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Component I(B) Description of Module

1	**Items**	**Description of Module**
2	Subject Name	Geography
3	Paper Name	Geomorphology
4	Module Name/Title	Earthquake
5	Module Id	GEO-12
6	Pre-requisites	
7	Objectives	To Define Earthquakes, Seismology and Components of Seismographs; Earthquake Processes; Types of Seismic Waves; Plate Tectonic and Earthquakes; Causes and Distribution of Earthquakes; Measurement of Earthquakes
8	Keywords	Seismology, Epicentre, Focus, Seismic waves, Convergent, Divergent and transform boundaries

EARTHQUAKES

Earthquake is vibration of the earth caused by shock waves due to sudden release of energy, that results from sudden displacement along faults or movement or magma or sudden ground subsidence. The energy is abruptly released after a long and slow accumulation of strain along a fault. The adjustments of the earth's surface after the initial earthquake generates series of low intensity earthquakes referred to as aftershocks. The scientific study of earthquake is called **seismology**, derived from the Greek *seismos,* meaning 'earthquake' and *logos,* meaning 'reason' or 'speech'. Data from seismology have become an integral part of the modern day scientific understanding of the constitution of the Earth's interior.

1. Modern seismology

The credit for developing the science of seismology goes to a group of British scientists chief amongst them being **John Milne** who is credited for the creation of the instrument called seismograph capable of detecting signals from distant earthquakes. The seismograph consists of-

- An inertia member,
- A transducer, and
- A recorder.

The **inertia member** is a weight suspended by spring so that it acts like a pendulum but capable of moving in one direction only. The inertia member tends to remain at rest as the earth waves pass by. The **transducer** is capable of detecting the relative motion between the mass and the ground which it converts into a recordable form. A standard **recorder** is a cylindrical drum with a sheet of recording paper wrapped on it. It rotates on a constant speed, producing a series of parallel lines.When an earthquake strikes a place, these lines move in response.

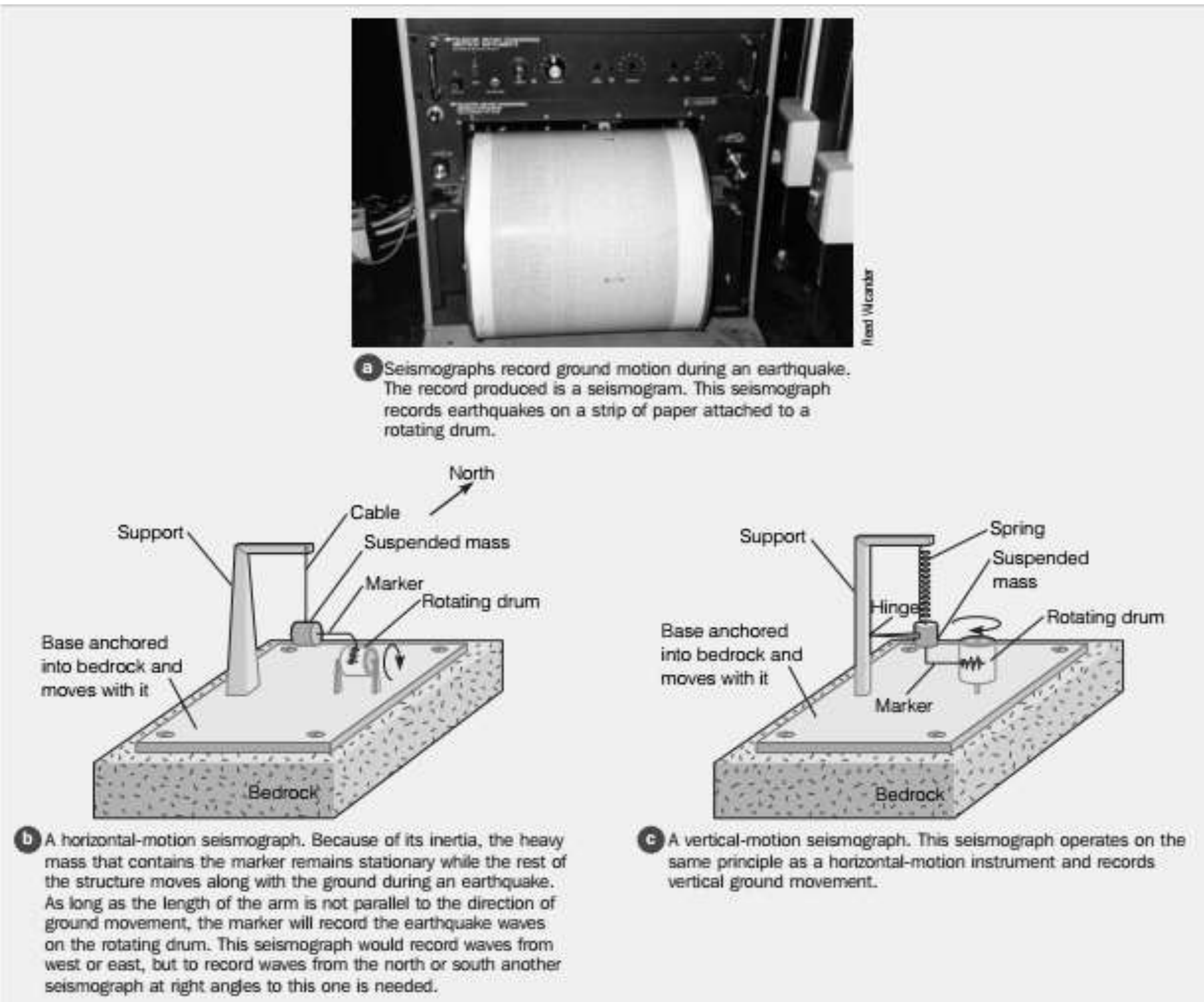


Fig.1: Seismographs

Source: Adopted from ‘Physical Geology: Exploring the Earth’ by Monroe, Wicander, Hazlett, 2007.

1.1 Epicentre and focus of an earthquake

The point at which the energy is first released is the **focus** of the earthquake or the hypocentre. **Epicentre** on the other hand, is the place on the surface of the earth which is directly above the focus. For instance, the December 26, 2004 earthquake that triggered the devastating tsunami in the Indian Ocean had an epicentre 160 km off the west coast of northern Sumatra and a focal depth of 30 km. (Figure 2a).

Depending upon the focal depth three categories of earthquakes can be recognised: shallow focus, intermediate focus and deep focus.

Shallow and **intermediate focus**earthquakes have focal depths of less than 70 km and between 70 and 300 km from the surface, respectively. While those with the foci located at a depth of more than 300 km are categorised as**deep focus** earthquakes. Shallow focus earthquakes are the most destructive as the energy has little time to dissipate before reaching the surface.

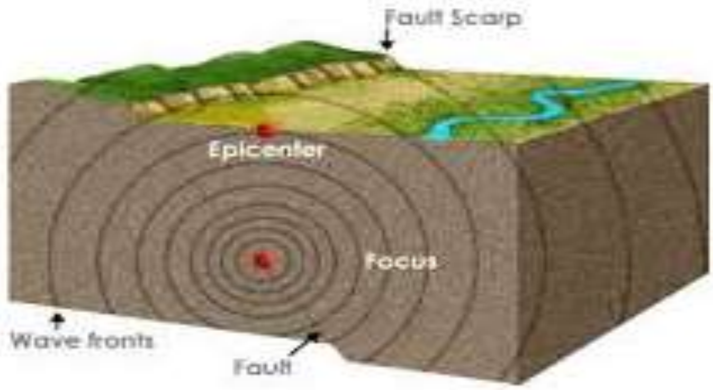


Figure 2: Focus and Epicentre of Earthquake

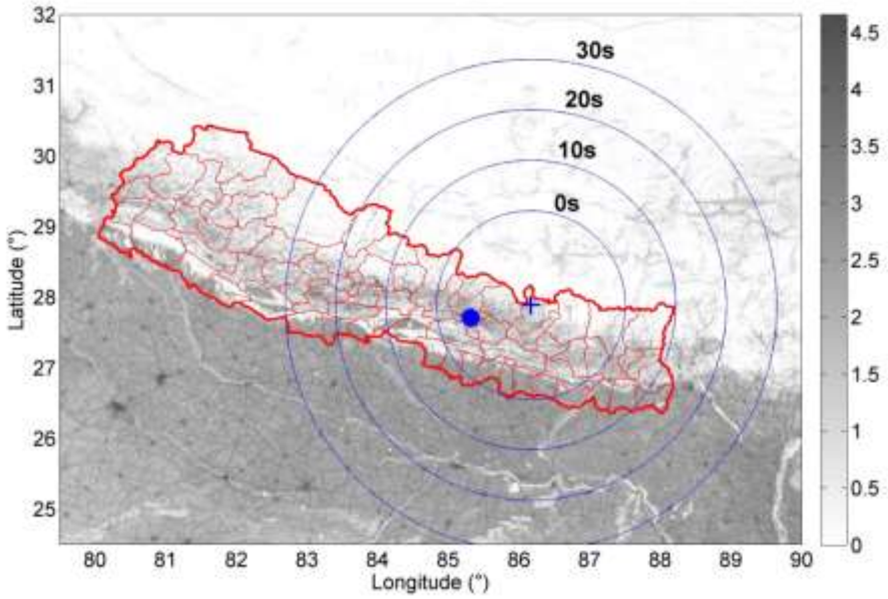


Figure 3: The Epicentre of Nepal earthquake, May 2015

Figure 4: Distribution of Earthquakes

2. Earthquake Processes

Various earthquake processes are classified as follows:

Faulting

A **fault** refers to a crack or a fracture in the earth's surface and **faulting** refers to the process of fault rupture. As the two lithospheric plates move past each other, they are slowed down due to friction along their boundaries, producing strain and deformation in the rocks. Increase in stress in these rocks over their strength, leads to rupture, forming a fault or a crack and producing earthquake. Rupturing starts to occur at the focus of the earthquake and continuesto move upwards, downwards and laterally. In this process, the stored energy is released, producing shock waves or earthquake waves or **seismic waves,**that vibrate the ground.

Tectonic creep

Tectonic creep refers to faults displaying gradual displacement and is usually not accompanied by earthquakes. Thisprocess however, can be potentially damaging causing deformation of roads, and other standing structures.

Slow earthquake

Slow earthquakes are relatively newly recognized earth process, also produced due to fault rupture. The rupture is relatively slow and may span over several days and even months. Their magnitude vary between 6 and 7 as they are located over large areasof the rupture. The amount of slip is generally very small up to a few centimetres.The continuous geodetic surveys and measurement with GPS (Global Positioning Satellites) has aided in the identification and recognition of these earthquakes.

FACTFILE

More than 90, 000 earthquakes are recorded annually worldwide. Majority of these are too small to be felt but are nonetheless recorded. It is observed that only about 30 percent are strong enough to be felt.

3. Types of seismic waves

When an earthquake strikes a place, it is the seismic waves that cause strong motion, crack the ground and causesimmense damage to standing structures and buildings. The energy released during earthquake moves mainly in two forms of seismic waves radiating in all directions from the focus – **Body waves** and **Surface waves**. While the **Body waves** travel through the solid body of the earth and are analogous to sound waves, the **Surface waves** travel along the ground and bear similarity to waves on water surface.

3.1 **Body waves:** Two type of Body waves are recognised **-P waves and S waves**.

P waves, or primary waves are the fastest moving seismic waves and are felt first. They can travel through solids, liquids and gases. P waves are similar to sound waves and are compressional waves propagating in same direction as the waves themselves in two and fro motion. The material through which the P waves travel compresses and expands as the waves move through it and comes back to its original position once the waves have passed by.**S waves**or secondary waves travel slower than P waves and can travel through solids only. S waves are also called **shear waves** due to strong side-to-side and up-and-down shearing motion. The movement of the particle is perpendicular to the wave motion. Since liquids are not rigid, they have no shear strength thus, S waves cannot be transmitted through them.

The P and S waves travel at different velocities that are determined by the density and elasticity of the materials through which they travel.The velocity of P waves is greater than S waves in all types of media and thus P waves arrive first at recording seismic stations. The P and S waves travel times are published in *time- distance graphs* that illustrate the difference between the arrival times of two waves as a function of the distance between the arrivals of the two Primary (P) and Secondary (S) waves. Since the two waves have varying velocities – P waves travel at about 6 kilometres per second through bedrock while the S waves travel at about 3.5 kilometres – the distance to the earthquakes focus can be calculated.

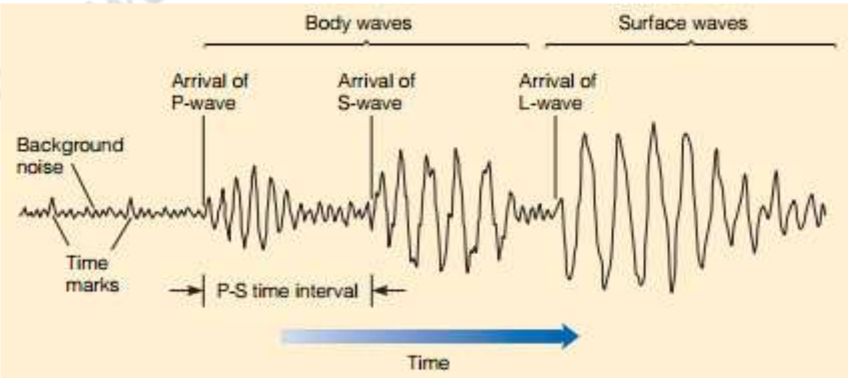


Figure5: Schematic seismogram showing the arrival order of the P, S and L waves.

Source: Adopted from 'Physical Geology: Exploring the Earth' by Monroe, Wicander and Hazlett, 2007.

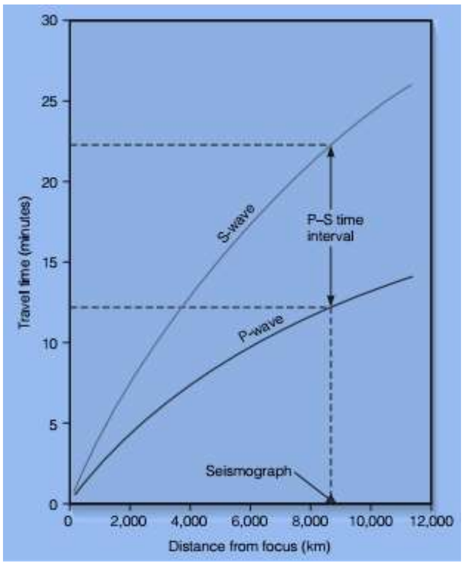


Figure 6: A time- distance graph showing the average travel times for P and S waves. Source: Adopted from 'Physical Geology: Exploring the Earth' by Monroe, Wicander and Hazlett, 2007.

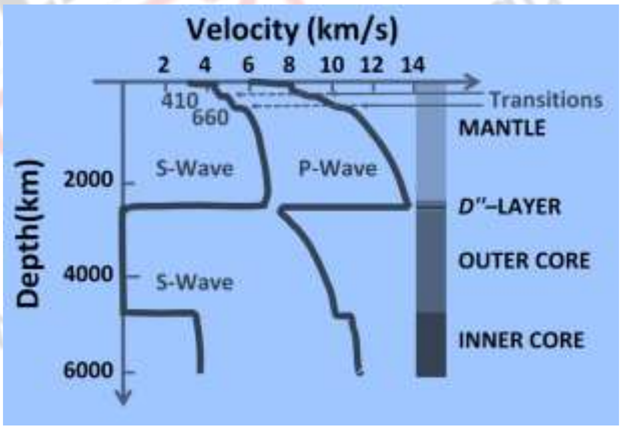


Figure 7: Change in Velocity of Waves with depth

3.2 Surface waves

The movement of **surface waves**is limited to the ground or just below it. These are slower than the body waves and arrive just after the **S waves**. Two important surface waves are **Rayleigh waves** and **Love waves,** named after the British scientists Lord Rayleigh and A.E.H. Love, respectively.

Rayleigh waves are slow waves and behave like water waves wherein the individual particles of the material move in elliptical path within a vertical plane oriented in the direction of wave movement.

Love waves aresimilar to an S wave, andthe individual particles move only back and forth in a horizontal plane perpendicular to the direction of wave travel.

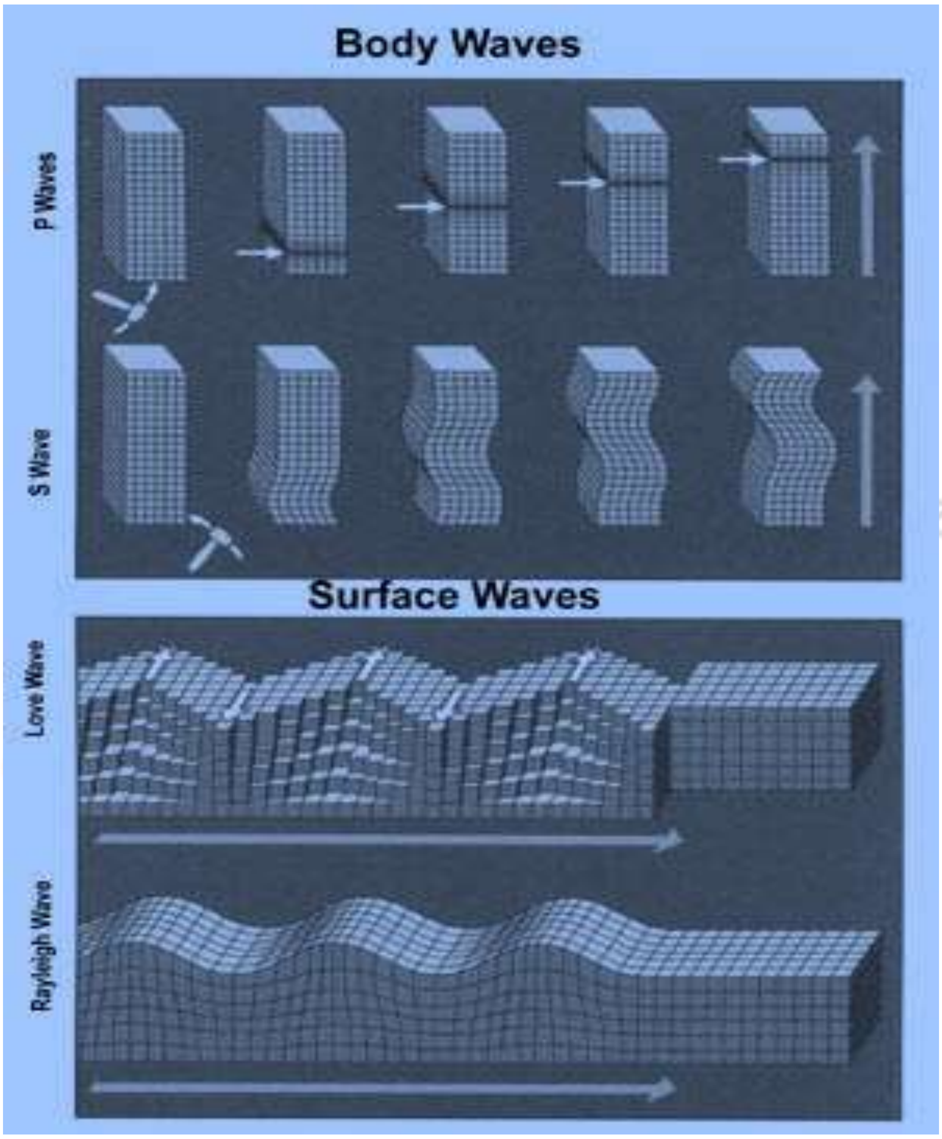


Figure 8: P waves and S waves are types of seismic body waves; Love and Rayleigh waves are surface waves that differ in the type of ground motion they cause.

4. Plate Tectonics and Earthquakes

The distribution of earthquakes is closely related to plate boundaries as they are triggered by the motion of the Earth's crust, when the plates move either towards each other, away from each other or slide past each other.

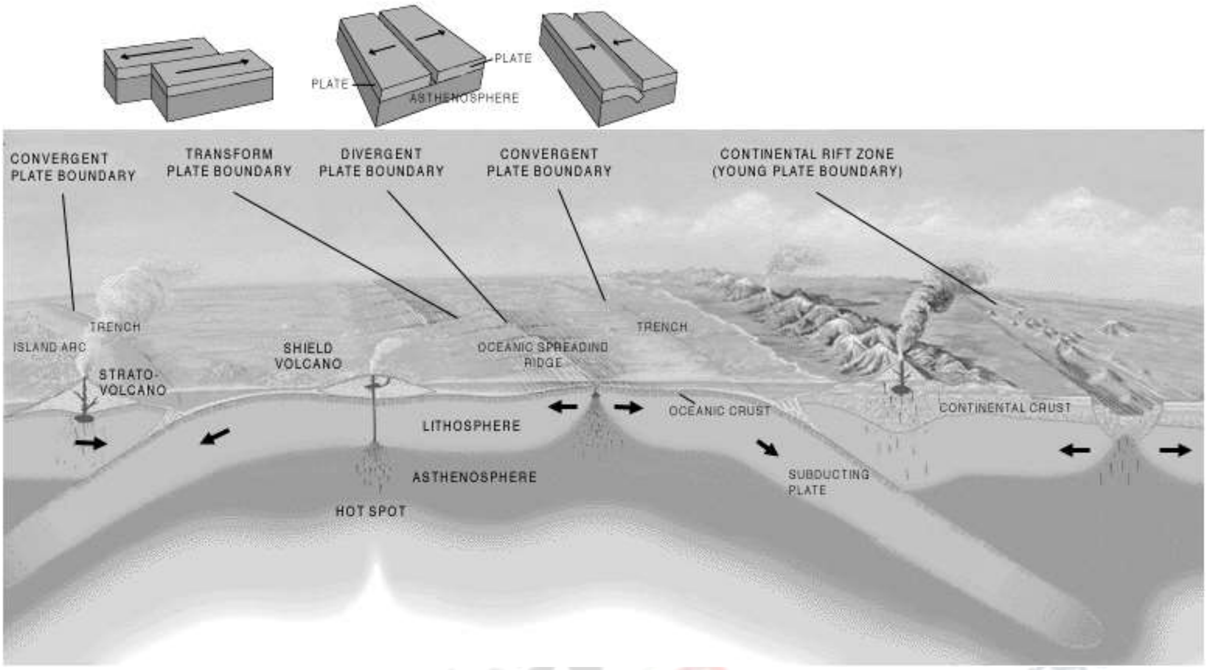


Figure 9: Activity at Plate Boundaries

- **Divergent plate boundaries**

At divergent plate boundary, the magma upwells through the opening between plates. This boundary mostly marks the **mid-oceanic ridge**, and may be an active or extinct spreading ridge. The basaltic lava spews out from the ocean floor and produce line of volcanic vents. In these spreading centres, *shallow focus earthquakes* are common. The rupture that produces the earthquakes are up to 70 kilometres in depth.Earthquakes are common in the **Continental rift valley** that are divergent boundaries developing within a continent. One such example is Rift valley of Africa. As the Arabian plate moves away from the African plate formation of Red Sea and Gulf of Eden is taking place. This 3000 kilometres long East African Rift System extends from Afar triple junction to Mozambique. The scientists are of the belief that this continental rift valley will develop into oceanic spreading centres such as the mid-oceanic ridge.

- **Transform plate boundaries**

There is a great deal of seismic activity when the lithospheric plates slide past each other laterally, across vertical fractures commonly referred to as transform faults. This zone is famous for occurrence of shallow focus earthquakes. The transform fault mostly occurs along short offsets related to slight bends in the mid-oceanic ridge system. But in some cases, such as San Andreas Fault in California, the transform fault extends through continental lithosphere.On April 18, 1906, earthquake of magnitude 7.9 struck California. Other examples of transform fault in continental lithosphere are the Alpine Fault in New Zealand, Queen Charlotte fault in North America and Anatolian fault in Turkey, which are witness to several shallow focus earthquakes. An earthquake of magnitude 7.8 struck Canada along the Queen Charlotte fault in 2012.

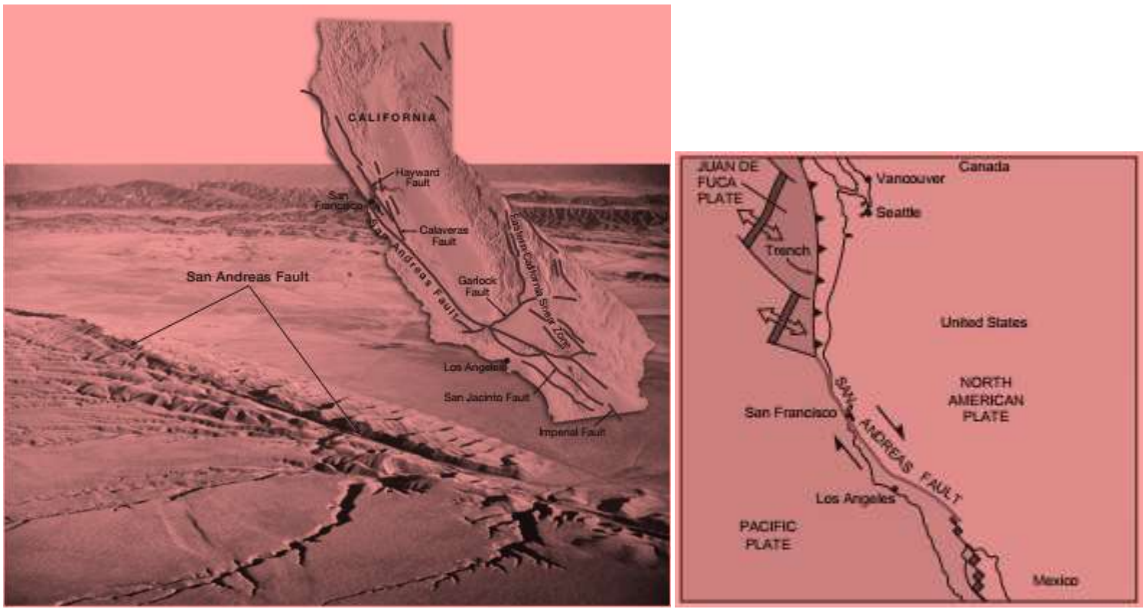


Figure 10: Trace of the San Andreas Fault, southern California. The map shows the extent of the San Andreas Fault system and the Eastern California Shear Zone (A) and a diagram showing at the northern end of the San Andreas Fault lies a subduction zone under the Pacific Northwest.

Sources: Adopted from ‘Earth Science’ by Tarbuck, Lutgens and Tasa, 2012 (A) and ‘Environmental Geology’ by Montgomery, C.W, 2011.

- **Convergent Plate Boundaries**

The lithospheric plates collide as they move towards each other, forming convergent boundaries. These are also called the destructive margins as here there is compression or removal of earth’s crust. Convergent boundaries can be of three types – oceanic-continental convergence, oceanic-oceanic convergence and the continental-continental convergence. In case of oceanic-continental convergence and oceanic-oceanic convergence, subduction of the denser stratum takes place with a great deal of seismic activity.In oceanic-continental convergence, the oceanic crust being dense subducts under the continental plate leading to shallow focus earthquake at the trench that is formed and deep focus earthquakes at more than 700 kilometres occur as the subducting plate descends into asthenosphere. These earthquakes are produced by slip on the subduction thrust fault as the oceanicplate is pushed into mantle. This zone is also referred to as **Benioff Zone.**

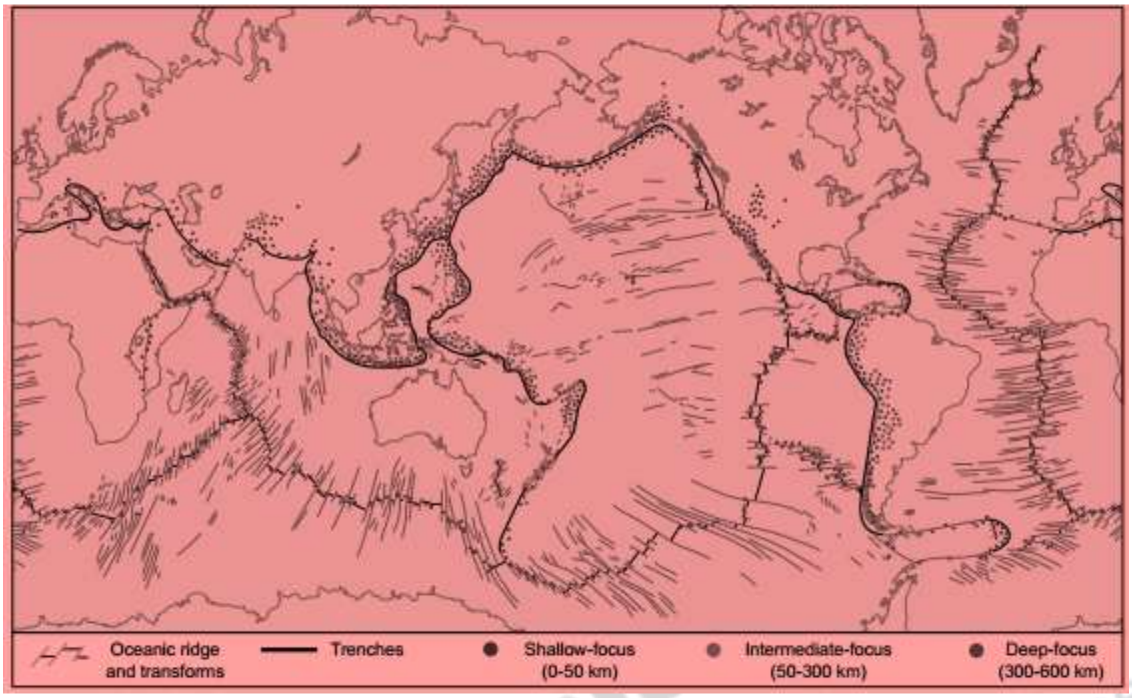


Figure 11: Earth's seismicity and the plate boundaries.
Source: Adopted from 'Physical Geology: Exploring the Earth' by Monroe, Wicander and Hazlett, 2007.

The above Map shows the concentration of shallow focus, intermediate focus and deep focus earthquakes along the circum-pacific belt, also referred to as the Ring of Fire. The Pacific plate subducts into the North American plate, forming the Aleutian trench – where earthquakes are a common feature. As the Nazca plate subducts beneath the South American plate, Peru-Chile trench is created. In the Indian Ocean, the Tsunami of 2004, was triggered by earthquake in Sumatra, Indonesia of magnitude of 9.1, along the megathrust where the Indo-Australian Plate subducts under the Burma Plate that is considered part of Eurasian plate. Large subduction zone earthquakes have continued to occur along this belt – Nias Island earthquake of magnitude 8.6 in 2005, 8.5 and 7.9 magnitude earthquakes in 2007 and 7.8 magnitude earthquake on portion of megathrust west of Mentawai Islands in 2010.

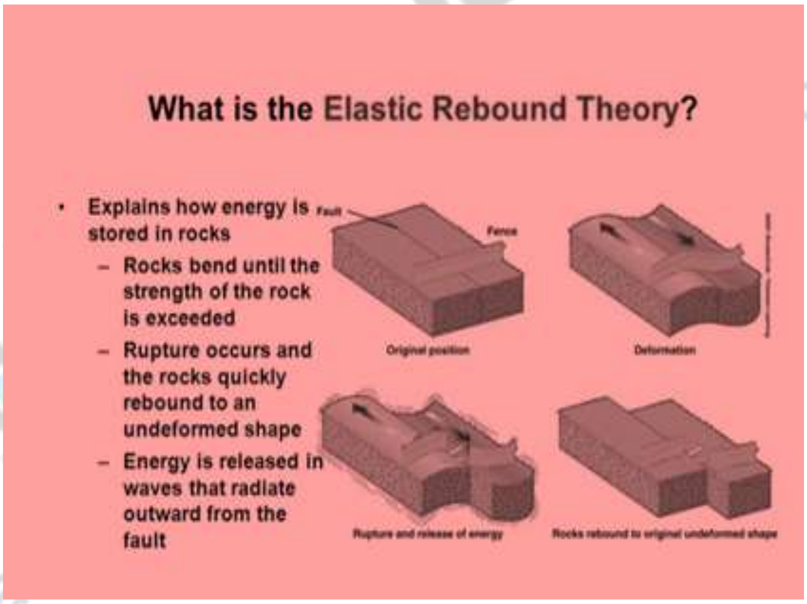
In case of oceanic-oceanic convergence, one oceanic plate subducts under the other leading to formation of oceanic trenches. The earthquakes both shallow and deep focus occur during this convergence. Mariana trench is result of convergence of fast moving Pacific plate against the slow-moving Philippine plate, which is also zone of earthquakes. The continental-continental convergence has no subduction due to buoyancy of the continental crust, but shallow focus earthquakes are quite common. The formation of huge mountain ranges such as Alps and Himalayas is attributed to this type of convergence. Earthquakes in Himalayas are common as the Indian plate and the Eurasian plates continue to converge at relative rate of 40-50mm/year. In Nepal on 25th April, 2015, shallow focus earthquake of magnitude of 7.8 occurred that devastated the small Himalayan nation. The epicentre was located 36 kilometres East of Khudi in Nepal and was followed by aftershocks of magnitude 6.1 and 6.6, on April 25th itself and 6.7 on April 26th 2017. In 2016, on 3rd January, 6.7 magnitude earthquake occurred 30 kilometres East of Imphal in India.

5. Causes of earthquakes

Most of the earthquakes are caused by the deforming forces in the Earth and the immediate cause is the sudden rupture of the earth materials distorted beyond the limit of their strength.

5.1 Elastic Rebound Theory

After the 1906 San Francisco earthquake, H.F. Reid, scientist at the John Hopkins University conducted a study to understand mechanics of earthquake. The field study showed that during thisearthquake, the Pacific Plate had moved past the adjacent North American plate by as much as 4.7 meters. According to Reid, tectonic stress builds up over hundreds of years deforming rocks on both side of a fault. When rocks experience continuous stress, they bend and store elastic energy. As soon as the strength of rock is exceeded, it ‘snaps’ back and rebounds to its original position and shape. Since the rocks behave like elastically like stretched rubber band, Reid termed it as **‘elastic rebound’** (fig. 9a). In this process of rocks snapping back to the original unstrained position, vibrations are generated that are felt as tremors or earthquake. During the San Francisco earthquake along the San Andreas fault, straight line fences and roads that crossed the fault gradually bent as the rocks on both sides moved relative to each other. (Fig. 9b).



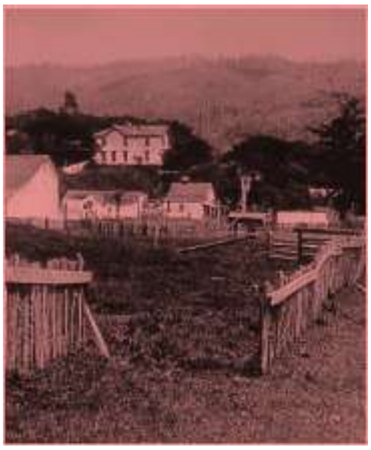


Figure 12: Elastic Rebound. As rock is deformed, it bends, storing elastic energy. Once strained beyond its breaking point, the rock cracks, releasing the stored up energy in the form of an earthquake (A) and a picture showing the 2.5 mt displaced fence post 1906 San Andreas Fault quake (B).

Source: Adopted from 'Earth Science' by Tarbuck, Lutgens and Tasa, 2012 (A) and 'Physical Geology' by Monroe, Wicander and Hazlett, 2007 (B).

5.2Earthquakes induced by anthropogenic activities

Human activities too are responsible for inducing large earthquakes causing widespread havoc and destruction. Three ways in which human activities trigger earthquakes include:

- Load of Dam or Reservoir on the crust
- Waste Disposal in deep underground wells
- Nuclear explosions.

Figure 13: 100 days after the Sichuan earthquake (A) and the destruction caused by the Sichuan earthquake (B)

Source: http://www.internationalrivers.org/earthquakes-triggered-by-dams

5.2.1Reservoir and Seismicity

Reservoir induced seismicity (RIS) has triggered hundreds of earthquakes. The construction of Zipingpu Dam induced the 7.9 magnitude Sichuan earthquake in May 2008, in which more than 80,000 people lost their lives. As the dams are constructed, extra water pressure is created in the micro cracks and fissures in the ground and near the reservoir. The increased pressure of water in rocks acts to lubricate faults already under tectonic strain, but have remained in place due to friction of rock surfaces.

5.2.2Deep waste disposal

Injecting waste into deep disposal wells like in disposal of produced waters from oil and natural gas wells has been known to cause earthquakes. The 2011 Oklahoma earthquake of magnitude 5.6 is believed to be the strongest earthquake induced by injection of waste materials.

5.2.3Nuclear explosions

Earthquakes with large magnitudes like M5 to M6.3 have been known to be triggered off by underground nuclear explosions. This was because the explosions caused simultaneous release of natural tectonic strain.

5.2.4Mining and quarrying

Mining generally alters the balance of forces in the rock, many times causing rock bursts.

6. Measuring the Earthquakes

Earthquake are measured on basis of their Magnitude and Intensity.

Magnitude- The amount of energy released during earthquake at the source is quantified through magnitude. It is measured with the help of seismographs, that plot the earthquake waves travelling though the earth. Two measures for earthquake magnitude are the Richter Scale and Moment magnitude.

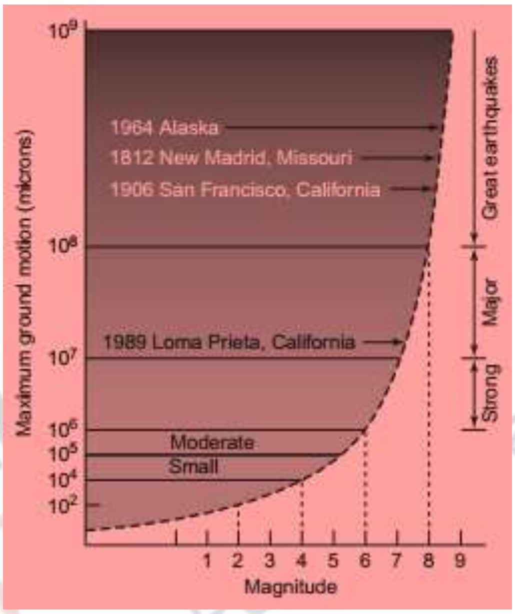


Figure 14: Earthquake Magnitude Scale

Source: Adopted from 'Environmental Geology' by Montgomery, C.W., 2011.

- **Richter Magnitude-** Using seismic records, Charles Richter in 1935 from California Institute of Technology, developed the first magnitude scale. The amount of ground displacement and shaking produced at the epicentre is measured on the Richter scale. It is a logarithmic scale, which means that each successive magnitude is 10 times stronger than the previous one. Magnitude 2 means that the energy release was 10 times more than that released during earthquake of magnitude 1 and in magnitude 3, 100 times more energy is released. The scale calculates the amplititude of the seismic waves (P, S and surface), as they recorded by the seismograph. The epicentre of the earthquake and the distance between the various seismograms is calculated and accordingly adjustments are made in the measurements obtained on the seismographs, as there is variation in the time taken by the seismic waves to travel through different rock types.Although earthquakes of smaller magnitude occur each day on the lithosphere, the most devastating are the ones with more than magnitude 8. It is shown by the symbol M_L where M is for magnitude and L is for local.

FACT FILE

Valdivia Earthquake, Chile, 1960 Magnitude 9.5

Great Alaska Earthquake, 1964 Magnitude 9.2

Sumatra-Andaman Island Earthquake, 2004 Magnitude 9.1

Tohuku Earthquake, 2011 Magnitude 9.1

Kamchatka Earthquake, 1952Magnitude 9.0

The merit of the Richter scale is the ease of describing the size of an earthquake by a single number that is calculated from a seismogram. Furthermore, unlike the intensity scales, which are popular for understanding earthquakes in densely populated areas of the globe, the magnitude of earthquakes in remotest regions can be measured by the Richter scale. Also, the events that occur in ocean basins can be measured by the same. Despite its usefulness, the Richter scale cannot be used to describe earthquakes of very high magnitude. For instance, the 1906 San Francisco earthquake and the 1964 Alaskan earthquake had roughly the same Richter magnitudes. However, based on the relative size of the affected area and the associated tectonic changes, the Alaskan earthquake released considerably large amount of energy. Thus, the Richter scale cannot distinguish between major earthquakes.

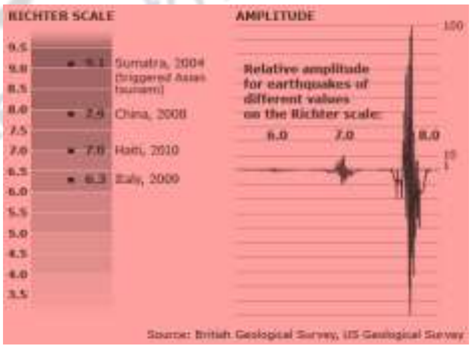


Figure 15: Richter Scale and Amplitude

- **Moment Magnitude**

An improvement over the shortcomings of the Richter scale the **moment magnitude** scale has been developed to measure the relative energy release. It is denoted by Mw. It is calculated by measuring the average slip on the fault, the area of the fault surface that slipped, and the strength of the faulted rock. This method is especially useful for measuring the large earthquakes. The largest earthquake which took place in Chile in 1960 had a Richter magnitude of 8.9, but an estimated moment magnitude of 9.5. All magnitude scales are logarithmic in nature.

Intensity- The Intensity scale is devised to interpret the qualitative measure of damage by the earthquake. News headlines vividly discuss the aftermath when an earthquake strikes a place. It gives us information about the death toll, the destruction and other such tragic details of the damage caused,all of which basically tell us how intense the earthquake had been.**Modified Mercalli Intensity Scale**, hasvalues ranging between **I and XII,** where **I** means that the earthquake is Not felt except by few and **XII** is total damage of the structures (Fig. 11)**.**

Modified Mercalli Scale

Intensity	Observed Effects
I	Felt by only a few people under very special circumstances
II	Felt by only a few people at rest, especially on the upper floors of buildings
III	Felt noticeably indoors, especially on upper floors of buildings
IV	Felt indoors by many people, outdoors by a few; some awaken
V	Felt by nearly everyone; many awaken; dishes and windows break; plaster cracks
VI	Felt by everyone; many frightened and run outdoors; heavy furniture moves
VII	Everyone runs outdoors; slight to moderate damage in ordinary structures
VIII	Considerable damage in ordinary structures; chimneys and monuments fall
IX	Considerable damage in all structures; ground cracks; underground pipes break
X	Most structures destroyed; rails bend; landslides occur; water splashes over banks
XI	Few structures left standing; bridges destroyed; broad fissures in the ground; underground pipes break
XII	Damage total; waves seen on ground surfaces; objects thrown in air

Figure 17: Modified Mercalli Scale

7. Summary

Earthquakes are the vibrations in the earth caused due to the tectonic movement of the lithospheric plates. The types of seismic waves generated during the earthquake are the P, S and Surface waves. The earthquakes are categorised according to their point of origin or focus as shallow focus, intermediate focus and deep focus. Earthquakes of shallow focus and intermediate focus are common on divergent and transform plate boundaries; the deep focus earthquakes occur in the subduction zone of oceanic-oceanic and oceanic-continental plate convergence. The magnitude and intensity of earthquakes is measured by Richter Scale and Modified Mercalli Scale respectively.