lower part of the Earth's crust and in the **upper portion of the mantle**. There, high temperatures and pressure cause some rocks to melt and form magma.

Since the rest of the earth is solid, in order for magmas to form, some part of the earth must get hot enough to melt the rocks present. Then, magma does not occur everywhere below us. There are only some specific places where volcanoes exist. This means that Magma is formed under some special conditions, which exist in some limited area.

Another point is that in the ocean basins, magmas are not likely to come from melting of the oceanic crust, since ***most magmas erupted in the ocean basins are basaltic.*** To produce basaltic magmas by melting of the basaltic oceanic crust would require nearly 100% melting, which can not happen. In the continents, both basaltic and rhyolitic magmas are erupted and intruded. Basaltic magmas are not likely to have come from the continental crust, since the average composition is more siliceous, but more siliceous magmas (andesitic – rhyolitic) could come from melting of the continental crust. Basaltic magmas must come from the underlying mantle. Thus, with the exception of the continents, ***magmas*** *are most likely to originate in the mantle from* ***melting of mantle peridotite, (a rock made up of olivine, pyroxene, and garnet)*** *— evidence comes from pieces brought up by erupting volcanoes.*

Does Geothermal Gradient causes melting of Rocks?

Temperature increases with depth or pressure in the Earth along the geothermal gradient. The normal geothermal gradient is somewhat higher beneath the oceans than beneath the continents, at least at shallow levels. But when we observe the normal geothermal gradients, we find that under the normal conditions, the *geothermal gradient is not high enough to melt rocks*, that is why that with the exception of the outer core, most of the Earth is solid. Thus, the **geothermal gradient is not a very substantial factor** contributing in the formation of the Magma.

Does Radioactive Heat Cause Melting of Rocks?

The radioactive elements such as Uranium, Thorium etc, keep decaying below. During radioactive decay, sub-atomic particles are released by the decaying isotope and move outward until they collide with other atomic particles. Upon collision, the kinetic energy of the moving particles is converted to heat. If this heat cannot be conducted away, then the temperature will rise. Most of the heat within the Earth is generated by radioactive decay, and this is the general reason why temperature increases with depth in the Earth. But again *this is not enough to prove the melting of the rocks*. We should know that ***most the radioactive isotopes are concentrated in the crust.*** Although there are areas in the continental crust where high concentrations of radioactive elements have locally raised the temperature, at least high enough to cause metamorphism, but it is more unlikely that areas of high concentration *develop within the mantle. Thus, concentrations of radioactive elements are not likely to cause melting.*

Does decrease in Pressure cause rock melt?

There are two things. First is that very high pressures in mantle rocks prevent atoms within minerals from breaking chemical bonds and moving freely from one another to form magma. Therefore, most rocks within the mantle do not melt even though their temperature may be greater than that necessary to melt the same rocks at the lower pressures of the Earth's surface. However, if something occurs that the pressure on mantle rock is decreased; the atoms may move freely from one another.

This would result in the partial melting of the already very hot solid rock. This process is called pressure-release melting. It is a scientifically proved theory and is found to be *common along divergent plate margins*, and within mantle plumes.

Does addition of Water causes melting?

The addition of small amounts water to peridotite will result in a decrease in its melting temperature. This is largely due to the electrically polarized nature of a water molecule, as there is an unequal distribution of electrons around the water molecule. The electrical polarization causes a decrease in cation-anion bond strengths within minerals, and so at very high temperatures the bonds may be broken so that atoms may move freely from one another to form a magma. This process also results in partial melting of the mantle rock. This type of melting occurs within subduction zones as water is 'squeezed' from the subducted oceanic lithosphere into the overlying ultramafic mantle wedge.

How Magma is finally formed?

The initial composition of the magma depends upon the composition of the source rock and the degree of partial melting. In general, melting of a mantle source (garnet peridotite) results in mafic/basaltic magmas, while melting of crustal sources yields more siliceous magmas. In general more siliceous magmas form by low degrees of partial melting. As the degree of partial melting

increases, less siliceous compositions can be generated. So, melting a mafic source thus yields a felsic or intermediate magma. Melting of ultramafic (peridotite source) yields a basaltic magma. Then, the transportation toward the surface or during storage in the crust can alter the chemical composition of the magma. This is called magmatic differentiation and includes some processes such as assimilation, mixing, and fractional crystallization.

Tides

Tides are a result of gravitational pull by **both Sun and Moon**, but the pull exerted by Sun is apparently weak. This is because of the larger distance as the gravitational force is inversely proportional to the square of the distance. The alignment of Sun and moon affects the size of the tides.

Tides are known to Indians since ancient times. In Rig-Veda there was no record about Tides, but in Samveda Chapter 10, Part II, 20, mentions *Soma….samudravardhanam,* links moon to tides. In the Indus Valley Civilization, a dockyard was found in Lothal in Gujarat. The 4 walls of this dock towards the estuary are made up of kiln burnt bricks, which prove that these people not only observed but also understood and created structures as per the phenomena & impact of tides.

Earliest geographer to state that the tides are caused by moon was Pytheas, an early Greek geographer around 300 BC. But he could not understand what the reason was. Newton's analysis of gravitation explained the phenomenon.

Stages of Tides

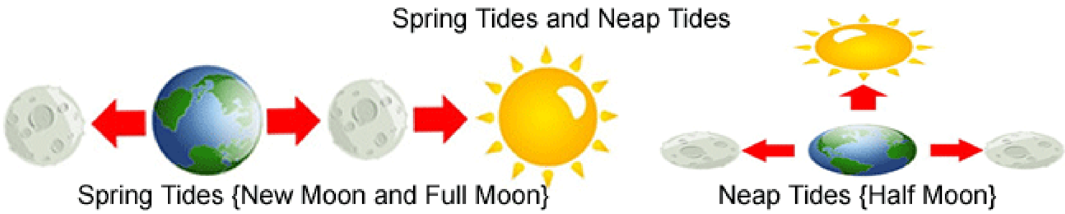
There are 4 distinct stages of tides:

- Stage I: Sea level rises over several hours, covering the intertidal zone and this is called **flood tide**.
- Stage II: The water rises to its highest level, known as **high tide**.
- Stage III: Sea level falls over several hours, revealing the intertidal zone. This is called **ebb tide**.
- Stage IV: The water stops falling, this is called **low tide**.

In general the rising tides are called *flood tides* and falling tides are called *ebb tides* and they are known as Jwar & Bhata in Hindi respectively. In astronomy, the alignment of three or more celestial bodies in the same gravitational system along a line is called **Syzygy** and eclipses occur at the time of Syzygy. Syzygy also affects tides in the form of variations between the High tides and Low Tides.

Spring Tides and Neap Tides

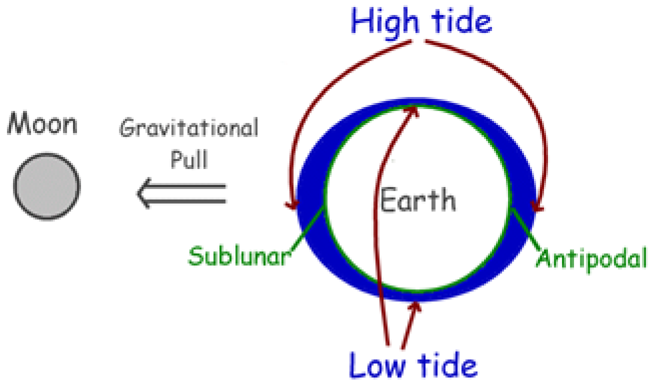
When there is greatest variation between the high tides and low tides, it is called Spring Tides. **Gulf of Fundy** is known for highest tides in the world (approximately 50 meters). At spring tide, Sun, Moon and Earth are in a line. When there is smallest difference between high and low a tide, it is called Neap tide. It occurs when Sun, moon and Earth are at right angles.



- Neap Tides occur when Moon is a quarter phase
- Spring tides occur on Full Moon as well as New Moon.
- *Spring tide has **higher than normal high tides** and lower than normal low tides.*
- During the Neap Tides, the high tide is lower and the low tide is higher than usual.

Daily Frequency of Tides

Earth rotates around its own axis and it takes 24 hours to finish its rotation. The direction of Earth rotation is the same in which Moon revolves around earth. The gravitational attraction moon raises the water on two opposite sides of Earth; these points are called Sub-lunar and antipodal points.



The tidal bulge shown in the above graphics follows the revolution of the moon, and the earth rotates eastward through the bulge once every **24 hours and 50 minutes**. (This is because, of the relative distance covered by moon in its orbit). This tidal bulge shows that the water of the entire world ocean is pulled by the moon's gravity.

On **both the opposite side of the earth simultaneously there is a high tide.** This high tide is on both sides due to inertia of the ocean water and because the earth is being pulled toward the moon by its gravitational field and the ocean water remains left behind. This means that Earth is pulled little away from the water. This creates a high tide on the side of the earth opposite the high tide caused by the direct pull of the moon.

Duration and Frequencies of Daily Tides

Most coastal areas experience **two high and two low tides per day**. One of these high tides is at the point on the earth which is closest to the moon (sub lunar) and other high tide is at the opposite point on the earth (antipodal).

One tidal cycle comprises two high tides and two low tides. One tidal cycle completes in 24 hours and 50.4 minutes. This is because of the revolution of Moon around the earth and both earth's rotation and moon revolution are in same direction. (Moon is not stationary, so there is a difference, if moon were stationary the high tides would have occurred exactly in 12 hours). The high tides occur at an interval of 12 hours and 25.2 minutes. This means that if there is a high tide is at 7.00 am, next high tide would be at 7.25 pm and next would be at 7.50 am, and so on. The time difference between two high tides is called "Tidal Interval". The tidal cycle in this pattern is called **semidiurnal.** However, most of the enclosed water bodies or away from the open ocean such as Caribbean sea or Caspian Sea, there are only one high tide and one low tide. This pattern is called Diurnal tides. At the coast of the oceans, there may be two high tides, of unequal length. This is called Mixed Tides.

Apogean Tides and perigean tides

When moon is at closest point to Earth during its revolution around earth it is called Perigee. The high tides are higher than usual and low tides are lower than usual at this point. When moon is farthest, it is called apogee and the high tides are lower than usual and low tides are higher than usual at this point of time. The highest Spring tides occur when the Moon is at its closest to the Earth…the so-called Perigee Tide.

Impact on tides if there was no moon?

If there is no moon, lunar water tides on the Earth go away, but the solar water tides still occur. At the same time, there would be no 'Spring' or 'Neap' tides.

The Tides Which Are Not Tides

The tide suffix has been used for various phenomena. Some of them are not at all related to the tides. The following are a few:

Storm Tides

Storm tides is the name given to the offshore rise of water associated with a low pressure weather system. Wind causes the water to pile up higher than the ordinary sea level and they are nowhere related to the tides.

Rip Tides

Rip tides are strong channel of water flowing seaward from near the shore, typically through the surf line. They are again caused by the winds and not related to Tides.

Tsunami

Tsunamis are called 'harbour wave', and they are result of displacement of a large volume of a body of water, usually an ocean due to Earthquakes, volcanic eruptions and other underwater explosions.

Other Terms Related to Tides

Tidal datum

A chart obtained from the long period of a tidal record is called tidal datum.

Tidal Flat

The sands uncovered by the low tides is called tidal flat

Tidal Range

Tidal range is the difference between the *height of water at low and high tides.*

Tidal Bore

Tidal bore is a Tidal phenomenon in which the leading edge of the incoming tide forms a wave (or waves) of water that travel up a river or narrow bay against the direction of the river or bay's current.

Earth's Tides

Earth's tides, also known as terrestrial tides affect the entire Earth's mass. This involves the movement of Earth's crust in all directions, due to solar and lunar gravitation.

Intertidal zone

Intertidal zone is sometimes known as littoral zone and it is that area of the sea shore or shore of water body such as Open Ocean, which is exposed to air at low tides and water at high tides. The examples are rocky cliffs, sandy beaches, or wetlands. **Bay of Fundy is an excellent Intertidal Zone Ecosystem.**

Do tides affect Earth's Magnetic Field?

Yes. The tidal forces generate currents in conducting fluids in the Earth's interior and they affect the Earth's magnetic field.

Tidal Ports

During high tides, water rushes into harbours (Tidal Bore). This helps ships enter and exit harbours safely. High tides make ocean/sea water rush into the mouths of rivers. This helps ships to enter port towns like New York, London, Rotterdam, and Hamburg. This is perfectly advantageous for some ports in India such as *Kandla, Mangalore and Kolkata's diamond harbour.*

Tides and prevention of siltation

Tides take away the terrigenous material brought by the rivers at the rivine harbours and thus help in the prevention of siltation.

Tides and prevention of Rivers Freezing

The temperature at which sea water freezes is much lower than that of river water. In cities like London, due to the high tide, the sea water enters the river and prevents it from freezing.

Tidal power

Power can be generated exploiting the huge energy of the tides. This can be done by making dams and the tidal zones where best tides occur and allowing the water to enter and exit through a turbine. However, this is a complicated work and not much success has been achieved as of now. The water accumulation during high tides can also be stored behind specially made dams, which can be then used for hydel power. World first tidal power station is Rance Tidal Power Station, located on the estuary of the Rance River, in Brittany, France. It is also world's largest tidal power station which started working in 1966. Its annual output is 600 GWh.

Some Questions Related to Tides

Why there are no high low tides at Equator?

For any particular location, their height and fluctuation in time depends to varying degrees on the location of the Sun and the Moon, and to the details of the shape of the beach, coastline, coastline depth and prevailing ocean currents. The tidal bulge of the Moon follows along the path on the earth's surface which intersects with the orbital plane of the Moon. This plane is tilted about 23 degrees with respect to the equatorial plane of the earth. The result is that near the equator, the difference between high tide and low tide is actually rather small, compared to other latitudes. Further also note that the Atlantic and Pacific coast tides are not the same. This is because of the fact that the nature of tides on the Earth's oceans is very complex. Every coastal location has its own unique tidal signature depending on its latitude, longitude, water depth and salinity.

What is use of Tides in Navigation?

Tidal flows as well as Tidal heights are of profound importance in navigation and very significant errors in position will occur if they are not taken into account. Many rivers and harbours have a shallow " bar" at the entrance which will prevent some boats with significant draught from entering at certain states of the tide. The timings and velocities of tidal flow can be found by looking at a tidal chart or tidal stream atlas for the particular local area.

How tides are useful in Fishing?

Tides move water, bringing water in and taking water out. Understanding the cycles and effects of tides on fish helps in better fishing. The full and new moons normally create better fishing conditions because of the spring tides. The reason behind this is that fish are easier to catch when they are feeding and it's the tide and currents that dictate this. When the water begins to move, smaller fishes are at the mercy of the current and get confused in the turbulent water. Larger fishes have an advantage because they are equipped to feed in this turbulent water. These larger fishes get more easily trapped when there are tides.

Prelims Model Questions

Earthquake Model Questions

1. Which among the following is are characteristic features of the boundaries of the Indian Plate?

1. Young fold mountains
2. Island arcs
3. Mid-Oceanic Ridges
4. Trenches

Choose the correct option from the codes given below:

[A] Only 1

[B] Only 1 & 2

[C] Only 1, 2 & 3

[D] 1, 2, 3 & 4

Answer: [D] 1, 2, 3 & 4

Salient features of the Indian Plate

The countries that lie within the Indian Plate are India, Sri Lanka, Bangladesh, Bhutan and parts of Pakistan, Nepal, and Afghanistan. Australia and Tasmania are also part of the Indian plate but are located on a separate continental crust. Some countries contiguous with the Indian plate are Iran, Afghanistan, China, Tibet, Tajikistan, Kyrgyzstan, Myanmar, and New Zealand. Diverse topographic features that characterize boundaries of the Indian plate include young mountain chains, trenches, island arcs, and mid-oceanic ridges. A large portion of the Indian plate is submerged below the Indian Ocean and the Pacific Ocean and consists of oceanic crust. The northern boundary of the Indian plate is defined by the Himalayan Mountains, which are part of the Alpine Himalayan seismic belt.

The Himalayas stretch from Kashmir in the west to Arunachal Pradesh in the east and straddle Nepal and Bhutan in between. From Arunachal Pradesh, the boundary of the Indian plate swings sharply southward, from where it extends as the Arakan Yoma range of mountains. From there, it extends eastward toward the Andaman, Nicobar, and Indonesian Islands as a long continuous chain of Andaman, Sumatra, Java, Sunda Trenches. This intersects the Circum Pacific Belt near Philippines and enters the Pacific Ocean. Beyond this, it again turns southward, toward and through New Zealand, via the Kermadec-Tonga Trench, New Hebrides Trench, and Macquarie Ridge. Beyond this, it re-enters the Indian Ocean as South East Indian Ocean Ridge and swings toward the Arabian Sea as the South West Indian Ocean Ridge, Central Indian Ocean Ridge, and the Carlsberg Ridge. There it joins the Sulaiman and Kirthar ranges of Pakistan. Several major fracture zones are associated with the oceanic ridges.

The Indian plate is bound by all three kinds of plate boundaries, i.e., destructive, constructive and conservative. A destructive boundary indicates the presence of a subduction zone, which manifests as shortening of the crust, and its topographic manifestation is the trench and island arc system. The Andaman Sumatra Java Sunda trench represents the convergent boundary between the Indian plate and the Eurasian plate in the Bay of Bengal and likewise further east, in the Pacific Ocean, the New Hebrides trench, Tonga trench and the Kennadec trench represent the boundary between the Indian and the Pacific plate. A divergent, i.e., a creative plate boundary indicates sea floor spreading and is indicated by mid-oceanic ridges. A long chain of midoceanic ridges exists in the Indian Ocean. A conservative boundary indicates that the Indian plate is sliding past the adjacent plate in that region.

(source: Understanding Earthquake Disasters By Amita Sinvhal, PP 52)

2. Which one of the following terms are related to volcanoes?

1. Caldera
2. Erg
3. Pumice
4. Dykes

Choose the correct option from the codes given below:

[A] 1, 2 & 3

[B] 1, 2, 3 & 4

[C] 1, 3 & 4

[D] 1 & 4

Answer: [C] 1, 3 & 4

Calderas are large volcanic craters that form by two different methods: 1) an explosive volcanic eruption; or, 2) collapse of surface rock into an empty magma chamber. Pumice is a is a volcanic rock that consists of highly vesicular rough textured volcanic glass, which may or may not contain crystals. It is typically light coloured.

3. Consider the following statements with reference to the spring tides and neap tides:

1. Neap Tides occur when Moon is a quarter phase
2. Spring tides occur on Full Moon as well as New Moon
3. Spring tide has higher than normal high tides and lower than normal low tides
4. During the Neap Tides, the high tide is lower and the low tide is higher than usual

Which among the above statements is / are correct?

[A] Only 1 & 2

[B] Only 1, 2 & 3

[C] Only 2, 3 & 4

[D] 1, 2, 3 & 4

Answer: [D] 1, 2, 3 & 4

Kindly note the above four differences between spring tides and neap tides.

4. A tourist in Mumbai observes high tide near Gateway of India at 7.00 AM. At what time, he should expect another high tide on the same day?

[A] 7.00 PM

[B] 7.25 PM

[C] 7.40 PM

[D] 8.50 PM

Answer: [B] 7.25 PM

Most coastal areas experience two high and two low tides per day. One of these high tides is at the point on the earth which is closest to the moon (sub lunar) and other high tide is at the opposite point on the earth (antipodal). One tidal cycle comprises two high tides and two low tides. One tidal cycle completes in 24 hours and 50.4 minutes. This is because of the revolution of Moon around the earth and both earth's rotation and moon revolution are in same direction. (Moon is not stationary, so there is a difference, if moon were stationary the high tides would have occurred exactly in 12 hours). The high tides occur at an interval of 12 hours and 25.2 minutes. This means that if there is a high tide is at 7.00 am, next high tide would be at 7.25 pm and next would be at 7.50 am, and so on. The time difference between two high tides is called "Tidal Interval". The tidal cycle in this pattern is called semidiurnal. However, most of the enclosed water bodies or away from the open ocean such as Caribbean Sea or Caspian Sea, there are only one high tide and one low tide. This pattern is called Diurnal tides. At the coast of the oceans, there may be two high tides, of unequal length. This is called Mixed Tides.

5. Which among the following is the outcome when tide enters the narrow and shallow estuary of a river?

[A] Tidal Bore

[B] Ocean Gyre

[C] Flood Tide

[D] Rotary current

Answer: [A] Tidal Bore

Tidal bore is a Tidal phenomenon in which the leading edge of the incoming tide forms a wave (or waves) of water that travel up a river or narrow bay against the direction of the river or bay's current.

6. Subduction is responsible for__:

1. Volcanoes
2. Earthquakes
3. Orogeny

Choose the correct option from the codes given below:

[A] Only 1 & 2

[B] Only 2 & 3

[C] Only 1 & 3

[D] 1, 2 & 3

Answer: [D] 1, 2 & 3

Subduction is responsible for high rates of volcanism, earthquakes, and mountain building. When the large pieces of material on the subducting plate are pressed into the overriding plate, it results in the Orogeny or Mountain formation. These areas are subject to many earthquakes.

7. With reference to the subduction, consider the following statements:

1. Subduction occurs when denser ocean crusts slide beneath lighter continental crusts
2. Subduction causes the formation of deep ocean trenches

3. Subduction is responsible for high occurrences of volcanoes and earthquakes in some areas

Which among the above statements is / are correct?

[A] 1 & 2

[B] 2 & 3

[C] 1 & 3

[D] 1, 2 & 3

Answer: [D] 1, 2 & 3

Subduction is the process that takes place at convergent boundaries by which one tectonic plate moves under another tectonic plate and sinks into the mantle as the plates converge. Plates include both oceanic crust and continental crust. Stable subduction zones involve the oceanic crust of one plate sliding beneath the continental crust or oceanic crust of another plate. That is, the subducted crust is always oceanic while the overriding crust may or may not be oceanic. Subduction zones are often noted for their high rates of volcanism, earthquakes, and mountain building. Formation of Trench: Trenches are centerpieces of the distinctive physiography of a convergent plate margin. As the subducting plate approaches the trench, it is first bent upwards to form the outer trench swell, then descends to form the outer trench slope. The outer trench slope is disrupted by a set of subparallel normal faults which staircase the seafloor down to the trench. The plate boundary is defined by the trench axis itself. Beneath the inner trench wall, the two plates slide past each other along the subduction decollement, the seafloor intersection of which defines the trench location. The overriding plate contains volcanic arc (generally) and a forearc. The volcanic arc is caused by physical and chemical interactions between the subducted plate at depth and asthenospheric mantle associated with the overriding plate. The forearc lies between the trench and the volcanic arc. Forearcs have the lowest heatflow from the interior Earth because there is no asthenosphere (convecting mantle) between the forearc lithosphere and the cold subducting plate.

8. Consider the following statements:

1. Convergent plate boundaries produce more explosive volcanoes in comparison to divergent plate boundaries

2. Convergent plate boundaries produce more dangerous earthquakes in comparison to divergent plate boundaries

Which among the above statements is / are correct?

[A] Only 1

[B] Only 2

[C] Both 1 & 2

[D] Neither 1 nor 2

Answer: [A] Only 1

Convergent Boundaries

- Explosive Volcanoes
- High Silicic Magma: The magma comes from the subduction of lithospheric crust so it has more of silicate.
- Stratovolcanoes
- Consumption of the Ocean Floor
- Shallow, Intermediate as well as Deep Focus Earthquakes

Divergent Boundaries

- Quite, Non explosive volcanoes
- High Basaltic Magma: Oceanic crust is created at the mid-oceanic ridges; it forms from up welling magma that cools and solidifies to igneous rock.
- Most of this is Basaltic.
- Shield Volcanoes
- Creation of Ocean Floor
- Shallow Focus earthquakes only

In the above question, the second statement is not correct, because any of them can produce dangerous earthquakes

9. What is / are the implications of the liquid outer core on the Earthquake waves?

1.The P waves can not pass through the liquid outer core

2.The S waves can not pass through the liquid outer core

3.The P-waves are deviated

4.The S-waves are deviated

Choose the correct option:

[A] 1 & 2

[B] 2 & 3

[C] 3 & 4

[D] 1 & 4

Answer: [B] 2 & 3

10. Consider the following general observations:

1. Roughly half of India's total area is earthquake prone

2. When we travel from north to south, the seismicity roughly decreases
3. Most epicentres are located near eastern and western syntaxes of Himalaya
Which among the above statements is / are correct?

[A] Only 1 & 2

[B] Only 2 & 3

[C] Only 1 & 3

[D] 1, 2 & 3

Answer: [D] 1, 2 & 3

11. If the earth had no satellite of its own i.e., the moon, which of the following phenomena will not occur ?

[A] Neap tides

[B] Ocean currents

[C] Spring tides

[D] Tides

Answer: [C] Spring tides

The moon has a significant impact on tides, due to the gravitational attraction of the moon on the Earth's water. This effect is magnified when the moon's gravitational attraction aligns with the gravitational pull of the sun. This produces the highest high tides and lowest low tides, known as spring tides. When the pull of the moon and the sun are perpendicular to each other, the lowest high tides and highest low tides, collectively termed neap tides, are produced. While ocean currents are primarily affected by winds and the Coriolis force, tides can have a large impact on currents near the coasts.

12. Consider the following:
1. Southeast Asia
2. Andes Mountains
3. Mid-Atlantic Ridge
4. Caribbean Plate
Which among the above is / are subduction zones?

[A] Only 1 & 2

[B] Only 2 & 3

[C] Only 2, 3 & 4

[D] Only 1, 2 & 4

Answer: [D] Only 1, 2 & 4

Mid Atlantic Ridge is where the two plates are diverging, which creates more oceanic floor. Thus, it is not subduction zone. Rest all are subduction zones.

13. With reference to the Earthquakes, consider the following statements:

1. Majority of earthquake devastation is caused by Love (L) and Rayleigh waves

2. The S waves can not pass through the liquid outer core

Which among the above is / are correct statements?

[A] Only 1

[B] Only 2

[C] Both 1 & 2

[D] Neither 1 nor 2

Answer: [C] Both 1 & 2

14. Consider the following statements:

1. The rotation of the earth on its axis generates centrifugal force on water.

2. Effect of centrifugal force in creating tides is of great use in determining the location of the high tides and low tides

Which among the above is / are correct statements?

[A] Only 1

[B] Only 2

[C] Both 1 & 2

[D] Neither 1 nor 2

Answer: [A] Only 1

The rotation of the earth on its axis generates centrifugal force on water. As a result there is a tendency for the water to be thrown away from the earth. The centrifugal force is directly proportional to the radius of the circle of rotation. Therefore the centrifugal force will be the maximum at the equator and minimum near the poles. However, the effect of the centrifugal force along parallels of latitude will be uniform irrespective of the longitude. Therefore, the effect of centrifugal force in creating tides is of no concern while determining the location of the high tides and low tides.

15. Which of the following phenomena pertain to the plate tectonics?

1. Polar Wandering

2. Continental drift

3. Sea floor spreading

4. Glaciation

Select the correct option from the codes given below:

[A] Only 1 & 2

[B] Only 2 & 3

[C] Only 1, 2 & 3

[D] 1, 2, 3 & 4

Answer: [C] Only 1, 2 & 3

Plate motion/movement takes place primarily due to three factors-Polar Wandering, Continental drift and Sea floor spreading.

Polar wandering is the relative movement of the earth's crust and upper mantle with respect to the rotational poles of the earth. Continental drift refers to the movement of the continents relative to each other.

Sea floor spreading describes the movement of oceanic plates relative to one another.

A glacial period (alternatively glacial or glaciation) is an interval of time (thousands of years) within an ice age that is marked by colder temperatures and glacier advances. Interglacials, on the other hand, are periods of warmer climate between glacial periods. The last glacial period ended about 15,000 years ago. The Holocene epoch is the current interglacial. A time when there are no glaciers on Earth is considered a greenhouse climate state.