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Geotectonics

ADITYA PATEL
Assistant Director,
DRDO, Ministry of Defence

Abstract:
The basic knowledge about the Erath as a part of solar system is very essential to understand the physical processes within the planet. A proper knowledge about the history of the Erath since 4.6 billion years through the ***'Geological Time Scale'*** *is very important to understand the processes of plate tectonic and mountain buildings.The prior knowledge of magnetic behaviour and why our Erath behave like a magnet are also important to study palaeomagnetism.Via this study* clarify the idea about earthquake and volcanoes, with their internal mechanism and world-wide distribution.

Keywords: *Earth, Earth Science, Magnetism of the Earth, Geotectonics*

4. Learning Activities

- An audio-visual teaching method using smart-classes could be helpful for the teachers to explain and students to understand the internal processes of the Earth, specially the processes of plate motion and their mechanism.
- The detail study on this field could scientifically solve the mysterious questions regarding the Erath since the study of geography.

1. Introduction

Earth Science is a complete discipline to know the different aspects of the Earth as a Planet of Solar System. The aspects are all individually known as a science of specific field viz. geophysics, geochemistry, geology, climatology, hydrology, biology, pedology, geomorphology, and others. Name of all sub-fields of Erath Science denotes characteristic of the respective aspect of the planet. However, none of them could exist independently. Therefore, the Earth Scientists need a broad perspective to understand entire Earth and its operating systems. Among them, 'Geotectonic' is a sub-field of geology deals with the form, arrangement, and structure of rock masses of the earth's crust resulting from folding or faulting. Geotectonics specially focus on the general and regional tectonics, structural geology, geodynamics, and experimental tectonics and considers the relation of tectonics to the deep structure of the earth, magmatism, metamorphism, and mineral resources.

2. Learning Objectives

Present subject module is a basic introduction about the Earth's physical processes, specially endogenic processes and picture of underlying surface. The major aims of the module are:

- To enrich the student's knowledge about the interiors of the Earth, which is not visual.
- To understand the magnetism of the Earth, and its dynamics.
- Developing the concept of Earth's broken and moving crust, in the name of Plate Tectonic.
- Understanding about the processes of mountain building and their types.
- To understand the importance of a geosynclines for a Himalaya like folded mountain.
- To clarify the idea about earthquake and volcanoes, with their internal mechanism and world-wide distribution.

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2. Examples and Illustrations

2.1 Internal Structure of the Earth

Geoscientists are still actively engaging to update the scientific information about the internal structure of the Earth. At present the most advanced drilling techniques make possible to know the detail information of Earth's interiors up to the 10 km only, whereas the radius of our planet is about 6371 km. There are three major sources to provide the evidences of the internal structure of the Earth, which are (i) meteorites, (ii) seismic waves, and (iii) volcanoes. **Meteorites**are fragmented extraterrestrial debris fall on the Earth with the influence of its gravity filed. It seems that the meteorites that they were all formed at about the same time as the solar system developed and carrying the evidences of the Earth's formation history. **Seismic waves** are shock waves produced as an earthquake and they travel differently through different types of material. The internal structures of the earth are mainly developed by studying seismic waves that travel through the earth and are measured at seismometer stations.

The site at which seismic waves are generated is termed the focus of the earthquake and the point on the Earth's surface directly above the focus is the epicenter. Seismic waves are mainly three types known as Primary (P) waves and Secondary (S)waves, and Surface (L) waves. Primary waves travel through both solids and liquids at a speed which is proportional to the density of the material. By determining the speed of the wave it is then possible to learn something of the density and state of the materials through which the wave has travelled. Secondary waves can only travels through solids, so if they meet a liquid layers within the Earth they are stopped. The variation in the velocity graphs of P and S waves are mainly used to study the interiors of the Earth. Based on that, the interior of the Earth has been divided into several sections. **Volcanoes** are also useful indicators of the internal structure of the crust mainly because they are sites at which rock from the lower part of the lithosphere is brought to the surface.

Basically, the Earth is built with three major concentric layers with varying density, thickness, and temperature. The names of these three layers are **Crust**, **Mantle**, and **Core**, respectively from the outer part to the centre of the Earth. The density and temperature are rise with increasing depth. Each layer is also classified into two parts based on the differentiation in their compositions. The imaginary line of differentiation between two layers is called '**line of discontinuity**'. The surface layer of the Earth is crust with an average thickness of 35 km for continents and 5 – 10 km for oceanic crust. The layer below of the crust is known as mantle and the distinction line between these two layers is call **Mohorovicic discontinuity** or **Moho**, after the Serbian seismologist who discovered it in 1909.

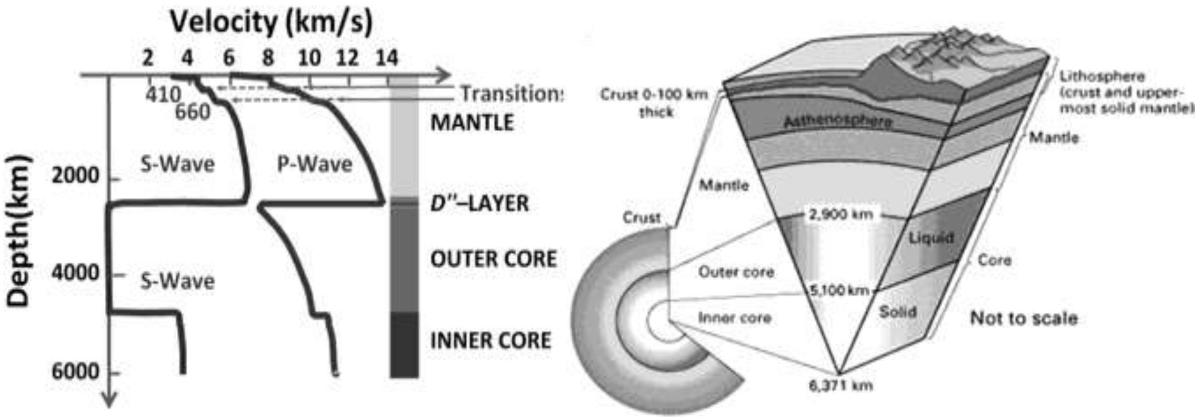

Fig. 1: Variation in the velocity of P and S waves towards the core of the Earth and schematic reorientations of the internal layers of the Earth (Source: Wikipedia.org, 2018)

Crust

- It is the outermost solid part of the earth, normally about 8-40 kms thick.
- It is brittle in nature.
- Nearly 1% of the earth's volume and 0.5% of earth's mass are made of the crust.
- The thicknesses of the crust under the oceanic and continental areas are different. Oceanic crust is thinner

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(about 5kms) as compared to the continental crust (about 30 kms).

- Major constituent elements of crust are Silica (Si) and Aluminium (Al) and thus, it is often termed as **SIAL.**
- The major constituent elements of the mantle are Silicon (Si) and Magnesium (Ma) and hence it is also termed as **SIMA**.
- The mean density of the materials in the crust is 3 g/cm3.
- The discontinuity between the **SIAL** and **SIMA** is termed as the **Conrad Discontinuity.**
- Mantle
- The portion of the interior beyond the crust is called as the mantle.
- The discontinuity between the **crust and mantle** is called as the **Mohorovicic Discontinuity or Moho discontinuity.**
- The mantle is about 2900 km in thickness.
- Nearly 84% of the earth's volume and 67% of the earth's mass is occupied by the mantle.
- The density of the layer is higher than the crust and varies from 3.3 – 5.4 g/cm3.
- The uppermost solid part of the mantle and the entire crust constitute the **Lithosphere**.
- The **asthenosphere** (in between 80-200 km) is a highly viscous, mechanically weak and ductile, deforming region of the upper mantle which lies just below the lithosphere.
- The asthenosphere is the main source of magma and it is the layer over which the lithospheric plates/ continental plates move (plate tectonics).
- The discontinuity between the **upper mantle and the lower mantle** is known as **Repetti Discontinuity**.
- Core
- It is the innermost layer surrounding the earth's centre.
- The core is separated from the mantle by Guttenberg's Discontinuity.
- It is composed mainly of iron (Fe) and nickel (Ni) and hence it is also called as **NIFE**.
- The core constitutes nearly 15% of earth's volume and 32.5% of earth's mass.
- The core is the densest layer of the earth with its density ranges between 9.5-14.5 g/cm3.
- The Core consists of two sub-layers: the inner core and the outer core.
- The inner core is in solid state and the outer core is in the liquid state (or semi-liquid).
- The discontinuity between the upper core and the lower core is called as **Lehmann Discontinuity.**
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2.2 Palaeomagnetism

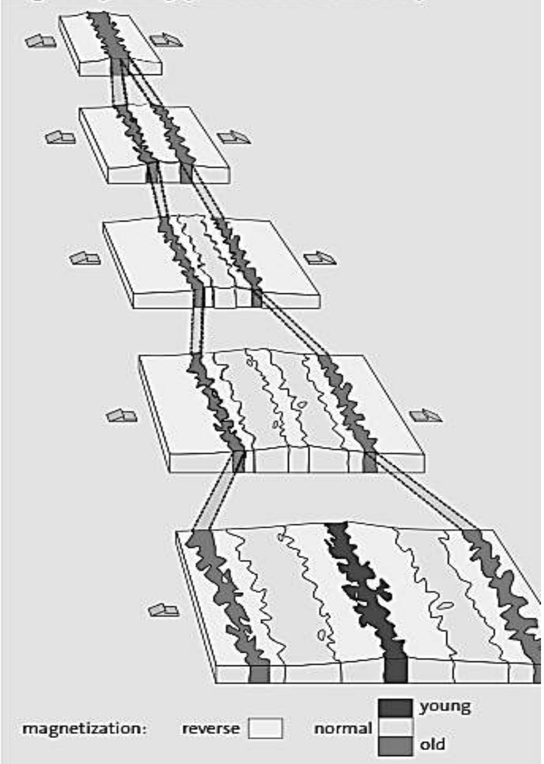
Palaeomagnetism is a record of the Earth's past magnetic field. When lava is erupted at the surface, magnetic minerals, such as iron, in the lava align parallel with the Earth's magnetic field. The magnetic minerals have a declination that points towards the magnetic north pole and an inclination related directly to latitude (at the equator inclination is ˚0 and at the North Pole inclination is 90˚). By looking at magnetized rocks we can work out. This is used to tell where the continents were in the past and how they have moved. This is used to construct apparent polar wander paths for continents.

The basic aim to study the palaeomagnetism is providing scientific evidences to the Alfred Wegener's Continental drift theory, published at 1912. The geophysical survey for the world- wide palaeomagnetism was started during mid-1950s, by S.K. Runcorn and his team in Britain. The team has observed significant anomalies in the samples. It was found that the palaeomagnetism of younger rock are closely associated with the present Earth's magnetic field, however older rocks are deviated from it. Therefore, it was assumed that the magnetic field of the Earth is not static and having a tendency of shifting, which can be correlated with the age of the sample rock and their location. Hence, the results of the palaeomagnetic survey have been helped to discover the concept of **polar wandering**. Runcorn and his team have demonstrated an apparent movement of the magnetic pole over the past 500 Ma (million years). The detail result shows the average duration of 'normal' fields (like the present one) had been about 420 ka (thousand year) and the 'reversed' field had been little longer about 480 ka. The period of a particular polarity are termed **epochs** and within an epoch the shorter phase of opposite magnetization called **events**.

2.3 Sea-floor Spreading

Seal-floor spreading is a significant geotectonic process to generate new crust along the mid-oceanic ridges (MOR) through volcanic activity then moves away from the ridge. The great Runcorn's geophysical survey of the Earth's palaeomagnetism, specially the detail magnetic characteristic of the crust of oceanic floor indicates the presence of anomalies in a linear pattern. Therefore, alternative bands of normal and reverse magnetized rock have been observed either side of the MOR.

Relationship between sea-floor spreading and magnetic polarity (after Frisch et al. 2011)



In 1962 **H.H. Hess**, of Princeton University in the USA, initially proposed that mid-oceanic ridges represent the regions where new crust is being generated by the upwelling of hot magma and this new crust spreads laterally away from the ridges until it.

reaches at a subduction zone. The term 'sea-floor spreading' was given by **Dietz**, an American geologist. It was **Vine and Matthews** (**1963**), two Cambridge geophysicists, have linked the idea of sea-floor spreading and palaeomagnetic data observed at the MOR and established the fact of geotectonic process operated at the MOR in the name of sea-floor spreading. It was a radical explanation to understand the continental drift theory and helps to develop the theory of **Plate Tectonic**.

In the late 1960s, Plate Tectonic is a result of incorporation of different ideas like continental drift, palaeomagnetism, sea-floor spreading, mid-oceanic ridges, subduction zone, conveyor belt etc. of number of workers around the world. The theory of plate tectonic proposes that the Earth's surface is not a continuous object. It comprises seven major and number of minor parts of lithospheric plates, which are composed of crust and upper most rigid mass of the mantle. The plates are in continuous motion in respect to each other in different direction at different rate. The rate of movement ranges up to 100 mm/year with an average of 70 mm/year. The study of plate tectonic deals with the mechanism and movement different plates, in addition with the geomorphological and geotectonic features and processes in and around of the plates.

There are three major types of plate boundary. **Divergent or Constructive or Accreting** plate boundary, where two plates are moving away from each other and new crust is formed, such as Mid-Atlantic Ridge. **Convergent or Destructive or Consuming** plate boundary, where two plates move towards each other (face to face) and collide along a line and the heavy plate slipping down below the lighter plate, e.g. the boundary of pacific plate. **Transform boundary**, where two plates move laterally past each other along a transform fault, e.g. San Andreas Fault System in California, USA. However, at some places three plates may come into contact, which is known as **Triple junction**, e.g. junction of the Pacific, Nazca, and Cocos plates.

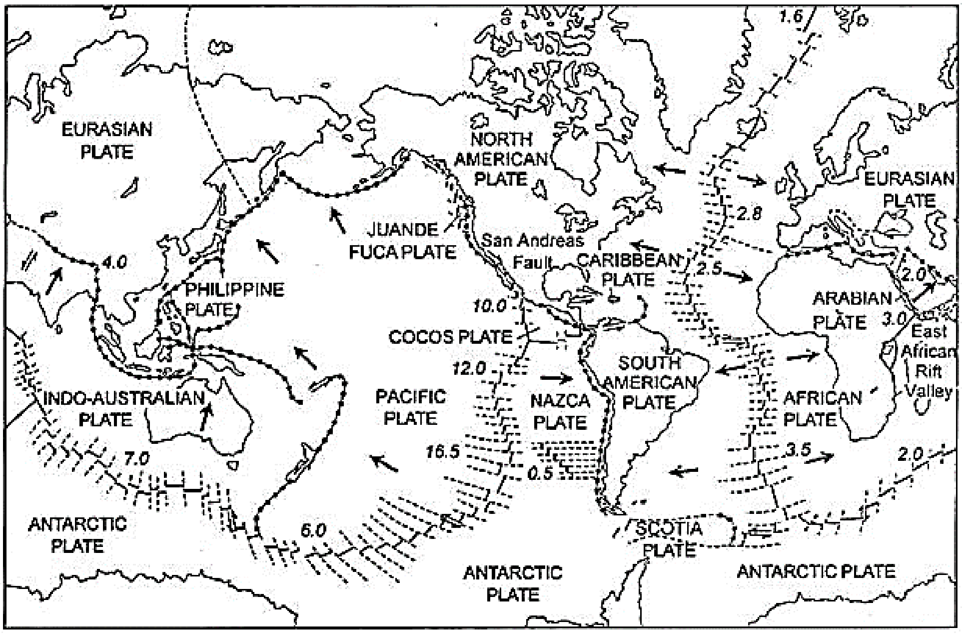


Fig. 3: Major and Minor Tectonic Plates and their relative movement (after USGS,2018)

2.4 Theories of Mountain Building

Mountains are the important second order relief feature on the earth surface. The highest mountain on Earth is Mount Everest in the Himalayas of Asia, whose summit is 8,850 m (29,035 ft) above mean sea level. Mountains can be classified in different types based on height, location, mode of origin, period of origin.

A) Types based on height: (i) Low mountain (height between 700 – 1000 m); (ii) Rough mountain (1000 – 1500 m); (iii) Rugged mountain (1500 – 2000 m); and (iv) High mountain (>1500 m).
B) Types based on location: (i) Continental mountain and (ii) Oceanic mountain.
C) Types based on mode of origin: (i) Folded mountain; (ii) Block mountain; (iii) Dome mountain; (iv) Mountain of accumulation.
D) Types based on period of origin: (i) Pre-Cambrian mountains; (ii) Caledonian mountains; (iii) Hercynian mountains; and (iv) Alpine mountains (Rockies, Andes, Alpine, Pamir, Himalaya mountain system come under this category).

The process of mountain building is basically deformation of earth crust due to the interaction between intrinsic and extrinsic forces of the Earth, as part of endogenetic processes. Therefore, the process of mountain building is very complex and long lasting. A number of hypothesizes and theories have been presented to explain the process of mountain building by number of geoscientists since very past. The major theories are as follows:

1. Geosynclinal Orogen Theory of Kobber: According to Kober, a German geologist, the present mountains are the result of interaction between mobile zones of water as geosynclines or '**orogen**' (place of mountain building) and rigid masses or '**kartogen**' in the surrounding of orogen. The major kartogens are Canadian Shield, Baltic Shield, Siberian Shield, Chinese Massif, Peninsular India, African Shield, Brazilian Mass, Australian, and Antarctic masses.

2. Thermal Contraction Theory of Jeffreys: The theory is based on the cooling process from initial phase of planet earth to present form. According to Jeffeys, the earth began to shrink because of contraction cased by gradual cooling of the earth due to loss of heat through radiation from the very

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beginning of its origin. The process of mountain building depends on the nature and strength of rocks. The soft and elastic rocks are most affected by contraction and easily developed folded mountain.

3. Sliding Continent Theory of Daly: Gravitational force of Erath is the key element of this theory. The gravity influenced to the continental masses for downhill sliding. The collapse part of the continent makes anomalies in temperature in the interior of the Earth and influenced surface geosynclines for folding or warping.

4. Thermal Convection Current Theory of Holmes: Arthur Holmes believed on the presence of two layers below the Erath surface, i.e. the crust and molted layer of substratum below of it. The convection current basically indicates the circular flow of magma within the layer of substratum layer. The current is significantly influenced the movement of crust and consequently helps to developed Earth's major relief features, such as folded mountain. Convection currents rise and diverge below the mid-oceanic ridges and converge and descend along the subduction zone. The causes behind the origin of convection current below the crust depend on the presence of radioactive elements in the rocks. The disintegration of radioactive elements generates the heat which caused the convection current.

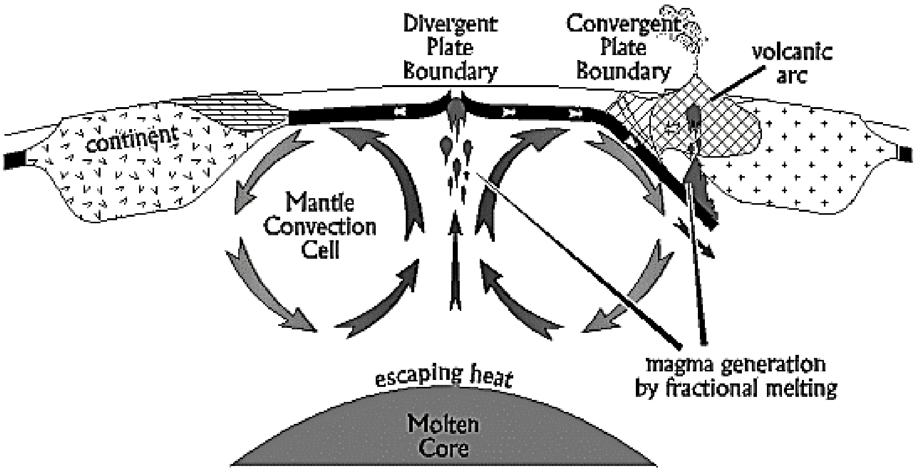


Fig. 4: Convection current theory and adjacent geotectonic events (Source: http://mrrudgegeography.weebly.com/continental-drift.html)

5. Radioactivity Theory of Joly: The theory also knows as 'thermal cycle theory', mainly based on the heat generated by the radioactive minerals in the substratum. According to Joly, the driving force of mountain building is provided by expansion and contraction of the substratum of the earth. Plate Tectonic Theory: The most fundamental theory was developed on the late 1960s, which able to explain all the tectonic events and relief features on the Earth surface using the concept of plate movements. In the aspect of mountain building, the theory explains majority of mountains are developed due to the collision of two plates or at the convergent plate boundary. The collision might happen between two oceanic plates, between to continental plates, or between one oceanic and one continental plate. For example, the Himalaya is a result of collision between Eurasian Plate and Indo-Australian Plate, a collision of two continental plain, Rockies and Andes are examples of the collision between one continent and one oceanic plate.

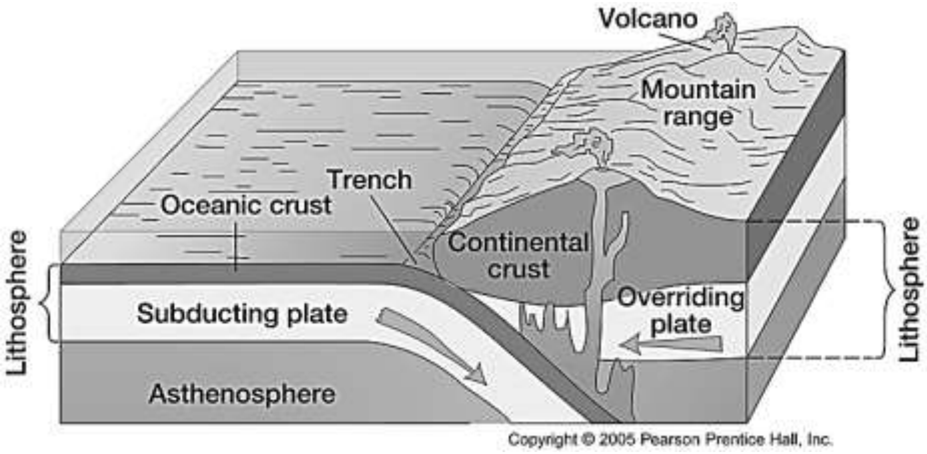


Fig. 5: Subduction zone and associated relief features through the process of plate tectonic
(Source: https://infogram.com/o-c-subduction-zone-1g957pr5g90vm01)

2.5 Geosynclines

Geosynclines is an important ancient relief feature characterised by long, narrow and shallow depression and accumulated with very thick sediments and are sometime results of earth subsidence. Erath scientists are believed that it was an ancient feature, started to develop since the origin of our planet surrounding the rigid masses. The concept of the geosyncline was introduced by the American geologist James Hall and Dana in 1859, but it was elaborate by J.A. Steers (1932). The geosynclines are blue-print of the folded mountain and its sediments are the source of material need for the formation of mountain ranges. The Himalaya is the result of Tethys geosysncline by the compressional force generated between Angaraland foreland and Deccan Plateau foreland.

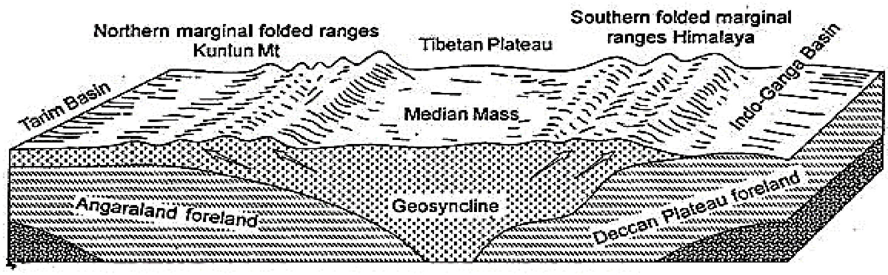


Fig. 6: Formation of Himalaya, Tibetan Plateau, Kunlun Mt. from the underling geosynclines (Tethys) (after Kober)

The history of geosyncline formation has been divided into three main stages.

1. Lithogenesis: the stage of formation with huge sedimentation and subsidence of beds of geosynclines.
2. Orogenesis: the stage of mountain building by squeezing and folding of accumulated sediments by the compression force from the foreland on the both side.
3. Gliptogenesis: the stage of gradual rising of mountain, and their denudation and associated reducing the height of the mountains.

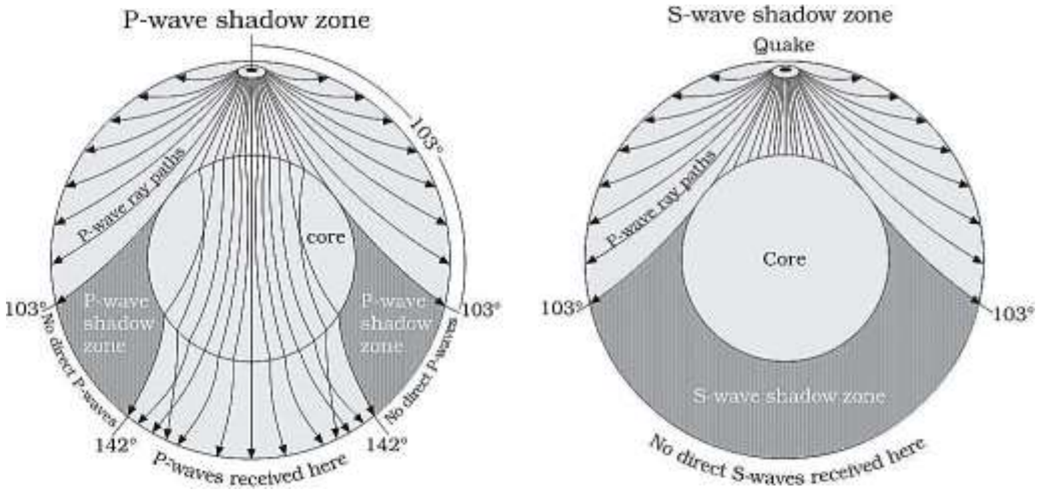
2.6 Earthquake: Mechanism and Distribution

The event of earthquake is a result of seismic wave movements generated beneath the earth surface due to the sudden release of epeirogenic energy. The magnitude of the earthquake depends on the nature of seismic waves. There are three types of seismic waves, i. Primary or P-wave, ii. Secondary or S-wave, and iii. Surface or L-wave.

P-wave

- High frequency, shorter wavelength, and longitudinal wave.
- Travelling within the Earth through the both liquid and solid masses.

- Speed rages from 5 – 7 km/s.
- It produces relatively small displacement of the ground.
- Their velocity depends on shear strength or elasticity of the material.
- The shadow zone for 'P' waves is an area that corresponds to an angle between 103^0 and 142^0



S-wave

- More slow than P-wave, speed range from 3 – 4 km/s.
- Low frequency, long wavelength, and transverse vibration.
- They cause displacement of rocks, and hence, the collapse of structures occurs.
- These waves are responsible for most the destructive force of earthquake.
- Travel only solid mass, so the entire zone beyond 105 ° does not receive S-waves.

L-wave

- 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.
- This wave created close to the epicenter and can only travel through the outer part of the crust.
- Together with secondary effects such as landslides, fires and tsunami are account for the loss of approximately 10000 lives and over $100 million annually.

Major causes of earthquakes are:

- Plate tectonic
- Volcanic activity
- Folding and faulting
- Human interference with nature (e.g. dam, dynamite blasting for mining etc.)

Major effects of earthquakes are:

- Shaking and ground rupture
- Landslides and avalanches
- Fires
- Soil liquefaction
- Tsunami
- Floods
- Effect on human life and property.

2.6.1 Distribution of Earthquakes

Earthquake can be event in ant part of the earth surface. However, the major allocation of the earthquake is direly correlated with the plate boundary, especially along the convergent boundaries. The distribution map can helps to correlate the world's plate boundaries and major earthquake events. There are five example of very high magnitude (>9.0) earthquake especially at the edge of pacific plate. Worldwide major earthquake prone areas are: i) around the Pacific Ocean, ii) Along the Indo-Australian plate boundary, iii) Eastern side of Eurasian plate, iv) western side of the North American plate.

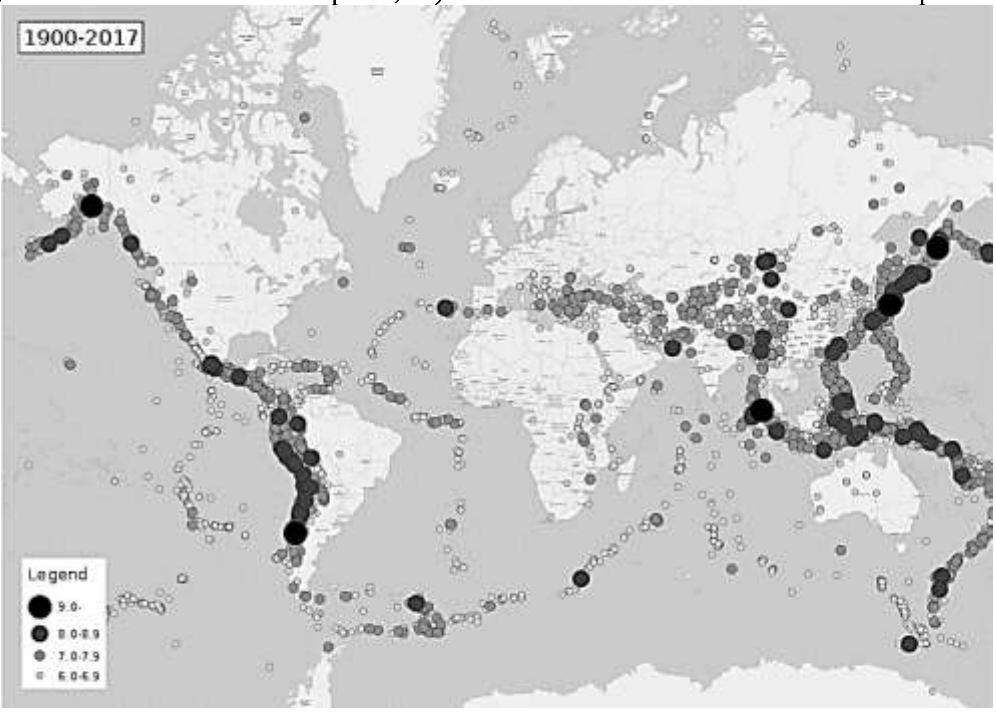


Fig. 8: Distribution map of the major earthquake (>6.0 magnitudes) over the world of last 117 years (Source: USGS, 2018)

2.7 Vulcanicity: Mechanism and Distribution

The term volcano refers the point of eruption or outlet of magma or highly heated gases, ashes, or pyroclastic materials from the below of crust. The form the volcano is usually circular or nearly circular, however it varying widely over the world. Whereas, vulcanicity includes all the processes of magma, gases and pyroclastic material eruption into the crust through volcanoes and thereafter way of solidify as a crystalline or semi-crystalline rock. The major components of a volcano are volcanic vent, volcanic crater, volcanic pipe, and volcanic cone.

The volcanic event basically associated with the weaker zone of the earth surface, represented by the mountain building areas or along the convergent or destructive plate boundaries. A wide range of variation has been observed in the mode of volcanic eruption and their periodicity. Therefore, volcanoes are classified into several types as follows.

A. Based on the Mode of Eruption

i) Central eruption types or explosive eruption type: a. Hawaiin, b. Strombolian, c. Vulcanian, d. Peleean, e. Visuvius

ii) Fisser eruption type or quite eruption type: a. Lava flow, b. Mud flow, c. Fumaroles

B. Based on the Periodicity

i) Active volcanoes

ii) Dormant volcanoes

iii) Extinct volcanoes

2.8 Distribution of the Volcanoes

The major volcanic belts of the earth are:

1. Circum-Pacific Belt (Fire Girdle of the pacific or the fire ring of the Pacific) Island arcs and Festoons

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E.g. Sakhalin, Kamchatka, Japan, Philippines, Aleutian Island, Hawaii, some Highest volcanic Peaks -Cotopaxi (S. America), Fujiyama (Japan), Shasta, Rainier and Hood (W. Cordillera of N. America), Valley of ten thousand smokes (Alaska), Mt. St. Helens (USA), Kilavea (Hawaii), Mt. Taral, Pinatubo and Mayon (Philippines).

2. Mid-Continental Belt (Volcanic Zones of convergent continental plate margins) Volcanes of Alpine Mt. Chains, Mediterranean Sea, Agean Sea, Fault zone of Africa (Kilimanjaro, Mem, Elgon, Birunga, Rungwe etc.)
3. Mid-Atlantic Belt- Hekla (Iceland) , Lesser Antilles, Southern Antilles, Azores, St. Helena, Mt. Pelee (Martinique) in Caribbean Sea.

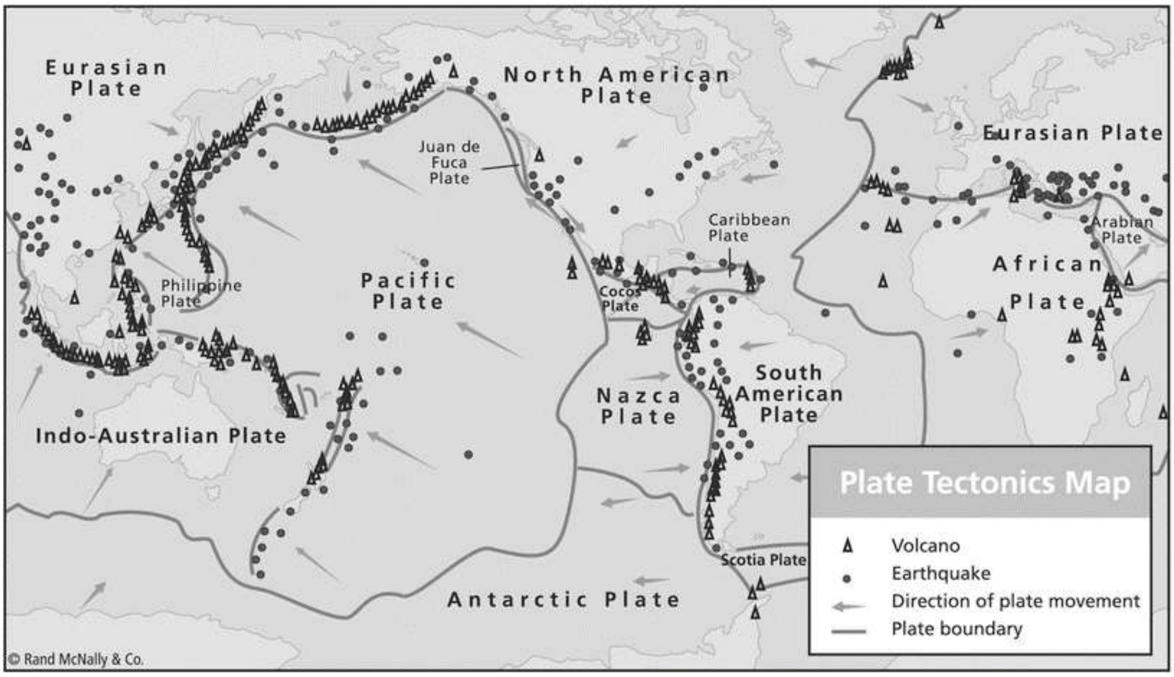

Fig. 9: Location of major volcanoes and point of earthquake across the world, which are directly corresponding with the convergent plate boundary (Source: USGS, 2018)

3. Summaries and Key Points

The understanding of the Earth as a planet of solar system, especially the internal ongoing processes, is very important for everyone to correlate with other physical and socio-economic condition of our environment. The brief knowledge about the above topics might be helpful to understand the movement of Earth surface and different natural calamities, specially earthquake and volcanic activities. The causes behind the mountain structure and types can be understood from this study material. With the knowledge of plate tectonic, the student can explain any type of crustal deformation and related landforms.

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