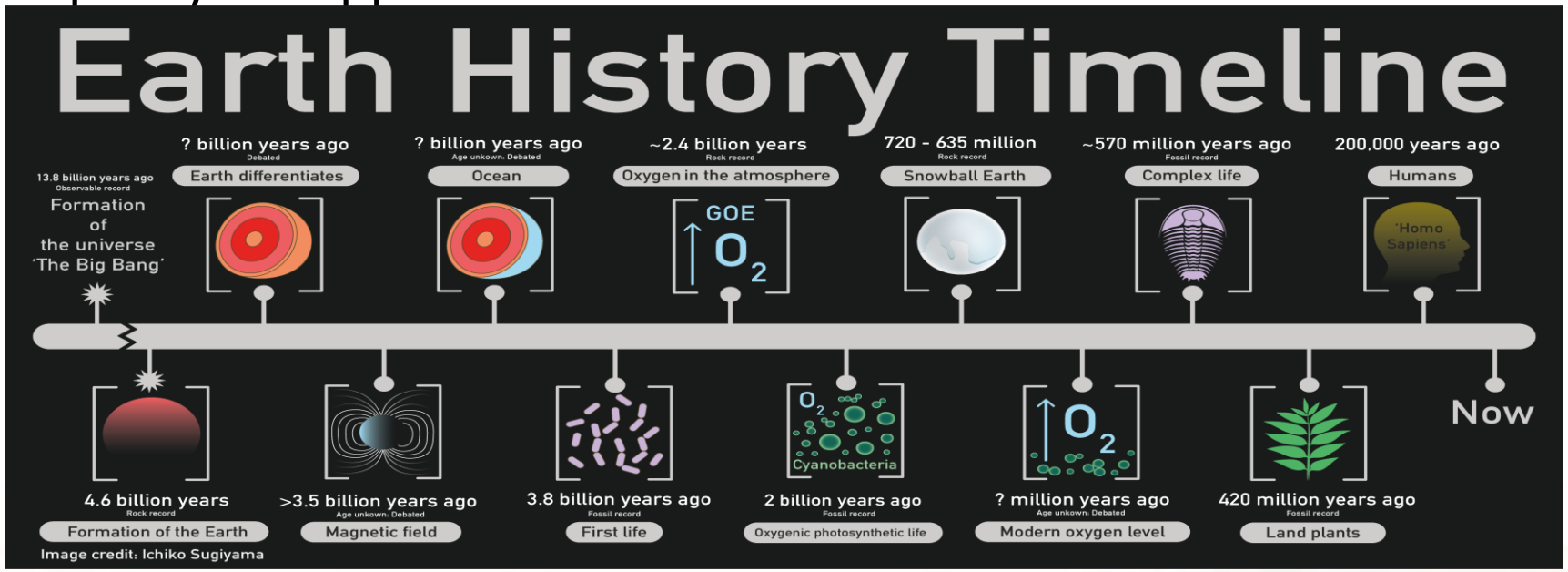
- FACULTY NAME:
  - KANHAIYA JHA
- SUBJECT:
  - GEOGRAPHY
- TOPIC NAME:
  - ORIGIN AND EVOLUTION OF EARTH
  - INTERIOR STRUCTURE OF EARTH

Origin and Evolution of Earth

- The origin and evolution of Earth is a complex process that began around 4.6 billion years ago with the formation of the solar system. Earth evolved through several major geological and atmospheric stages, including accretion, internal differentiation, degassing, ocean formation, and biological development.
- Each stage played a crucial role in shaping Earth's present structure, atmosphere, and capacity to support life.



- **1. Accretion Phase (~4.6 billion years ago)**
  - Earth began to form from the **solar nebula** (cloud of gas and dust).
  - Dust particles collided and stuck together, forming larger bodies called **planetesimals**.
  - Through continued collisions and gravitational attraction, a **proto-Earth** (early Earth) was formed.
  - The early Earth was extremely **hot** due to constant bombardment and compression.
- **2. Differentiation Phase (~4.5 billion years ago)**
  - Internal heat caused the Earth to **melt partially**.
  - **Heavy elements** like iron and nickel sank to form the **core**.
  - **Lighter elements** rose to form the **mantle and crust**.
  - This process of separation into layers is called **differentiation**.
  - **Role of Theia**
  - A **Mars-sized body named Theia** collided with Earth.
  - This **giant impact**:
    - Ejected material that later formed the **Moon**
    - Added more heat to Earth's interior
  - Possibly helped accelerate core formation and Earth's tilt

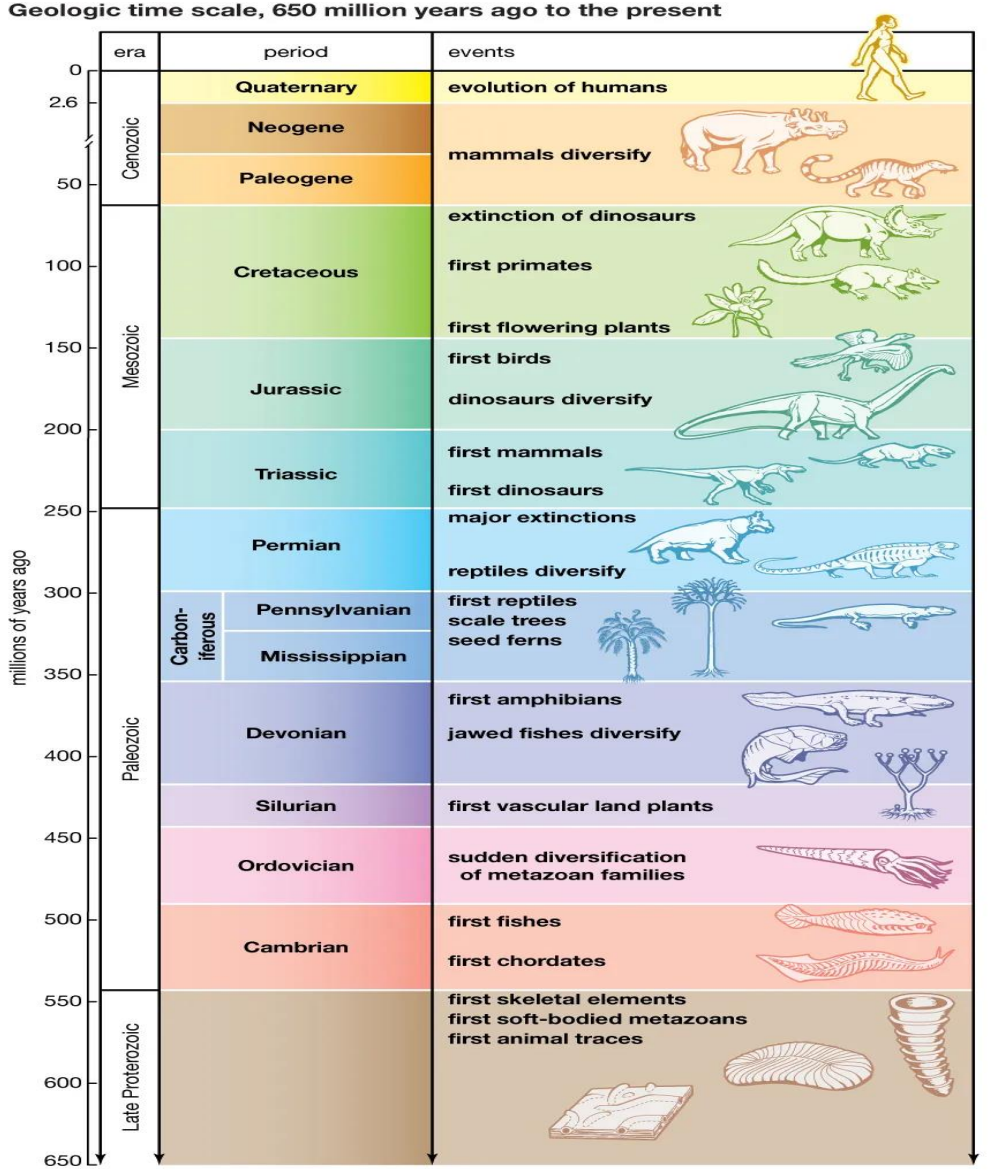
- **3. Degassing and Formation of Secondary Atmosphere (~4.4 to 4.0 billion years ago)**
  - After differentiation, Earth became geologically active.
  - **Volcanic eruptions** released trapped gases from the interior—this is called **degassing**.
  - These gases formed Earth's **secondary atmosphere**.
  - Main gases released: **Water vapor (H_2O), Carbon dioxide (CO_2), Nitrogen (N_2), Ammonia (NH_3), Methane (CH_4), Sulphur dioxide (SO_2)**
  - **Free oxygen (O_2) was absent** during this stage.
  - This atmosphere was **dense and hot**, trapping heat.
- **4. Ocean Formation (~4.0 to 3.8 billion years ago)**
  - As Earth's surface cooled, **water vapor condensed into clouds**.
  - Continuous rainfall over thousands of years formed **oceans**.
  - Some water may have also come from **comet impacts**.
  - At this stage, Earth was likely **covered almost entirely by water**, with very little exposed land.
  - It appeared as a **"water world"** with only volcanic islands or ridges.

- **5. Origin of Life (~3.8 to 3.5 billion years ago)**
  - In the newly formed oceans, **organic molecules** formed through chemical reactions.
  - These molecules evolved into **primitive single-celled organisms**.
  - The first life forms were **anaerobic prokaryotes**, which did not require oxygen.
- **6. Oxygenation of the Atmosphere (~2.5 to 2.0 billion years ago)**
  - Some microorganisms (like **cyanobacteria**) developed **photosynthesis**.
  - They released **oxygen** as a byproduct into oceans and atmosphere.
  - Over millions of years, this led to the **Great Oxygenation Event**.
  - Oxygen levels rose, forming the **ozone layer** and paving the way for **complex life**.

Geological Time Scale

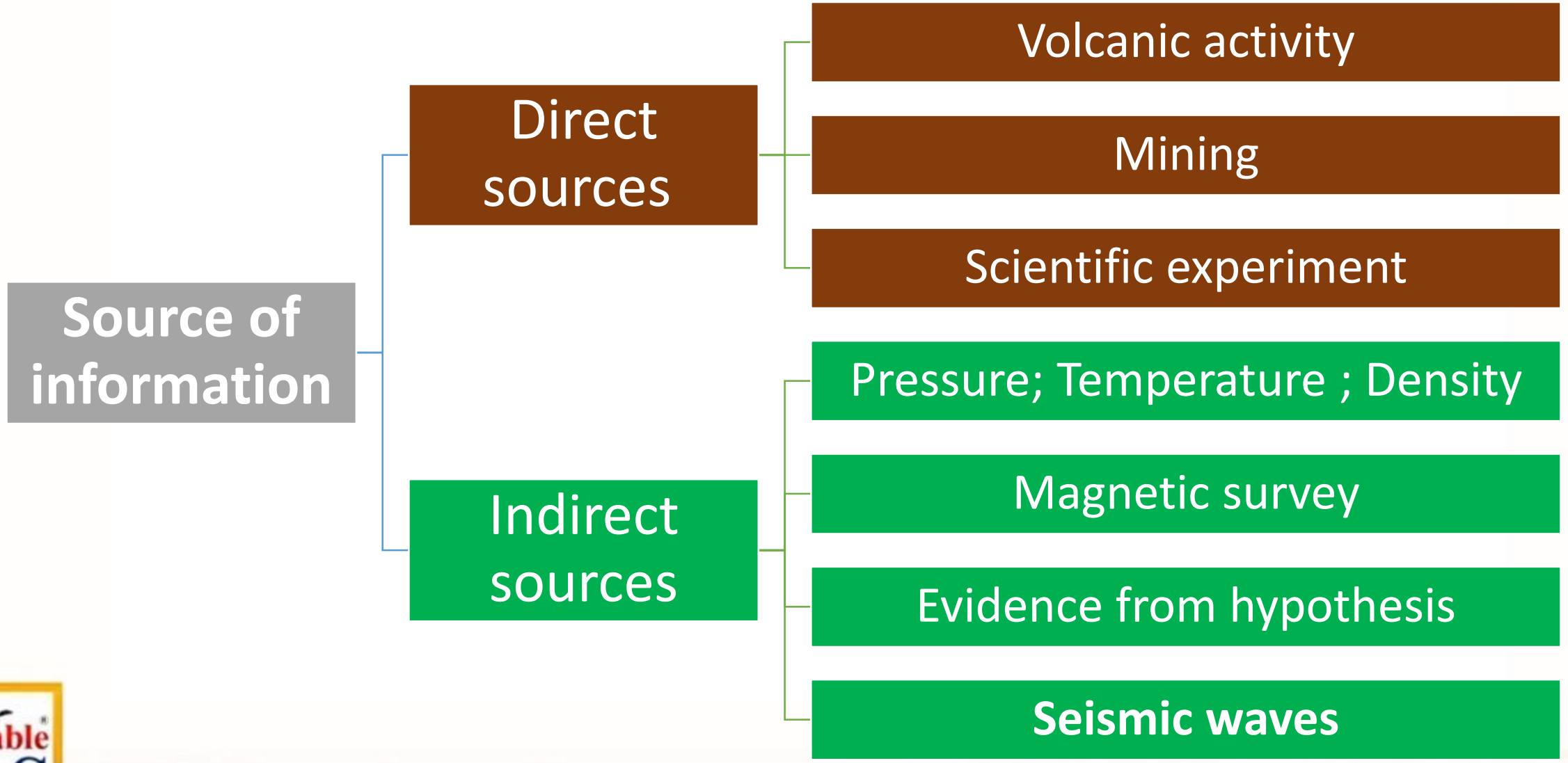
Eons	*Era*	*Period*	*Epoch*	*Age/ Years Before Present*	*Life/ Major Events*
	Cainozoic (From 65 million years to the present times)	Quaternary	Holocene	0 - 10,000	Modern Man
			Pleistocene	10,000 - 2 million	Homo Sapiens
		Tertiary	Pliocene	2 - 5 million	Early Human Ancestor
			Miocene	5 - 24 million	Ape: Flowering Plants and Trees
			Oligocene	24 - 37 million	Anthropoid Ape
			Eocene	37 - 58 Million	Rabbits and Hare
			Palaeocene	57 - 65 Million	Small Mammals : Rats – Mice
	Mesozoic 65 - 245 Million Mammals	Cretaceous		65 - 144 Million	Extinction of Dinosaurs
		Jurassic		144 - 208 Million	Age of Dinosaurs
		Triassic		208 - 245 Million	Frogs and turtles
	Palaeozoic 245 - 570 Million	Permian		245 - 286 Million	Reptile dominate-replace amphibians
		Carboniferous		286 - 360 Million	First Reptiles: Vertebrates: Coal beds
		Devonian		360 - 408 Million	Amphibians
		Silurian		408 - 438 Million	First trace of life on land: Plants
		Ordovician		438 - 505 Million	First Fish
		Cambrian		505 - 570 Million	No terrestrial Life : Marine Invertebrate
Proterozoic	Pre-Cambrian 570 Million - 4,800 Million			570 - 2,500 Million	Soft-bodied arthropods
Archean				2,500 - 3,800 Million	Blue green Algae: Unicellular bacteria
Hadean				3,800 - 4,800 Million	Oceans and Continents form – Ocean and Atmosphere are rich in Carbon dioxide
Origin of Stars	5,000 - 13,700 Million			5,000 Million	Origin of the sun
Supernova				12,000 Million	Origin of the universe
Big Bang				13,700 Million	

Geologic time scale, 650 million years ago to the present

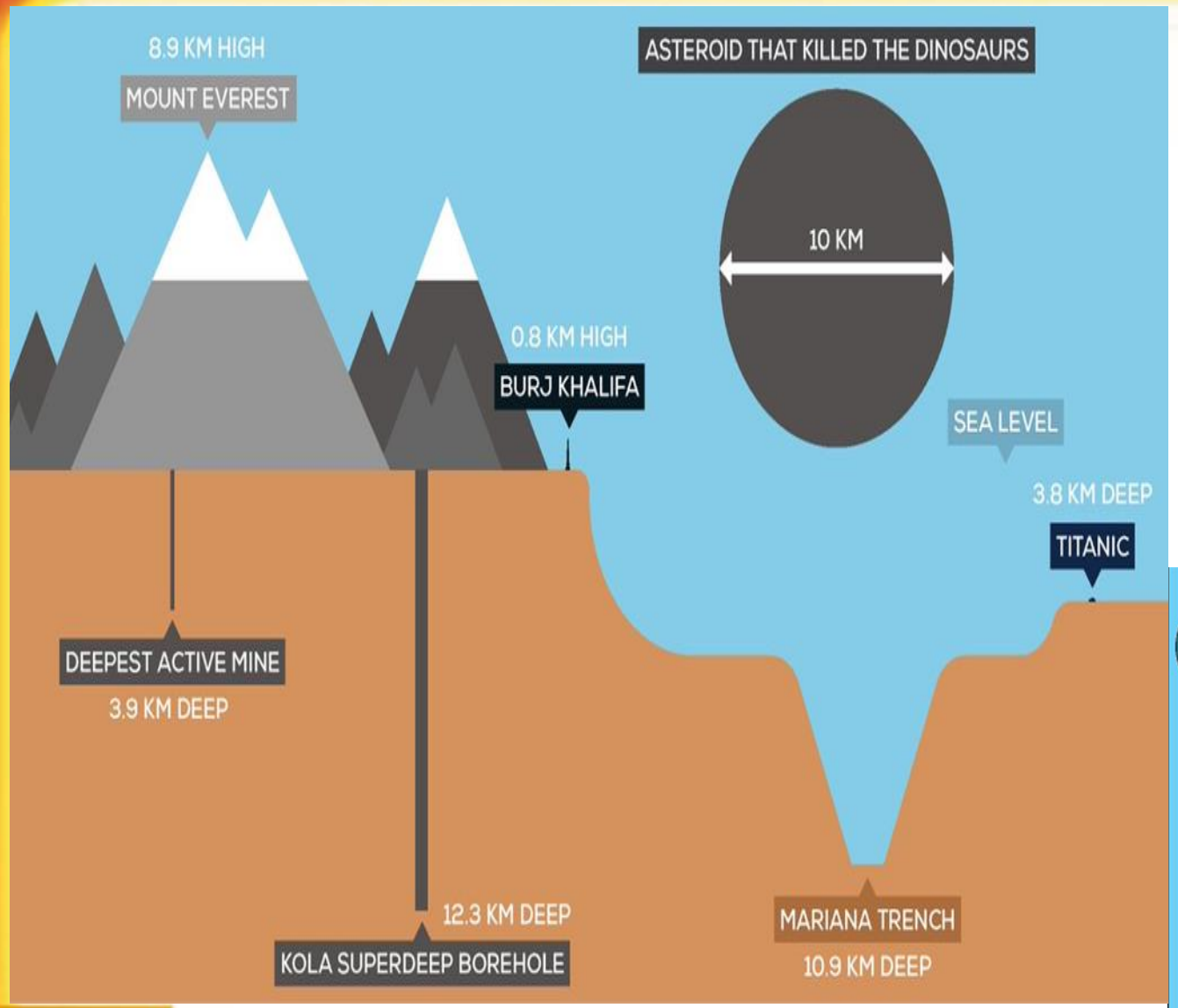


INTERIOR STRUCTURE OF EARTH

- The **earth is a living planet**. Therefore, the change is taking place over the surface of earth continuously. All the changes over the Earth's surface is largely produced by interior force of Earth (endogenic force).
- The elementary knowledge of Earth's interior is necessary **for explaining geo-morphological incidents- earthquake, volcano , tsunami and even formation of continents and earth.**
- Human life over the **Earth's surface is also largely influenced by physiographic structure of the earth surface. The study of the earth's interior is the subject of geology**..
- Ironically, The interior of earth is beyond **the direct observation of mankind**.
- The **radius of earth is about 6,370 km** of death therefore no such instrument has been invented which can explore the interior of Earth clearly.


Source of information
Direct sources
Volcanic activity
Mining
Scientific experiment
Indirect sources
Pressure; Temperature ; Density
Magnetic survey
Evidence from hypothesis
Seismic waves

Reuters


8.9 KM HIGH
MOUNT EVEREST
ASTEROID THAT KILLED THE DINOSAURS
10 KM
0.8 KM HIGH
BURJ KHALIFA
SEA LEVEL
3.8 KM DEEP
TITANIC
DEEPEST ACTIVE MINE
3.9 KM DEEP
12.3 KM DEEP
KOLA SUPERDEEP BOREHOLE
MARIANA TRENCH
10.9 KM DEEP


Mysterious Hole


Barents Sea
N
Kola Superdeep Borehole
Murmansk
Norwegian Sea
Kola Peninsula
White Sea
SWEDEN
FINLAND
NORWAY
RUSSIA
Helsinki
Oslo
Stockholm
Baltic Sea
Tallinn
ESTONIA
0 200 Miles
0 200 400 Kilometers
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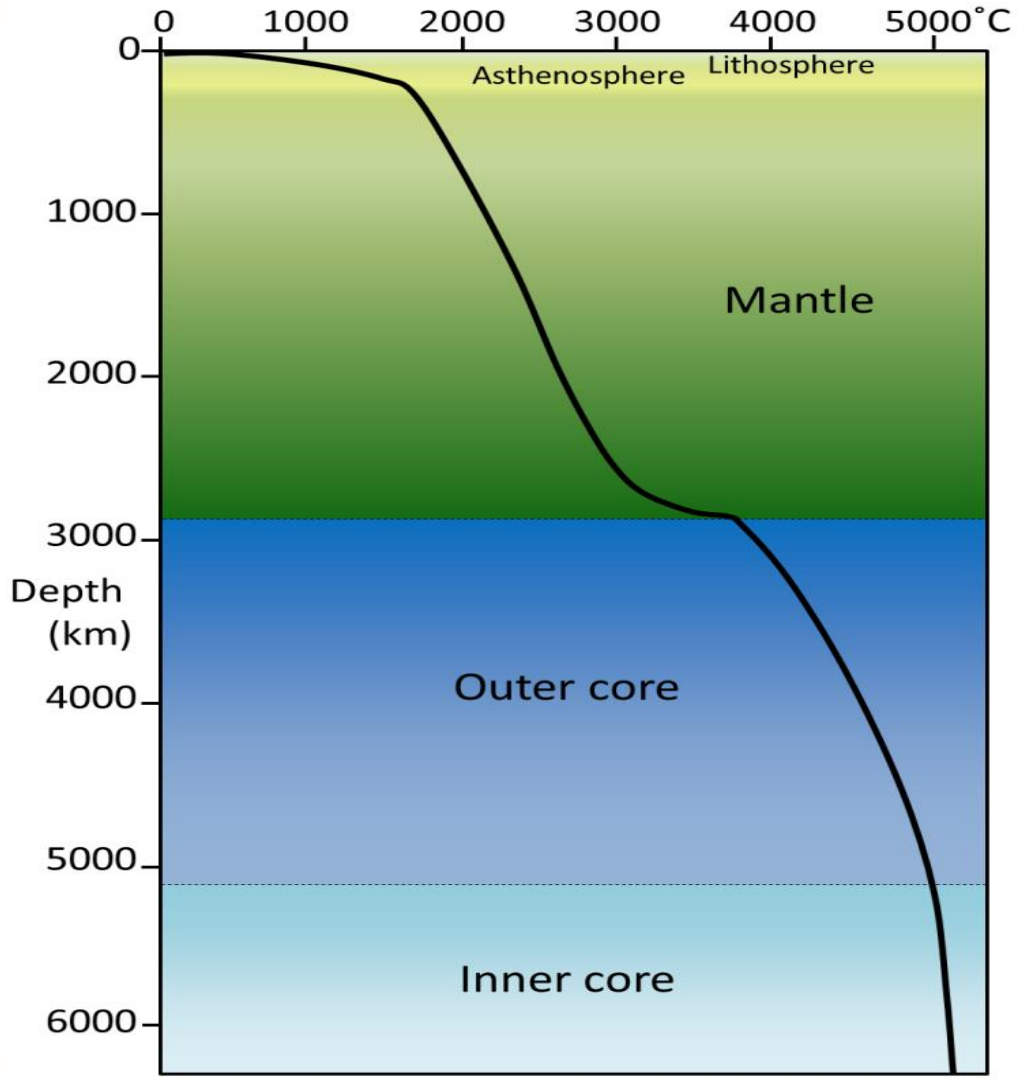
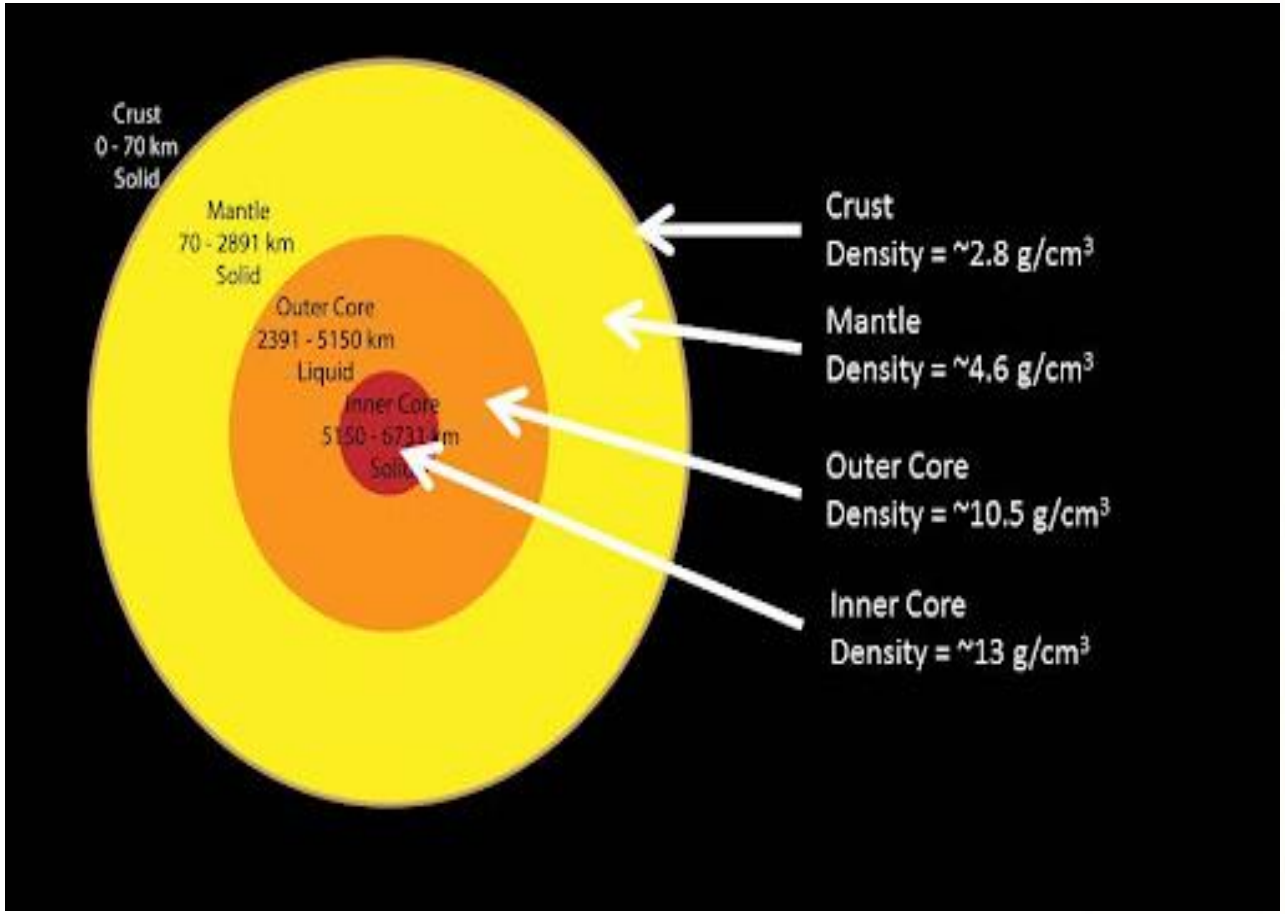
Indirect source

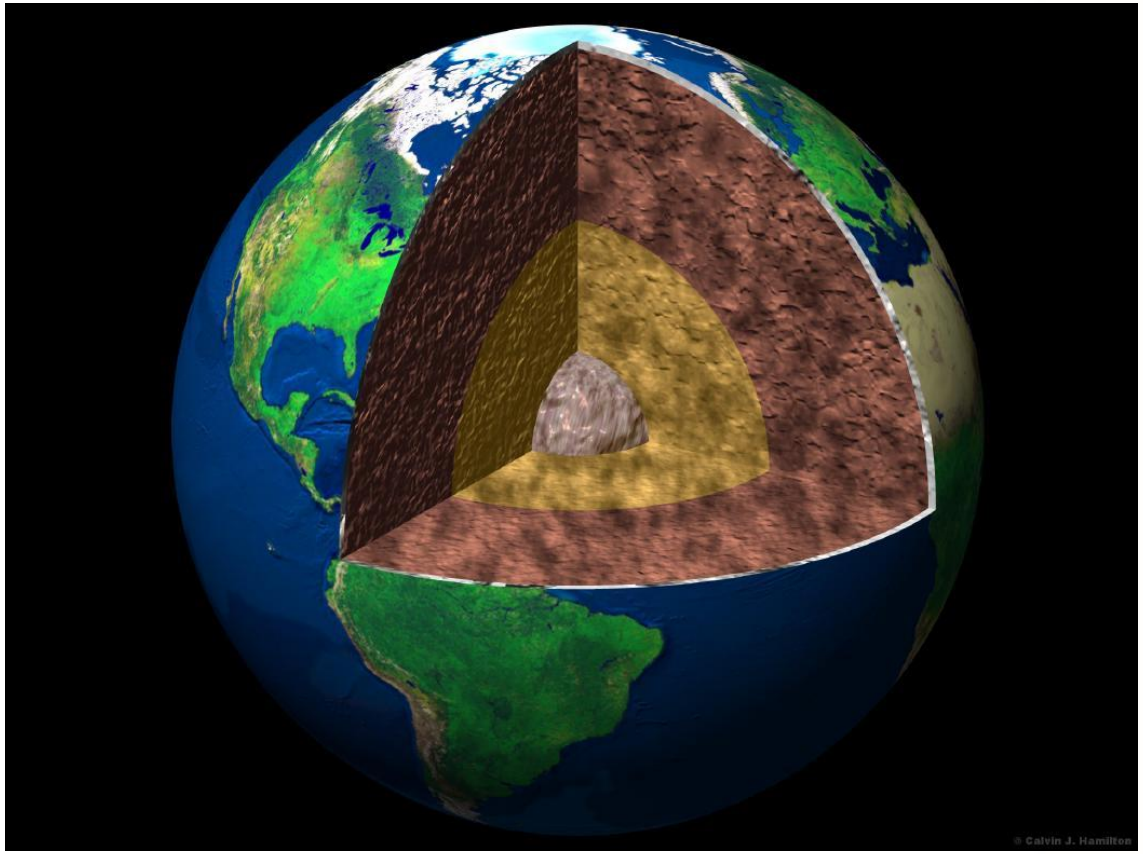
- **Temperature –**
- Usually, temperature increases with increasing depth.
- **With an average rate of about 1 Degree Celsius for every 32 depth**.
- It happens due to decay and disintegration of radioactive element growing pressure of overlying rocks faster chemical reaction beneath.



- **Density –**
- Following Newton's law of gravitation, the average density of the entire Earth is calculated around 5.5 gram per cubic centimeter.
- Nevertheless, Density varies with increasing depth, Which is :-
  - Crust- 2.8
  - mental- 4.6
  - Core - 11



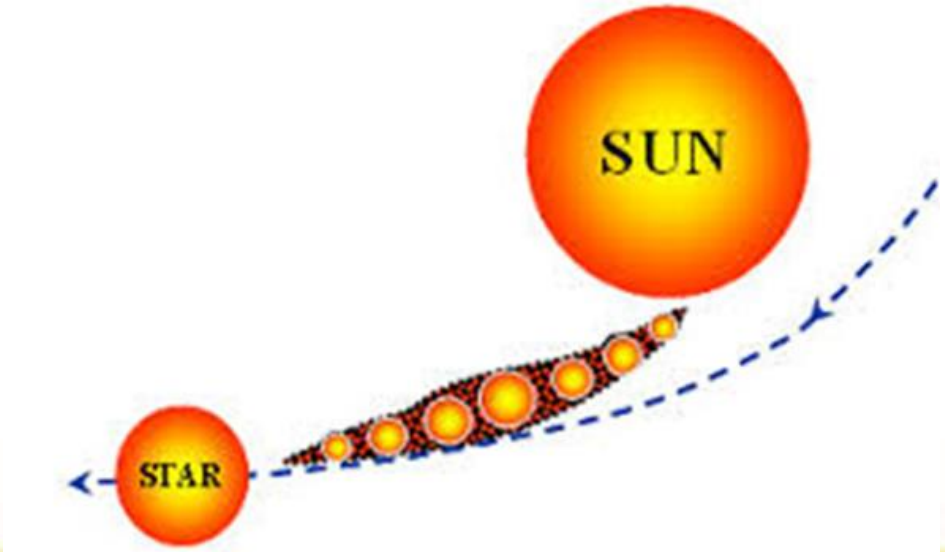
- **Pressure –**
- It is apparent that pressure increases with increasing density since overlying rock exert pressure with their weight.
- Therefore, it is asserted that pressure increases with increasing depth.

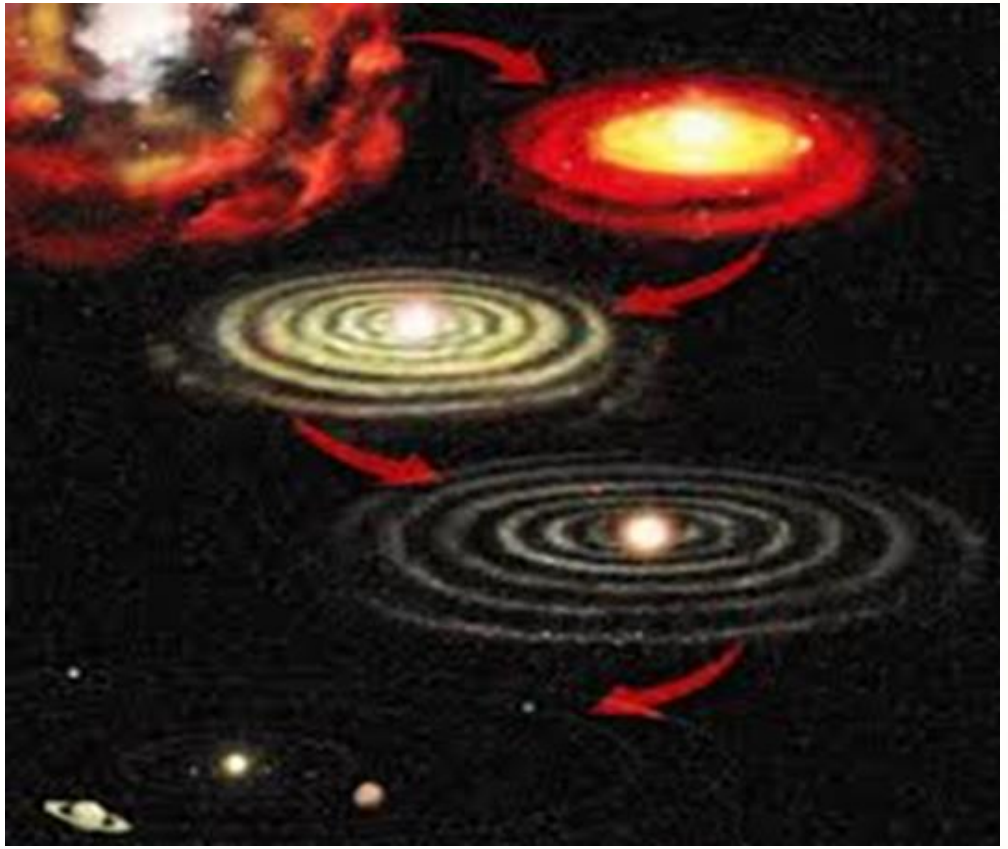


Evidence from studies-

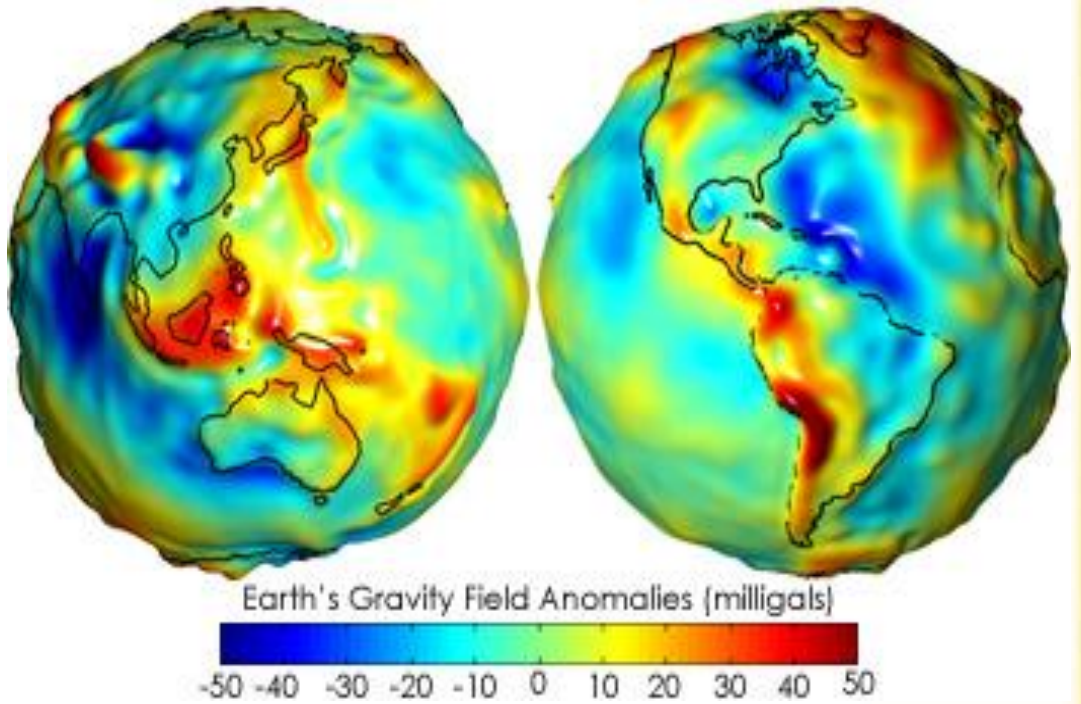
- According **to Chamberlain "planetesimal theory", Planetesimal** is the embryo material of planet Earth.
- **Solid dust** particles and other material got condense and accumulated over this planetesimal. Hence Earth's core might happen in solid state.

- The **Tidal hypothesis of James jeans** claimed that the core of earth should be in a liquid state.

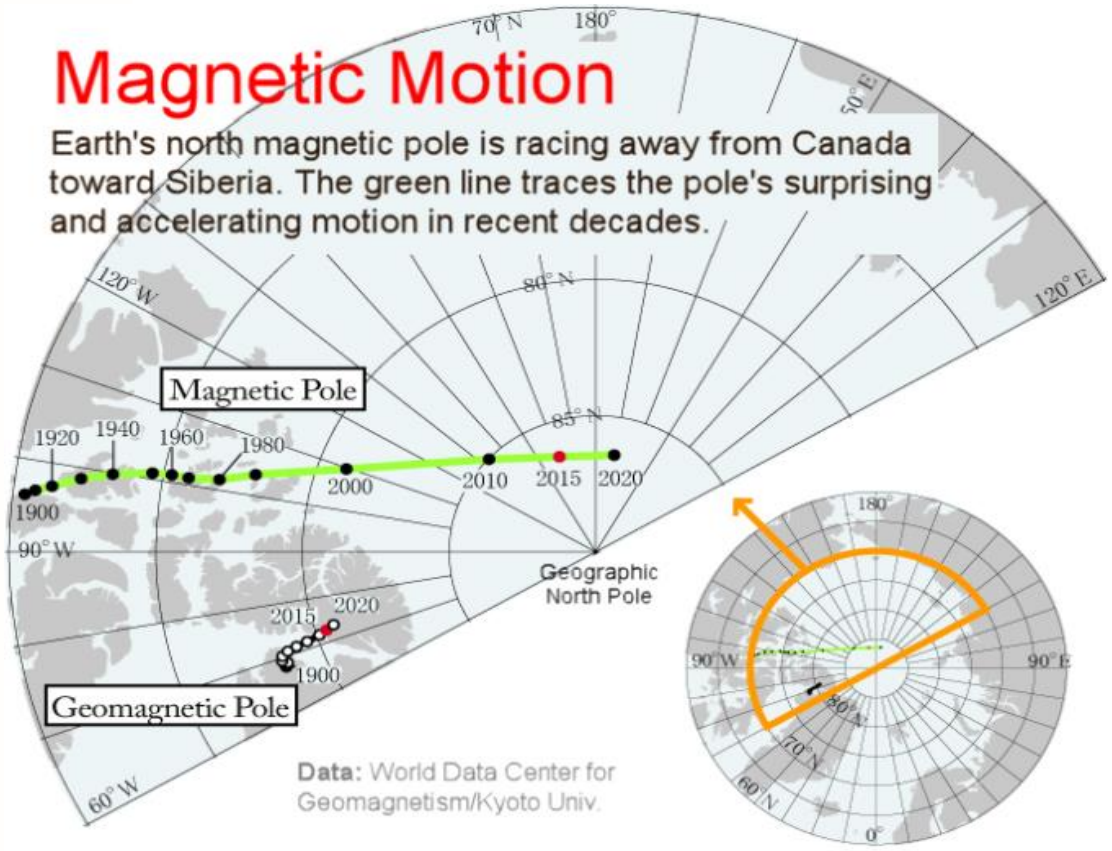


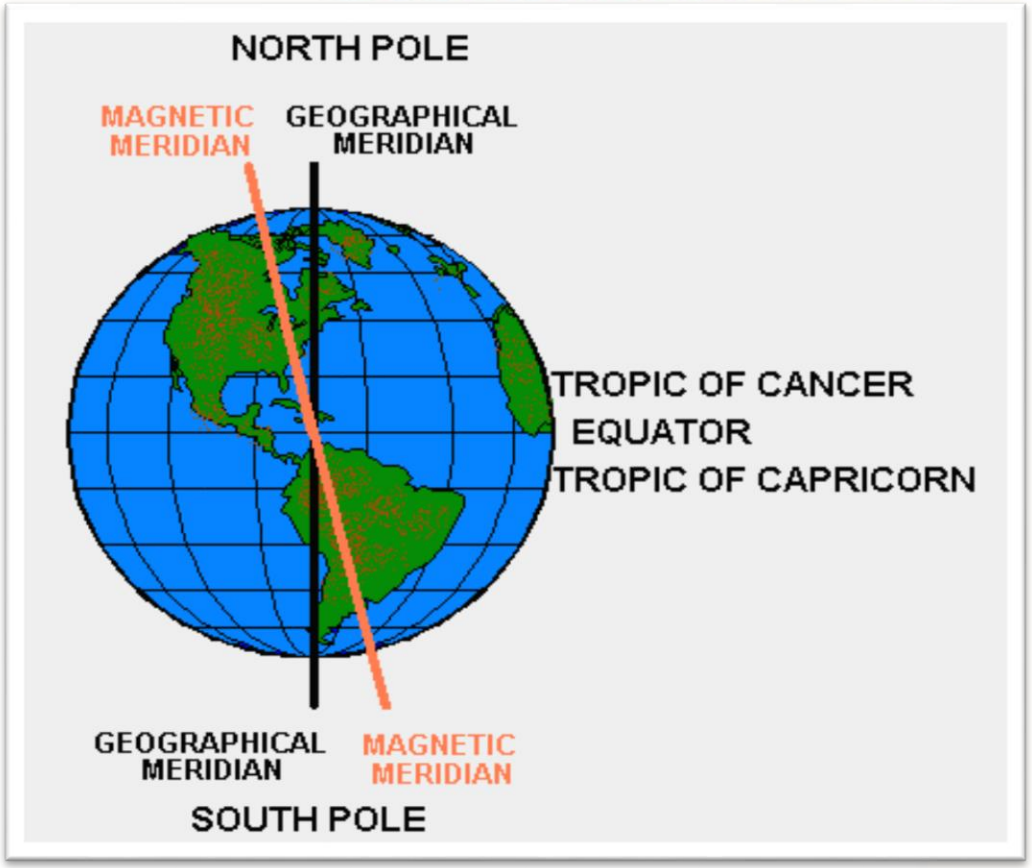


- **Gravitational anomaly -**
- A **gravitational anomaly** is the **difference between the measured gravitational force at a location and the expected value** based on Earth's average structure and shape.
- It indicates irregularities in the distribution of mass beneath the Earth's surface.
- In general, it is **Greater near the pole** and **lesser near the equator**.
- The gravity values also differ according to the mass of material.



Magnetic survey



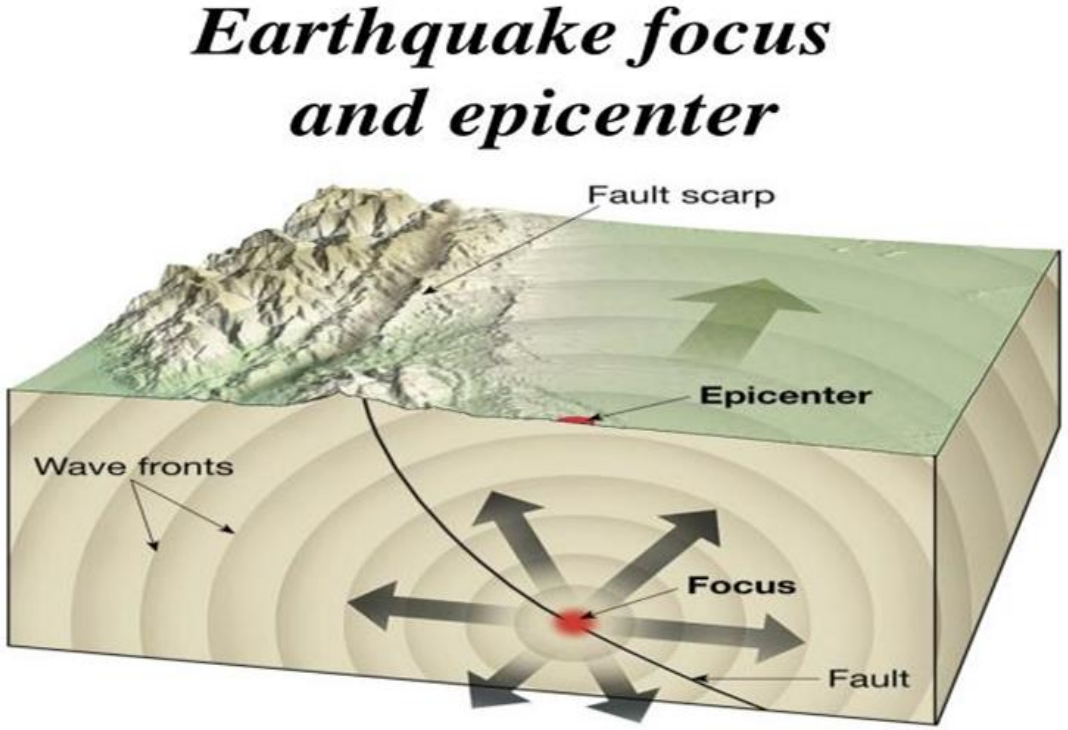


- **Earth's Magnetic Field**
  - The Earth behaves like a giant bar magnet, producing a **magnetic field** that extends from its **magnetic south pole to magnetic north pole**. This field is invisible but plays a vital role in protecting the planet and guiding natural and human-made systems.
- **Origin**
  - The magnetic field is generated by the **movement of molten iron and nickel** in the **Earth's outer core**.
  - This movement creates electric currents, which in turn produce a magnetic field—a process known as the **geodynamo**.
- **Structure**
  - The magnetic field forms a region called the **magnetosphere**, which extends thousands of kilometers into space.
  - It **shields Earth from solar wind and cosmic radiation**, helping preserve the atmosphere and enabling life.
- **Magnetic Poles**
  - The **magnetic poles** are not fixed and **gradually drift** due to changes in the core's movement.
  - They are different from the **geographic poles** and can move several kilometers each year.

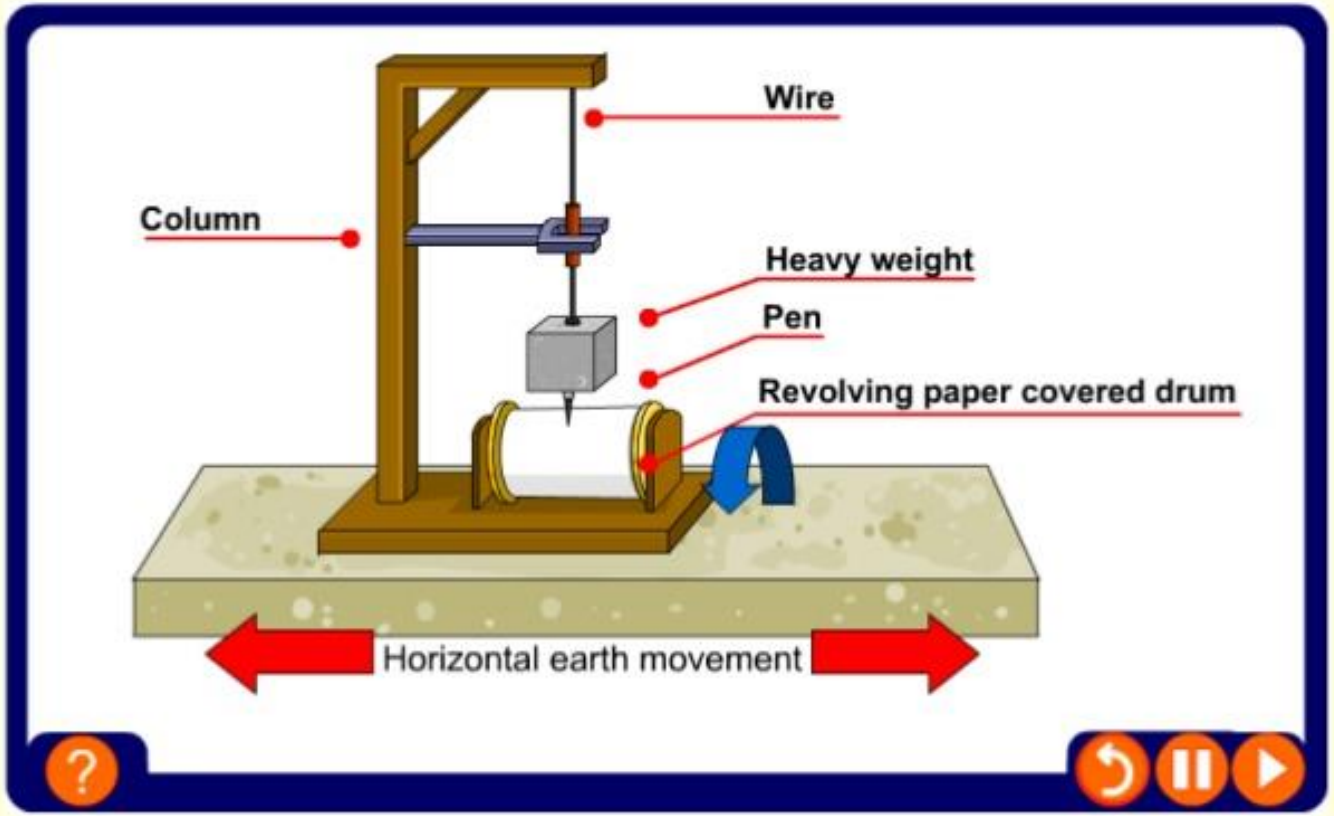
- **Earth's Magnetic Reversal**
  - A **magnetic reversal** (or geomagnetic reversal) occurs when the **Earth's magnetic field flips**, and the **north magnetic pole becomes south**, and vice versa.
- **Cause**
  - Caused by complex and unstable flows in the outer core.
  - When the geodynamo becomes disturbed, the magnetic field **weakens**, changes direction, and **reverses**.
- **Time Scale**
  - Reversals are **irregular** and can occur every **200,000 to 300,000 million years**.
  - The **last full reversal** was the **Brunhes–Matuyama reversal**, around **780,000 years ago**.

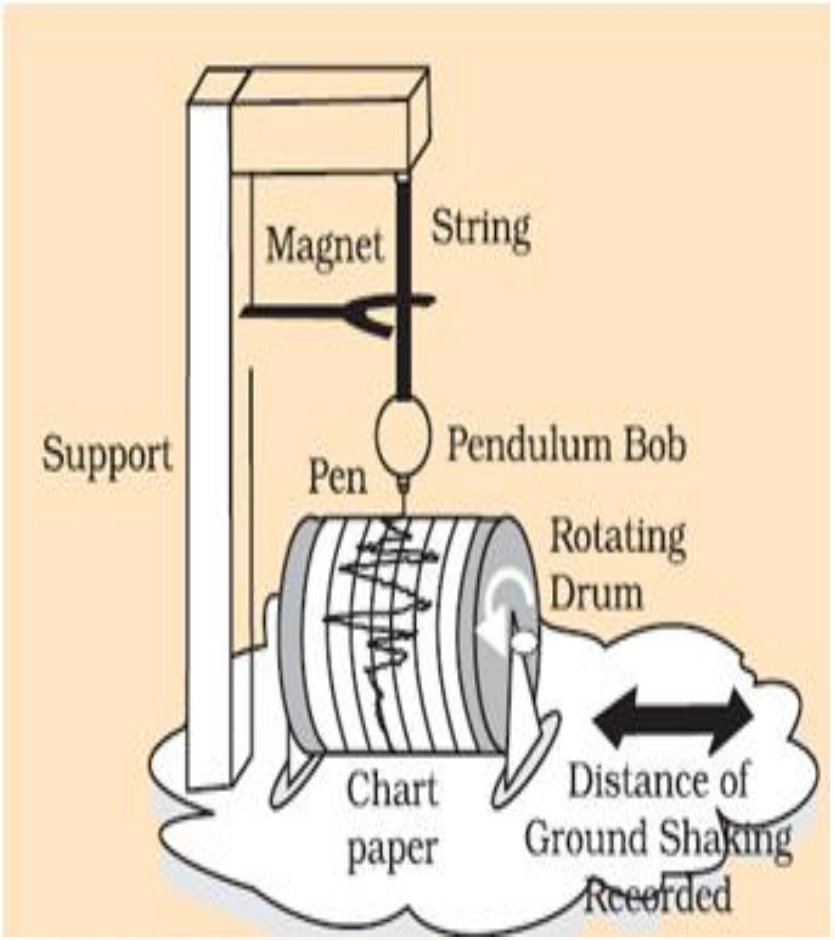
SEISMIC WAVES AND EARTH'S INTERIOR

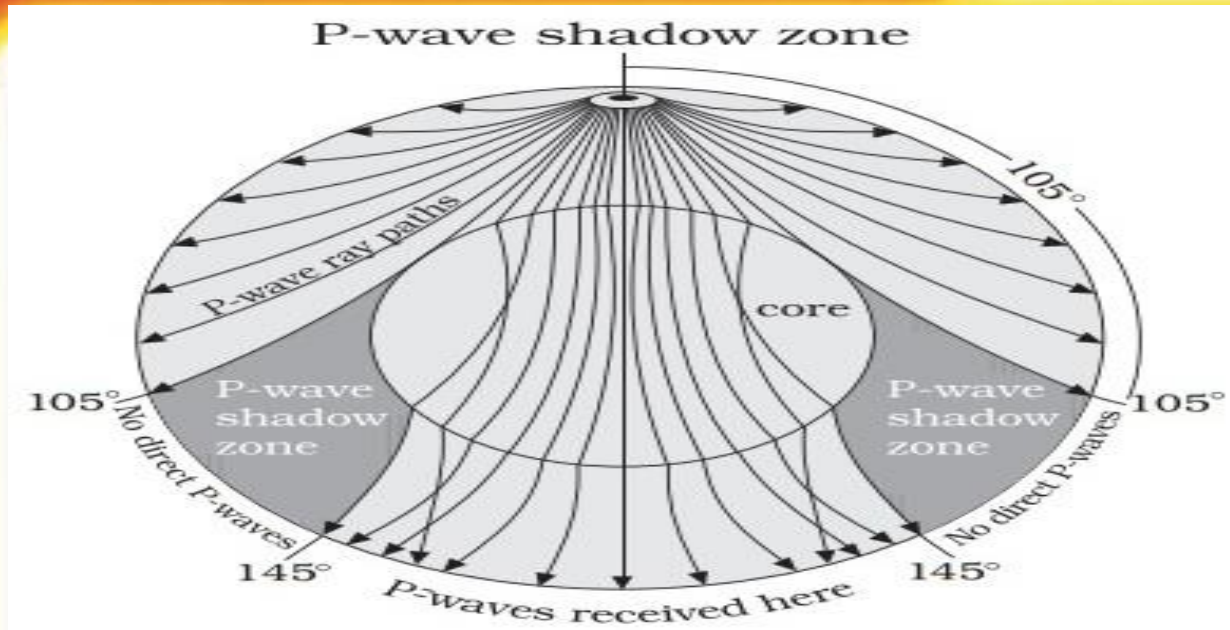
- It is the most important source that reveals the clear picture of the earth's interior.
- **Abrupt shaking of earth is known as earthquake**.
- During this seismic wave forms and travels in different directions.
- An instrument called 'seismograph' records the waves reaching the surface
- **Electromagnetic seismography** was invented in **in 1856 by Luigi Palmieri to record seismic wave.**

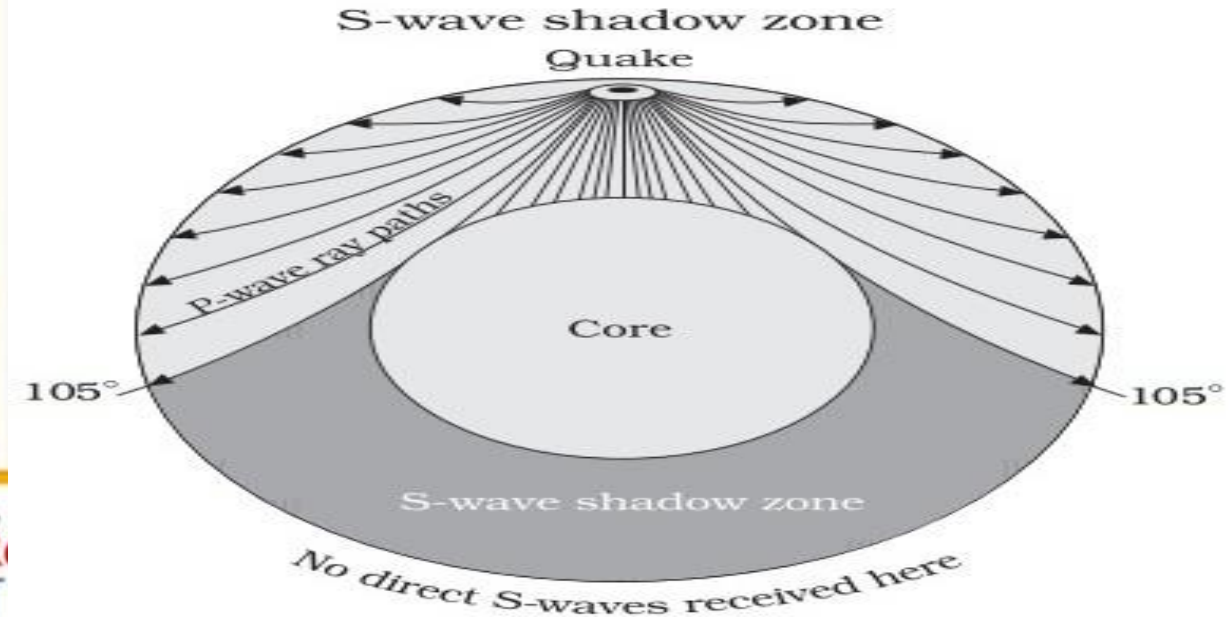


A seismograph





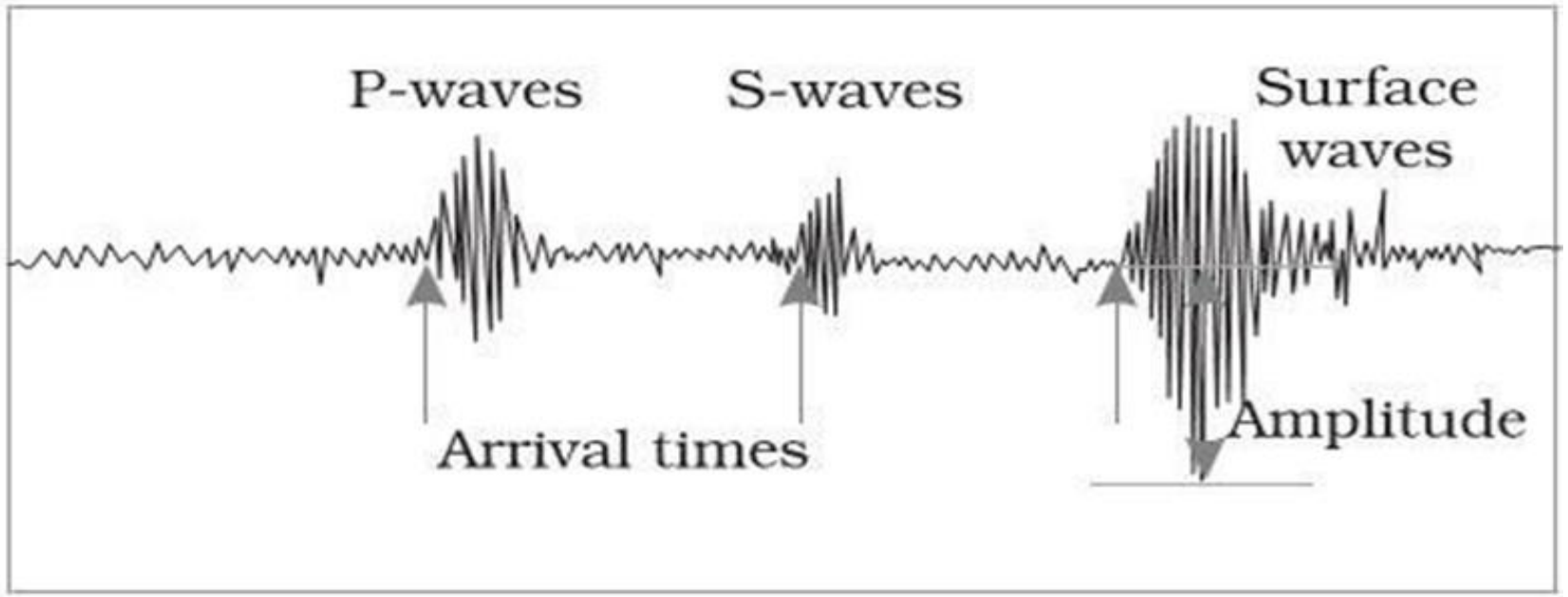




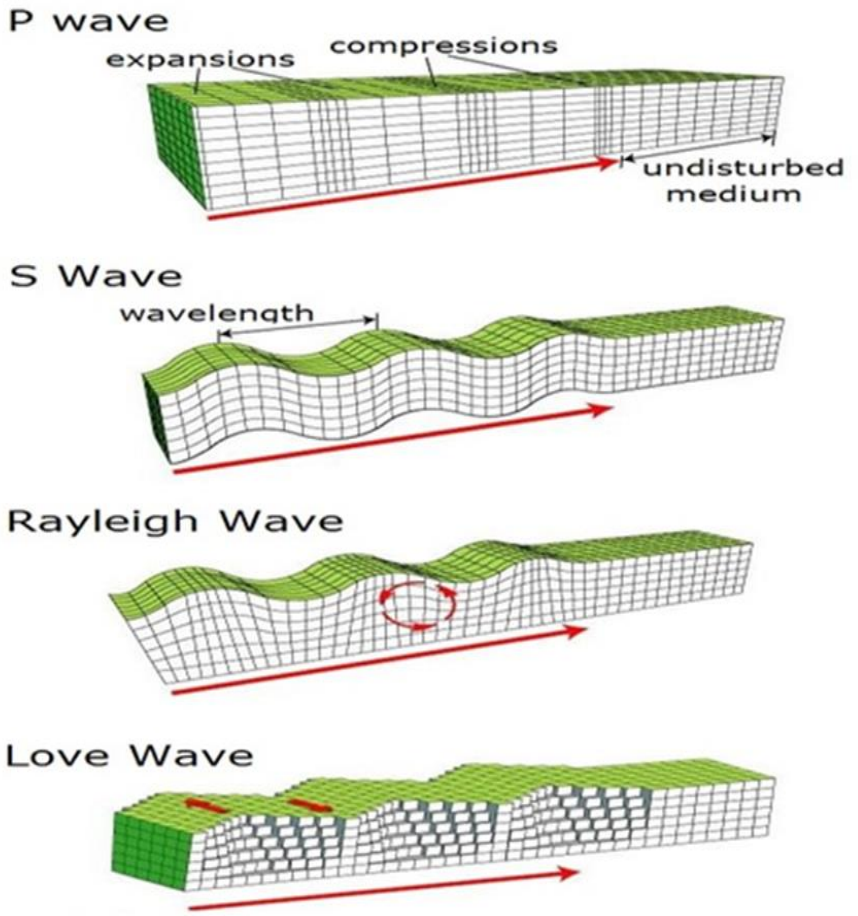
The waves are basically the wave of energy. It can be classified into two group –

1. **Body waves and**
2. **Surface waves**

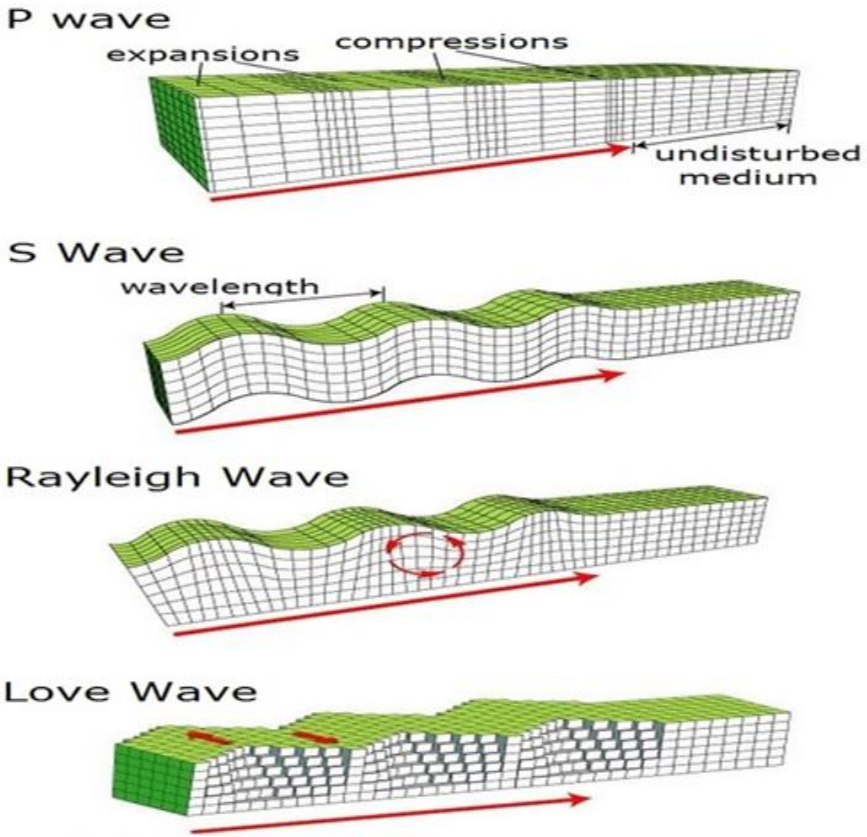
- Body waves are generated due to the release of energy at the focus and move in all directions **travelling through the body of the earth**.

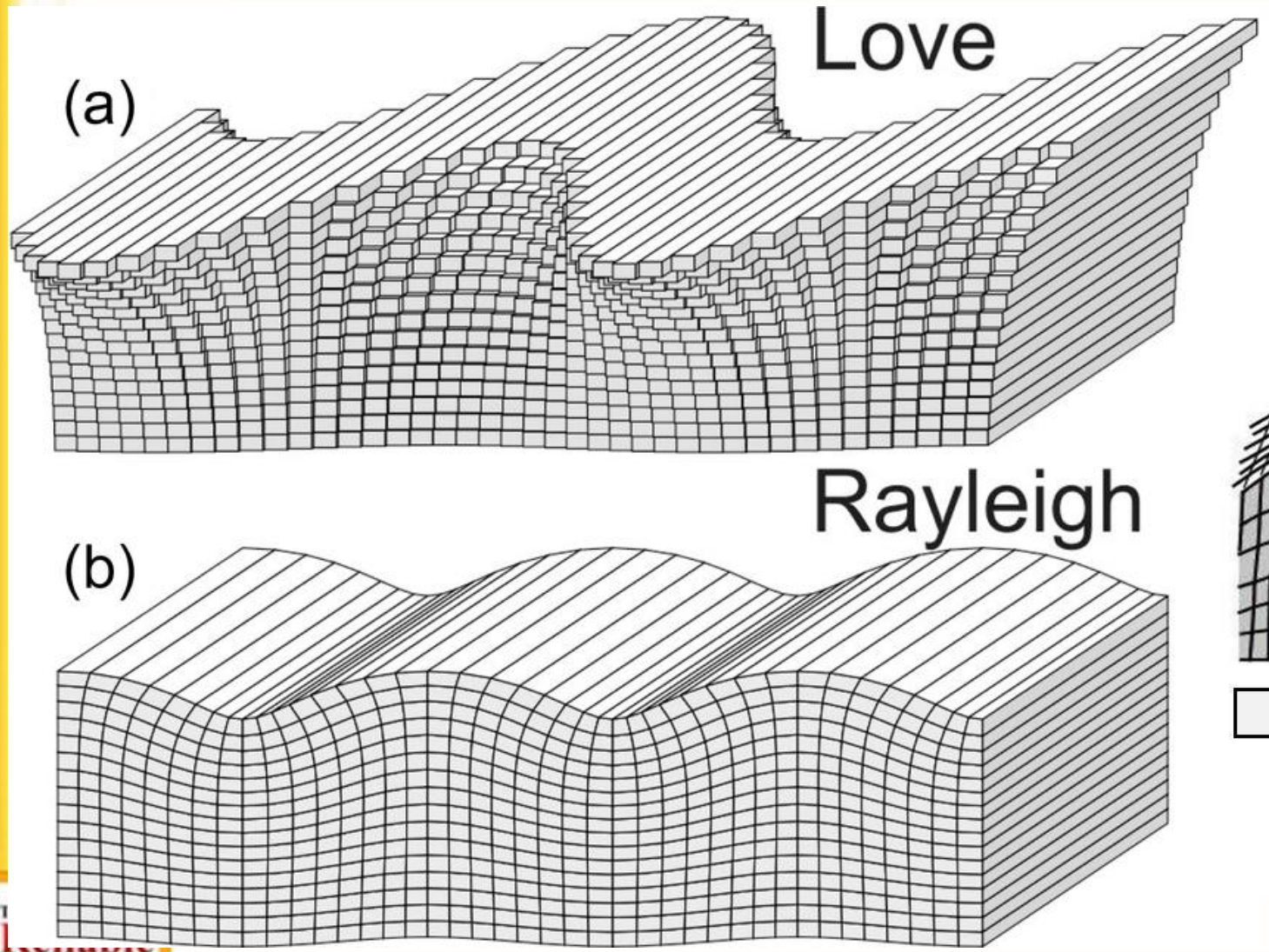

P-waves
S-waves
Surface waves
Arrival times
Amplitude

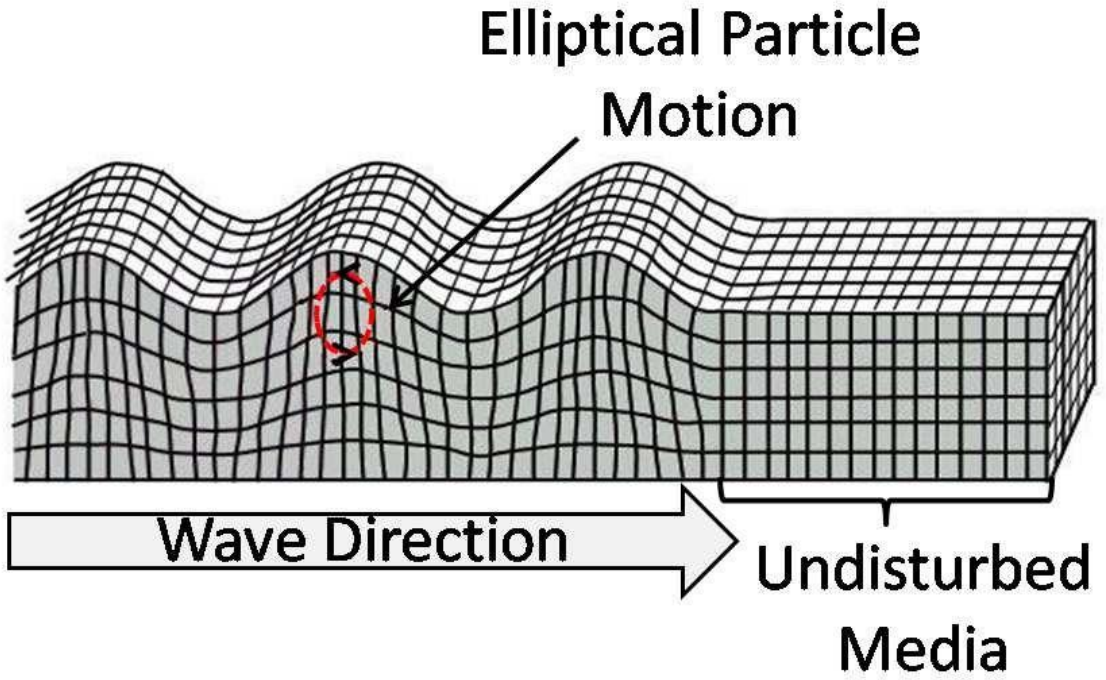
- There are two type of body waves:-
- **P-waves** –
  - move faster and are the first to arrive at the surface.
  - These are also called ‘primary waves’.
  - The P-waves are similar to **sound waves**(**Longitudinal waves** or **compressional waves**).
  - They travel through gaseous, liquid and solid materials.
- **S-wave –**
  - S-waves arrive at the surface with some time lag.
  - These are called secondary waves.
  - S-waves is that they can travel only through **solid materials**.
  - It is similar to **light waves** (transverse waves).

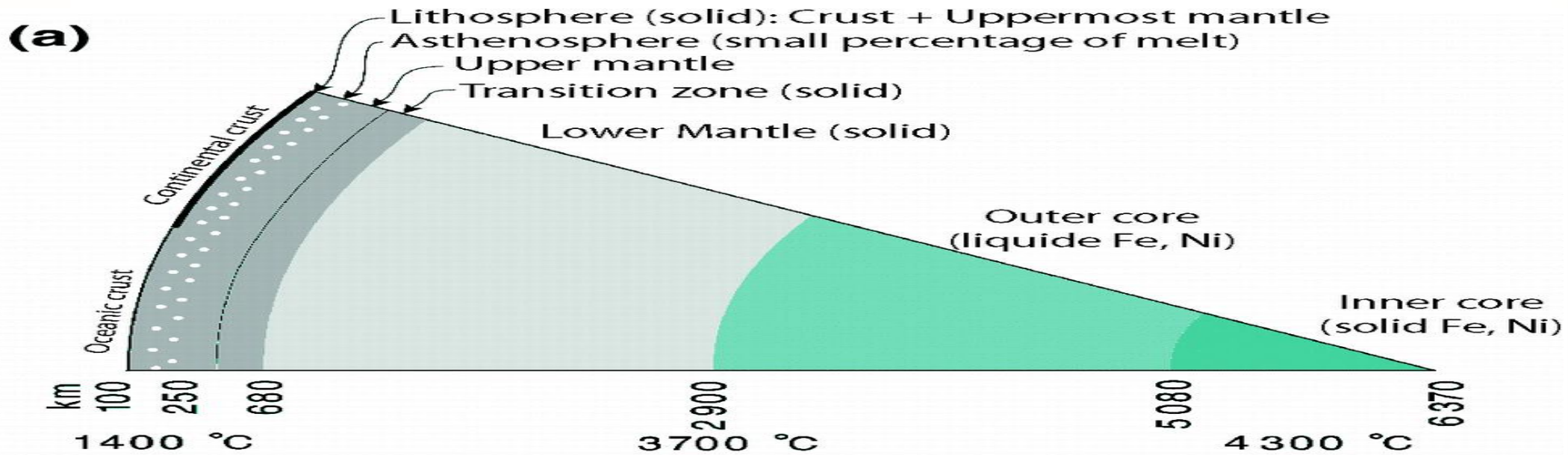


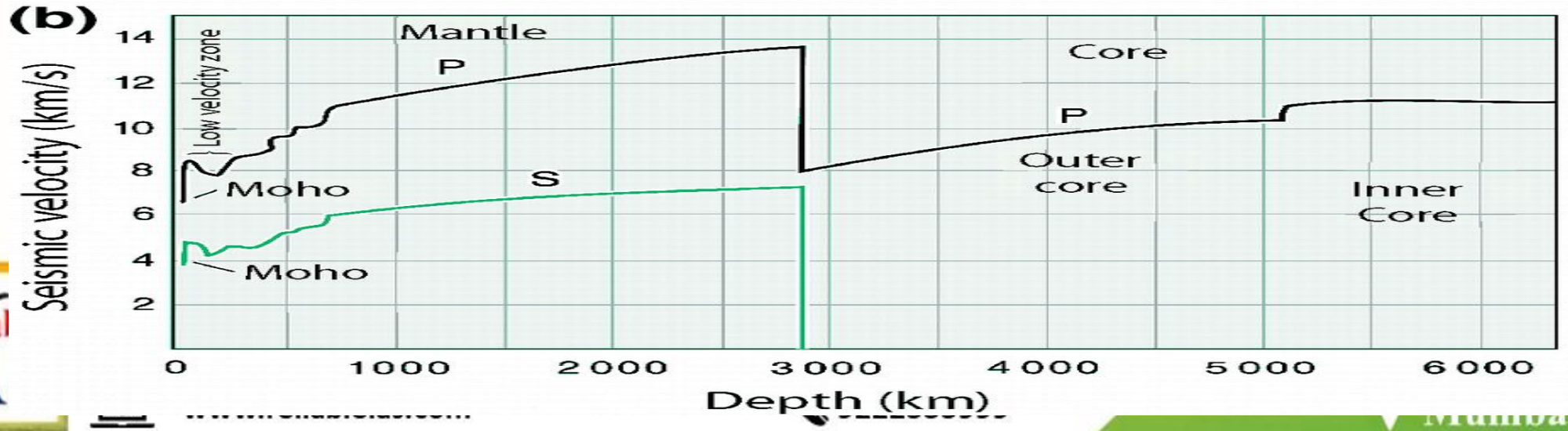
- The body waves interact with the surface rocks and generate new set of waves called surface waves.
- These waves move along the surface. The velocity of waves changes as they travel through materials with different densities. The denser the material, the higher is the velocity.
- There are two type of surface waves-
- **L-wave** –
  - It is called Long period wave.
  - It is also known as the love wave, named after **A.E.H. love**.
  - It is a transverse wave and affects only the surface of Earth.
  - It **covers the longest distance** and causes devastating impact.
  - It is the last wave to be recorded on seismographs.
- **Rayleigh wave** –
  - It is named after British physicist **Lord Rayleigh** who first demonstrated its existence.
  - It causes the ground to be shaken in elliptical motion.
  - It is slower than L-wave.




(a)
Love
(b)
Rayleigh

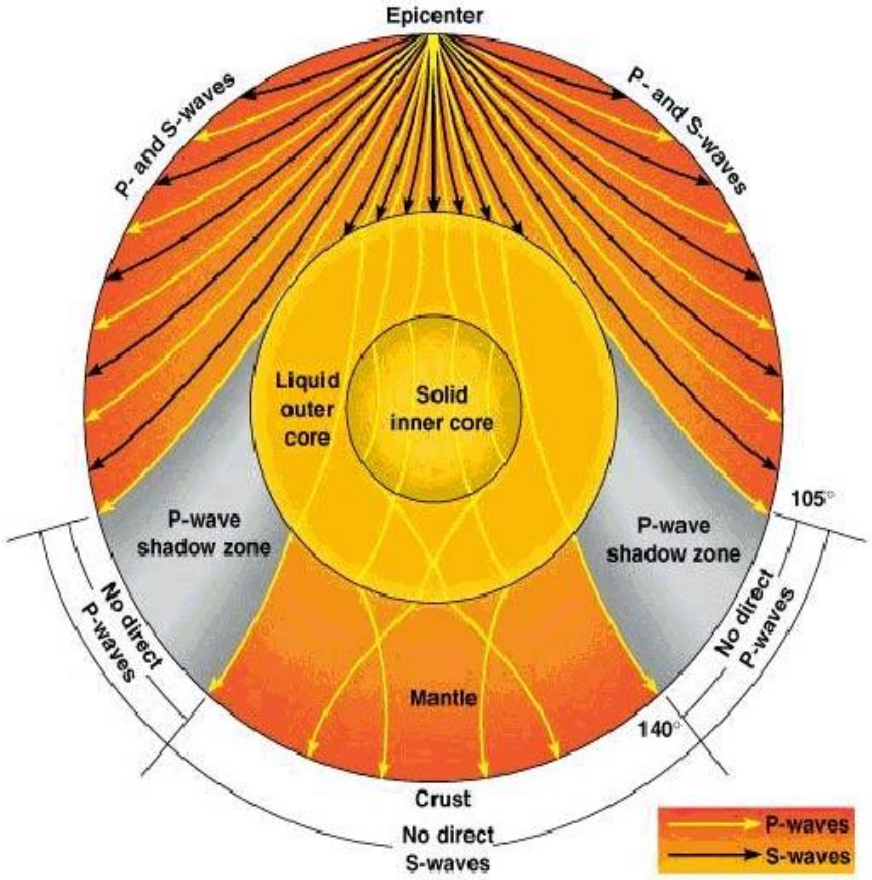

Elliptical Particle Motion
Wave Direction
Undisturbed Media



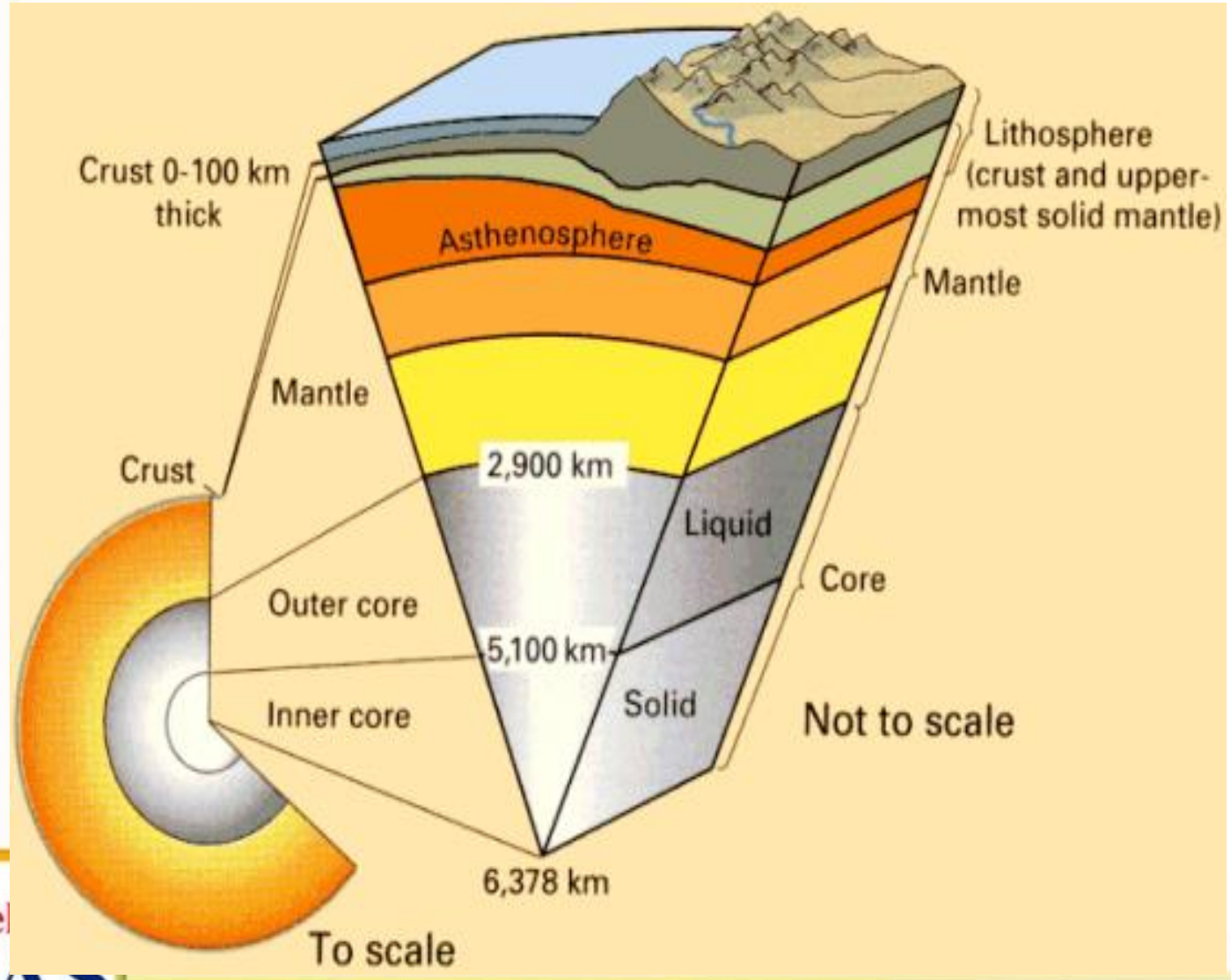


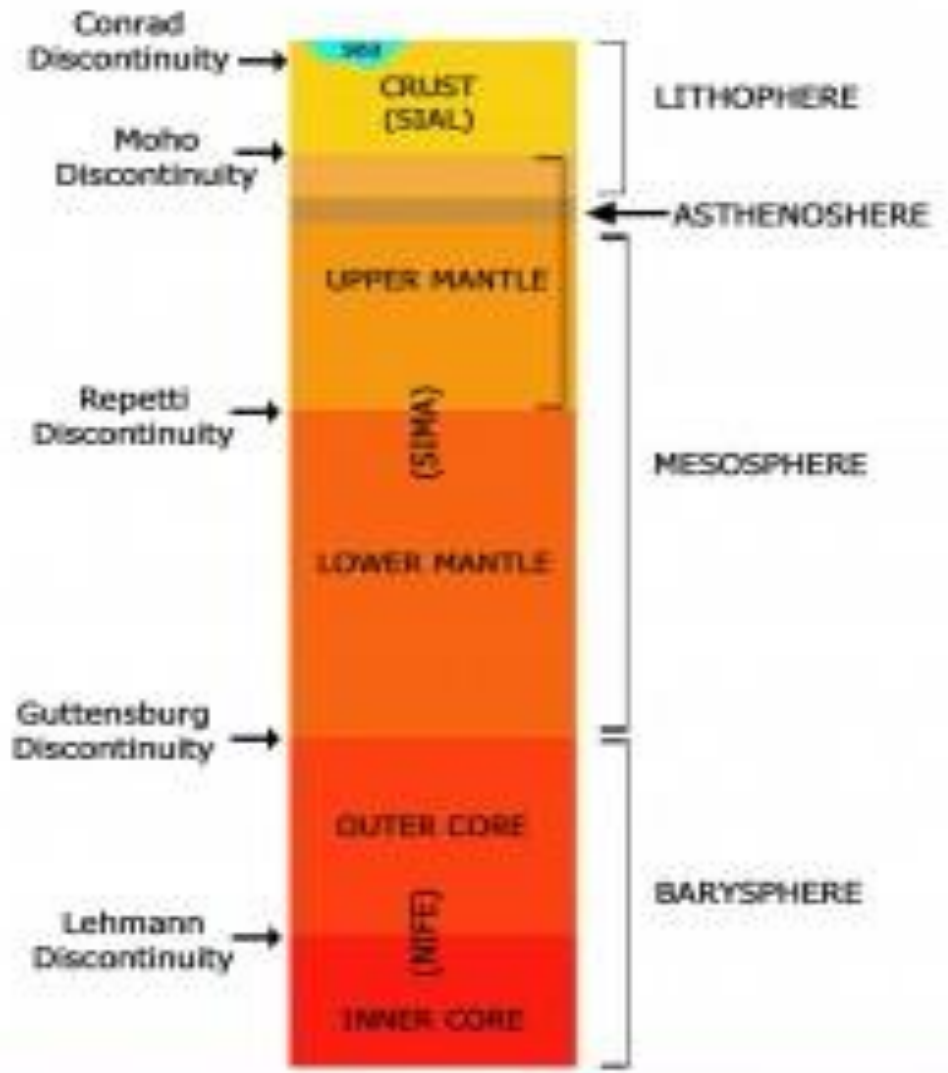
EMERGENCE OF SHADOW ZONE

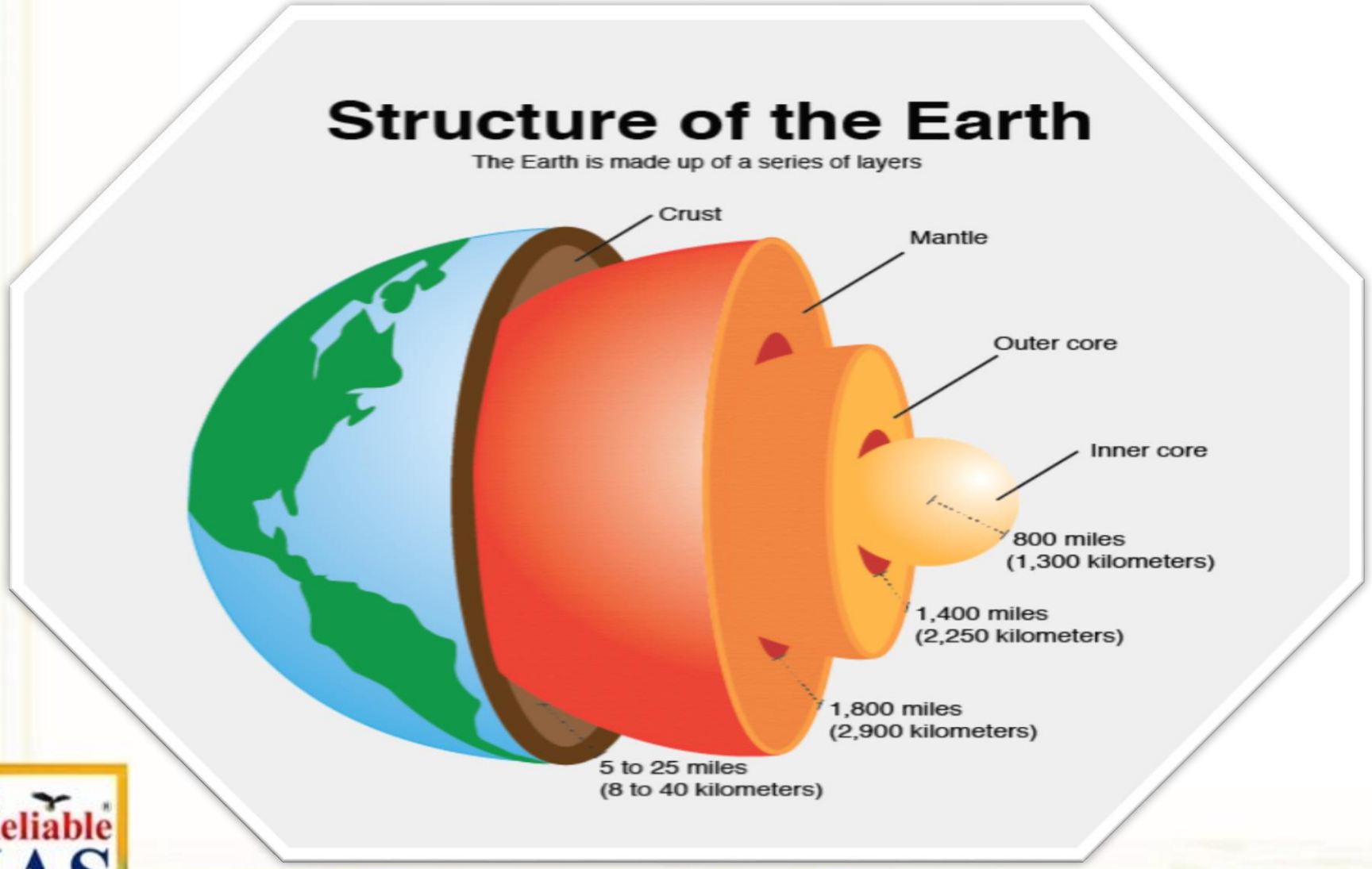
- There exist some specific areas where the waves are not reported **called shadow zone of seismic wave.**
- It was observed that seismographs located at any distance **within 105° from** the epicenter, recorded the arrival of both P and S-waves.
- However, the seismographs located **beyond 145° from epicenter, record the arrival of P-waves, but not that of S-waves**.
- Thus, a **zone between 105° and 145° from epicenter was identified as the shadow zone for both the types of waves.**
- **The entire zone beyond 105° does not receive S-waves.**
- The shadow zone of P-waves appears as a band around the earth between 105° and 145° away from the epicenter.
- **The shadow zone of S-wave is much larger than that of the P-waves**. **The shadow zone of S-waves is also a little over 40 per cent of the earth surface.**

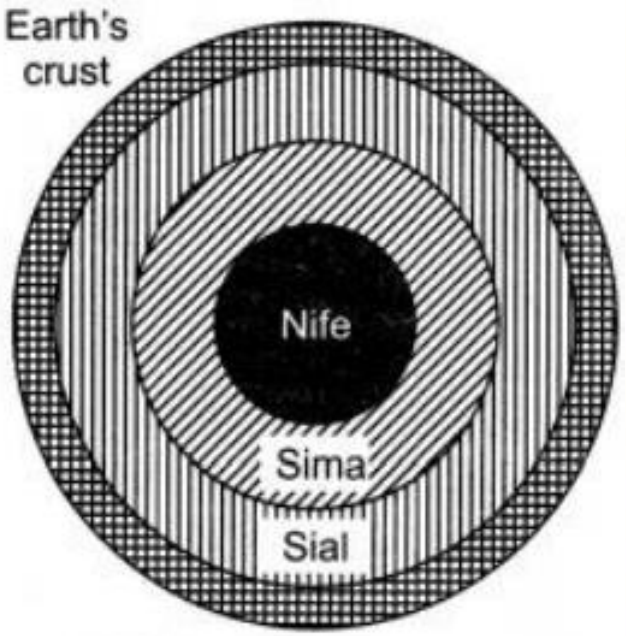


EARTH'S LAYER







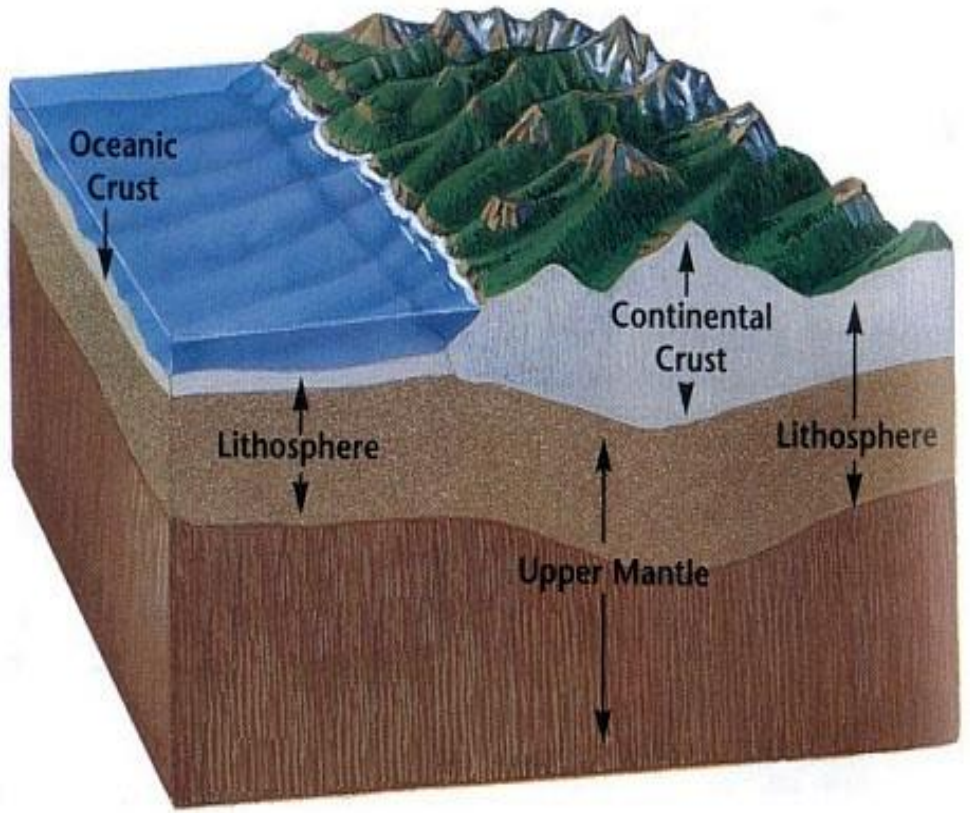


Internal structure of earth, according to Suess

Eduard Suess

CRUST

- Uppermost part of earth; brittle
- Thickness 0 to 30 kilometer
- called SIAL (silicon + aluminum)
- Divided into two layer
  1. Upper/continental crust (granite)
  2. Lower / oceanic crust (basalt)
- CONARD discontinuity b/w upper crust and lower crust

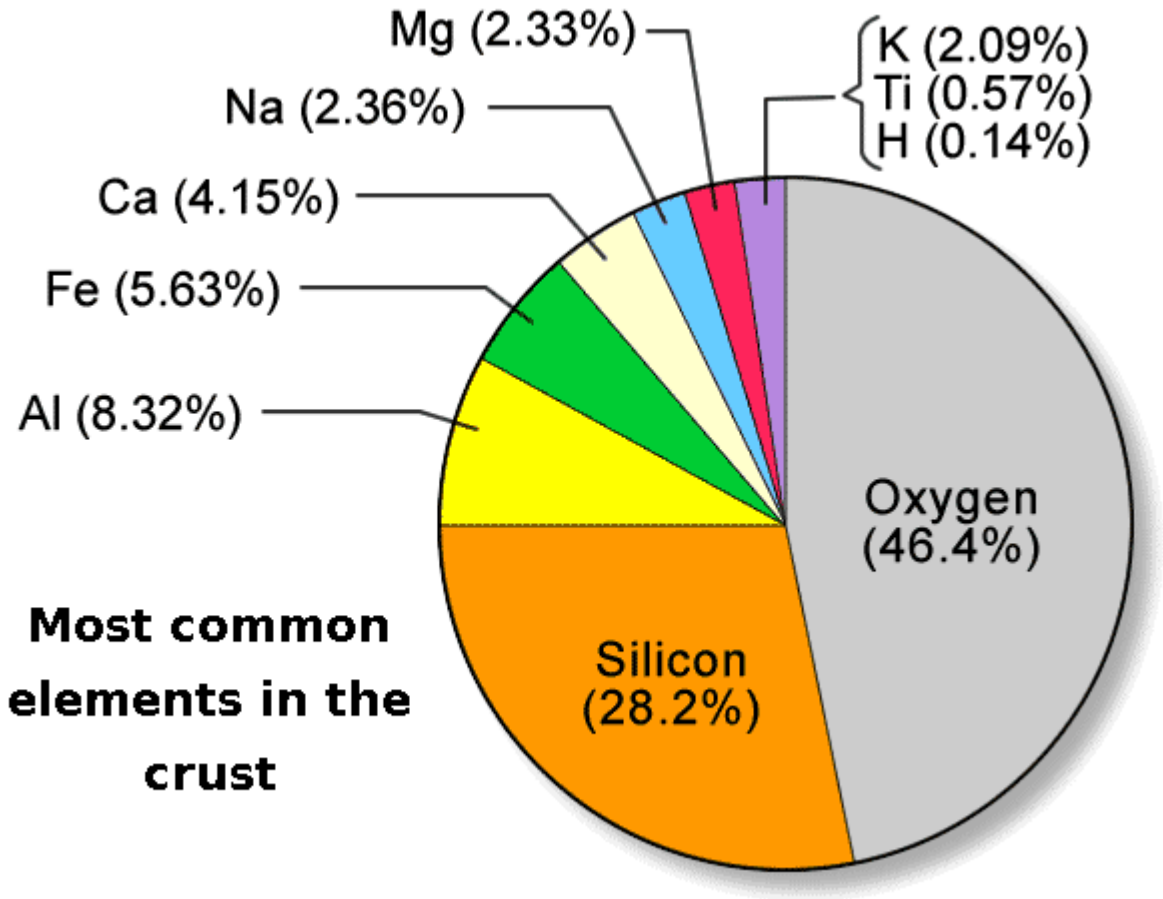


Layers	Volume % of Earth	Mass % of Earth	Density (Earth - 5.5)
CRUST	1 %	--	2.8
MENTAL	83 %	68 %	4.6
CORE	16 %	32 %	11

Key Differences Between Continental and Oceanic Crust

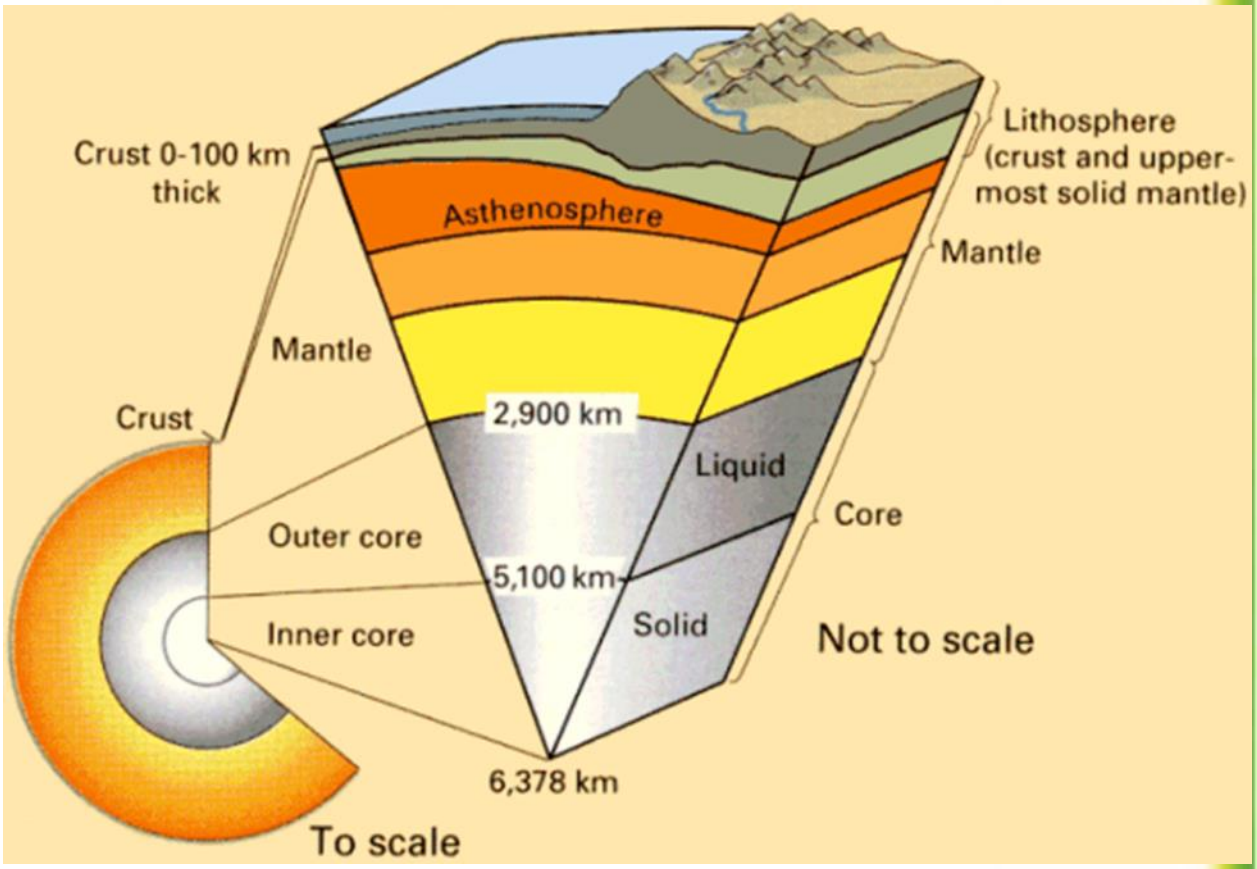
Feature	Continental Crust	Oceanic Crust
Thickness	30–70 km (thicker)	5–10 km (thinner)
Density	~2.7 g/cm³ (lower)	~3.0 g/cm³ (higher)
Composition	Granite (rich in SiAl)	Basalt (rich in SiMa)
Age	Older (up to 4 billion years)	Younger (up to 200 million years)
Key Elements	Silica (Si), Aluminum (Al), Potassium (K), Sodium (Na)	Magnesium (Mg), Iron (Fe), Silica (Si)
Formation	Part of continents and landmasses	Found under ocean basins

Rank	Element	Atomic Number	Crustal Abundance %
1	oxygen	8	46.60
2	silicon	14	27.70
3	aluminium	13	8.13
4	iron	26	5.00
5	calcium	20	3.63
6	sodium	11	2.83
7	magnesium	12	2.59
8	potassium	19	2.09
9	titanium	22	0.44
10	hydrogen	1	0.14
10 +	Other		0.85



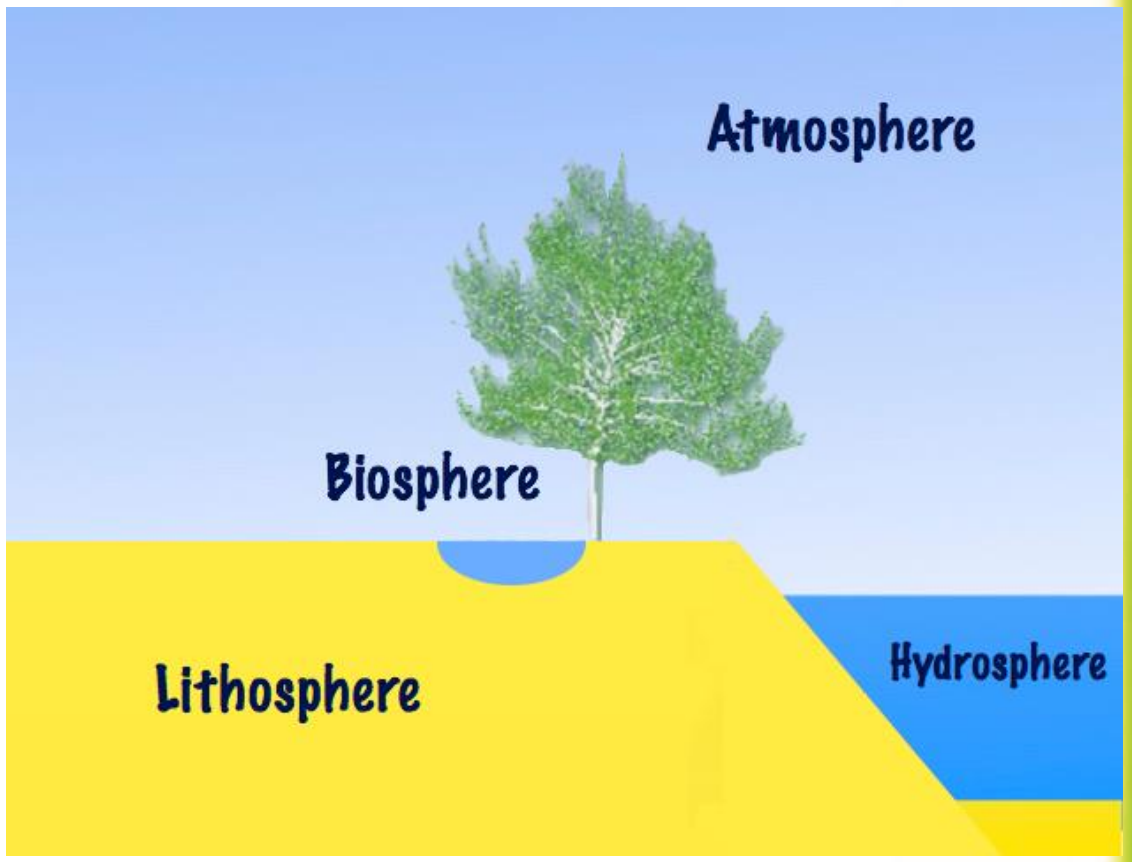
MANTLE

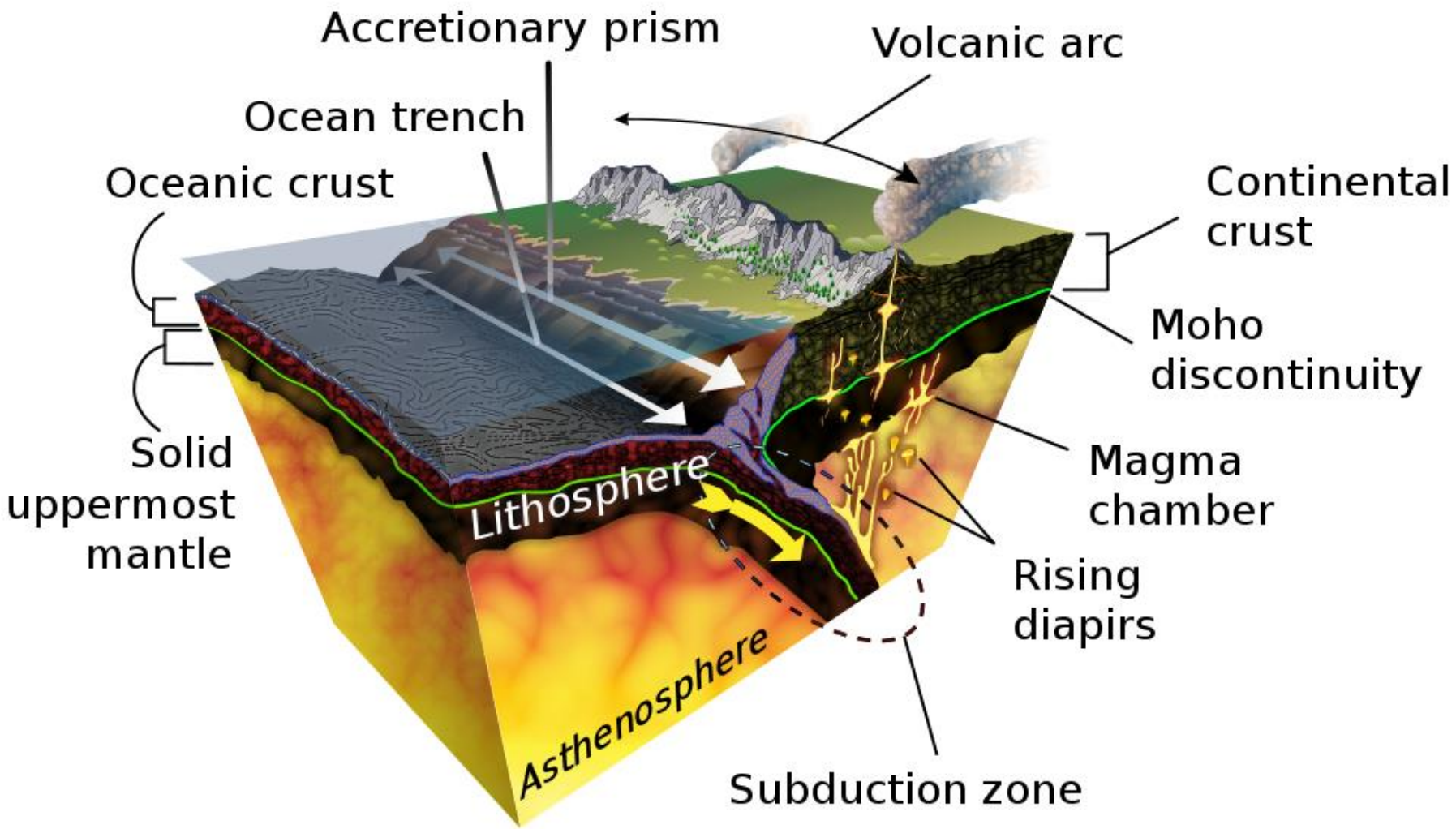
- Between 30 to 2900 km
- contains 68% of total mass of Earth
- 83% of volume of Earth,
- Called SIMA (Silicon + magnesium)
- Moho Discontinuity :- found between Crust and Mantle
- According to **International Union of Geodesy and Geophysics** Can be divided into 3 layer
  1. Upper mental :- 30-200 km
  2. Middle mental :- 200-700 km
  3. Lower mental : 700-2900 km
- **Repeti Discontinuity** :- an obsolete discontinuity believed to be found between upper Mantle and lower Mantle



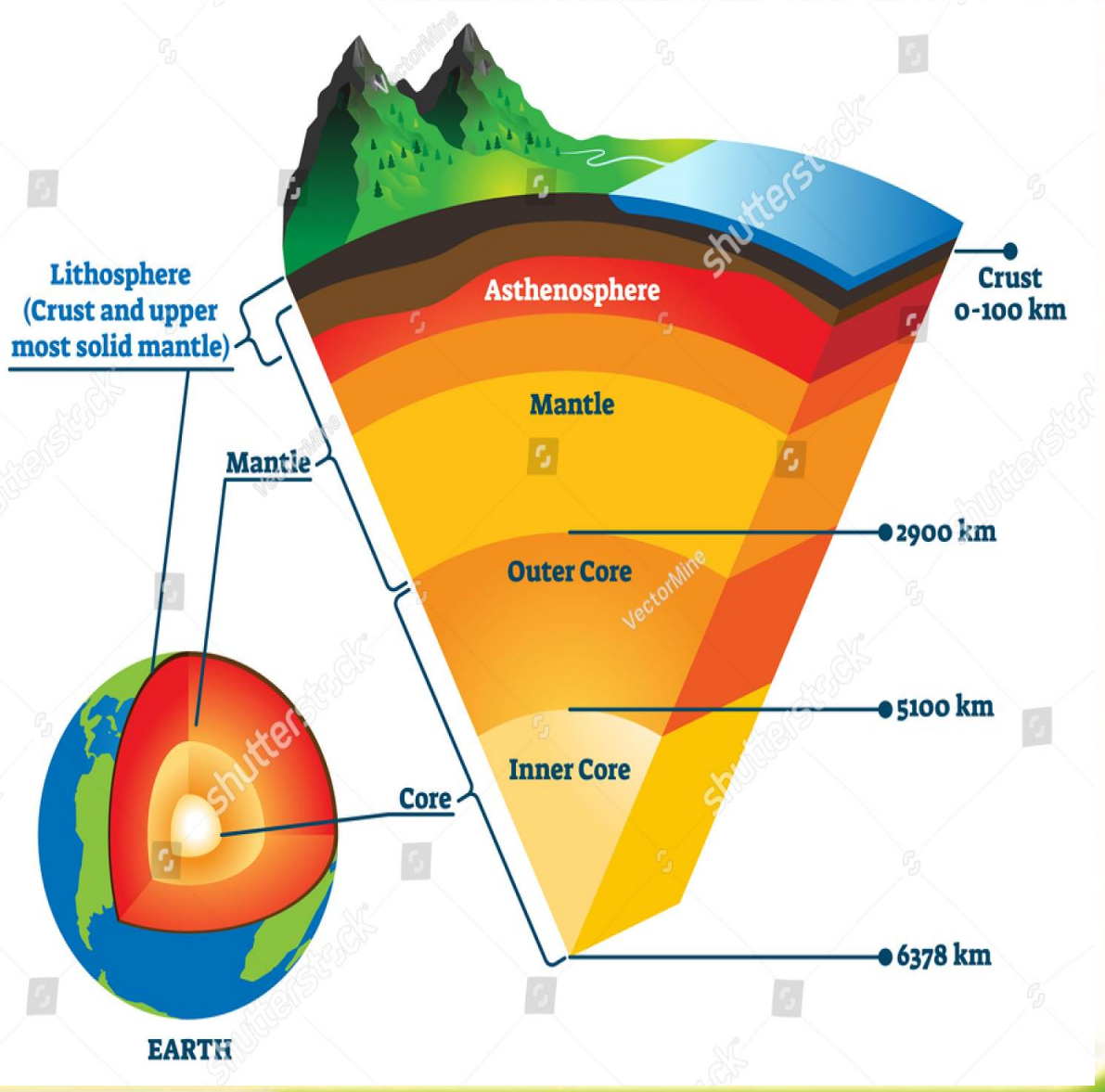
- Upper Mantle
  - **Composition**: Silicate minerals like olivine and pyroxene.
  - **Physical State**: Rigid in the uppermost part (lithosphere), partially molten and ductile in the asthenosphere.
  - **Density**: 3.3–3.9 g/cm³.
  - **Key Features**: Facilitates plate tectonics and is the primary source of magma for volcanic activity.
- Middle Mantle
  - **Composition**: High-pressure minerals like wadsleyite and ringwoodite (transformed from olivine).
  - **Physical State**: Solid but capable of slow plastic deformation under high pressure.
  - **Density**: 3.9–4.5 g/cm³.
  - **Key Features**: Known as the transition zone, it features significant mineral transformations that separate the upper and lower mantle.
- Lower Mantle
  - **Composition**: Dense minerals like bridgmanite and ferropericlase.
  - **Physical State**: Solid, with extremely slow flow due to immense pressure and heat.
  - **Density**: 4.5–5.6 g/cm³.
  - **Key Features**: Drives mantle convection and interacts with the outer core, influencing heat transfer and geodynamics.

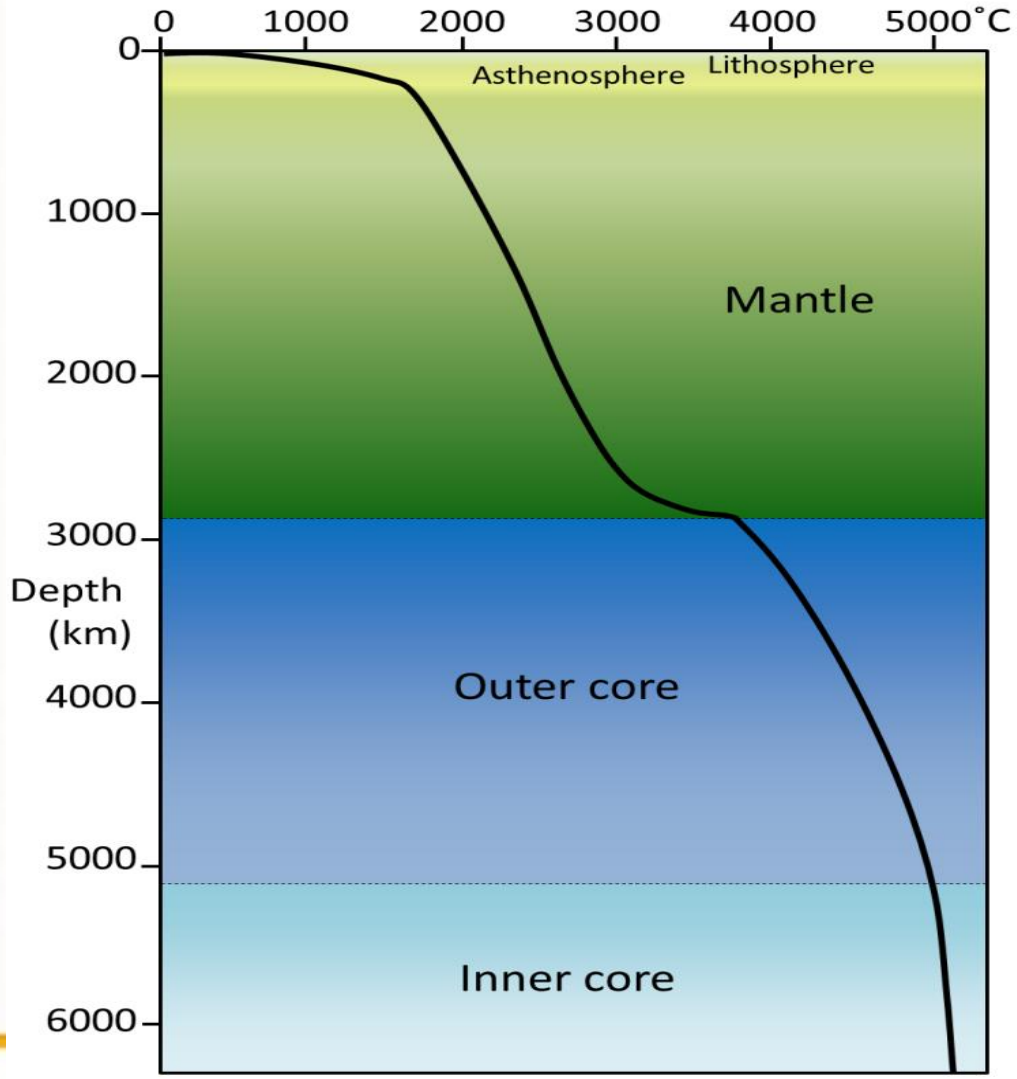
- **lithosphere :-**
- The lithosphere is the solid, outer part of Earth. The lithosphere includes the brittle **upper portion of the mantle and the crust,** the outermost layers of Earth's structure.
- It is bounded by the atmosphere above and the asthenosphere (another part of the upper mantle) below.
- **spreaded b/w lower crust & upper Mantle (lithos –rock).**
- The lithosphere is subdivided horizontally into tectonic plates.




Accretionary prism
Volcanic arc
Ocean trench
Oceanic crust
Continental crust
Moho discontinuity
Solid uppermost mantle
Lithosphere
Magma chamber
Rising diapirs
Asthenosphere
Subduction zone

- ***Asthenosphere :-***
- The asthenosphere is the **denser, weaker layer** beneath the lithospheric mantle (upper Mantle.)
- It lies between about *100 kilometers and 410 kilometers beneath Earth's surface*.
- The **temperature and pressure of the asthenosphere are so high that rocks soften and partly melt, becoming semi-molten.**
- This is the most important source of **magma on Earth**. It is the source of mid-ocean ridge basalt (MORB) and of some magmas that erupted above subduction zones or in regions of continental rifting.

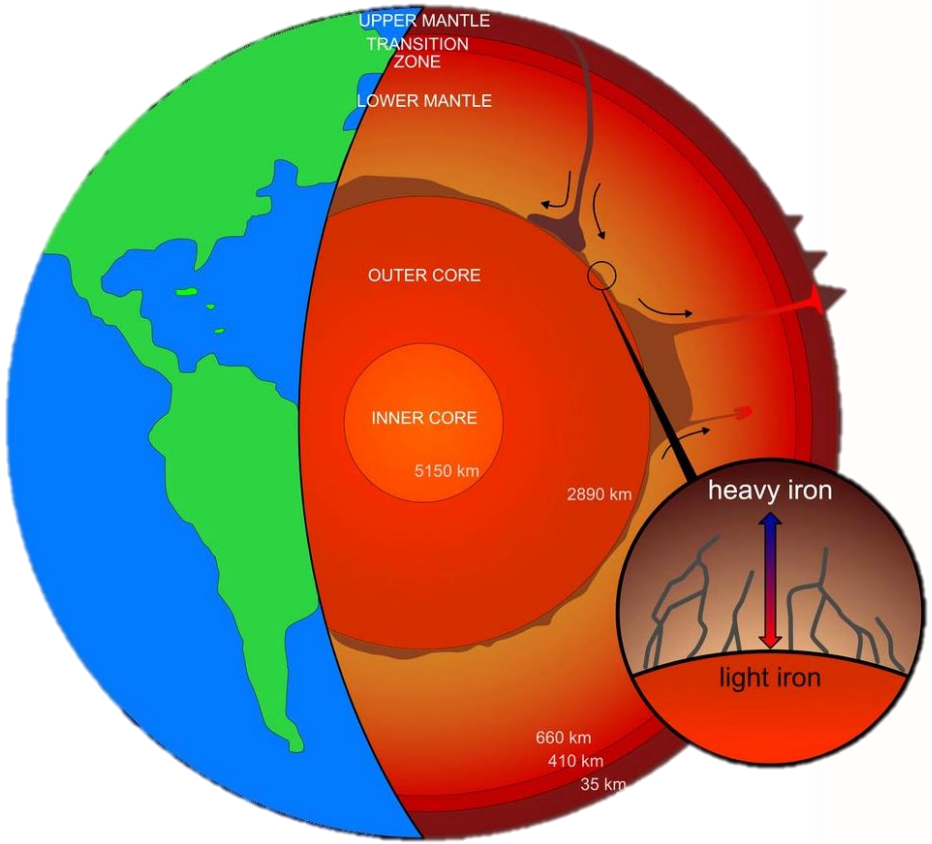


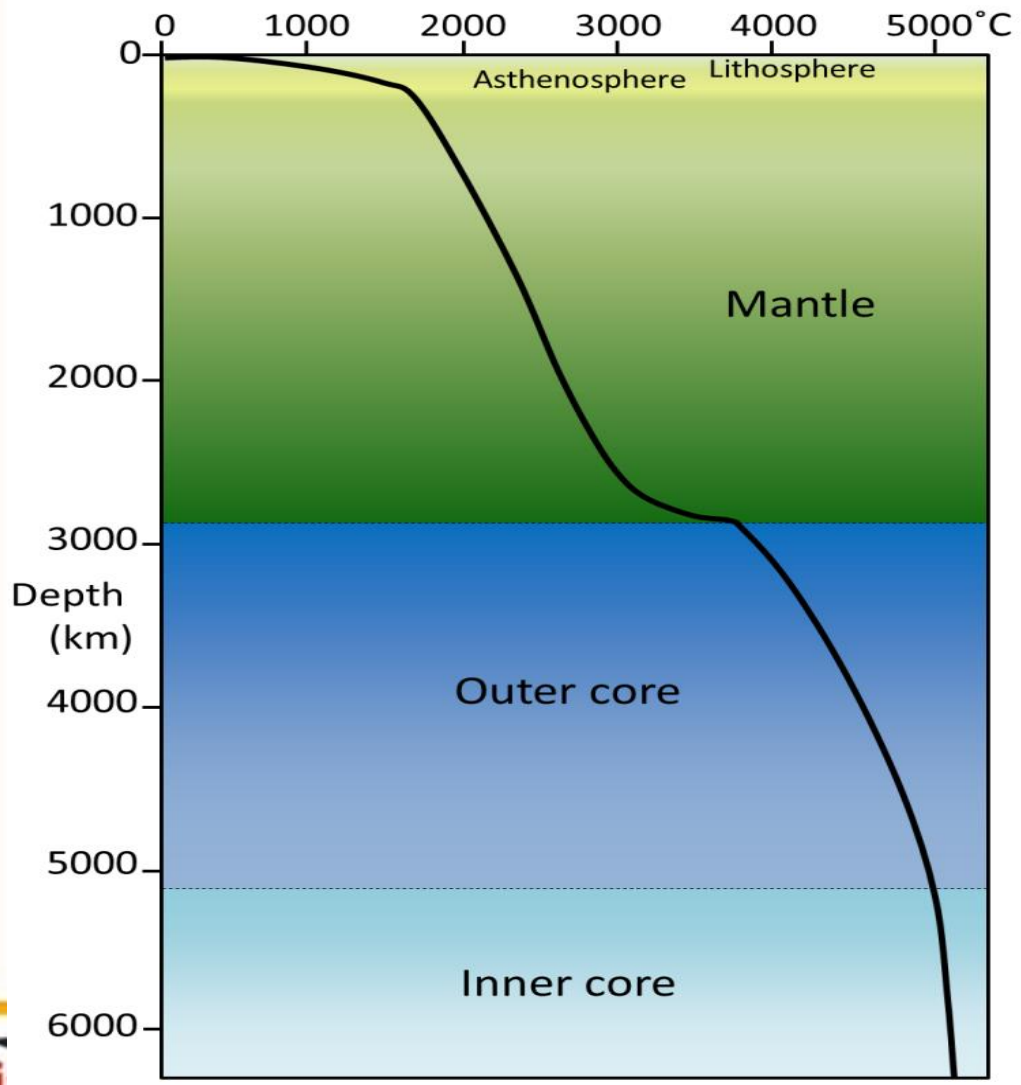


- The lithosphere-asthenosphere boundary is conventionally taken at the **1,300 °C isotherm**.
- Seismic waves pass relatively slowly through the asthenosphere compared to the overlying lithospheric mantle. Thus, it has been called the low-velocity zone (LVZ).

CORE

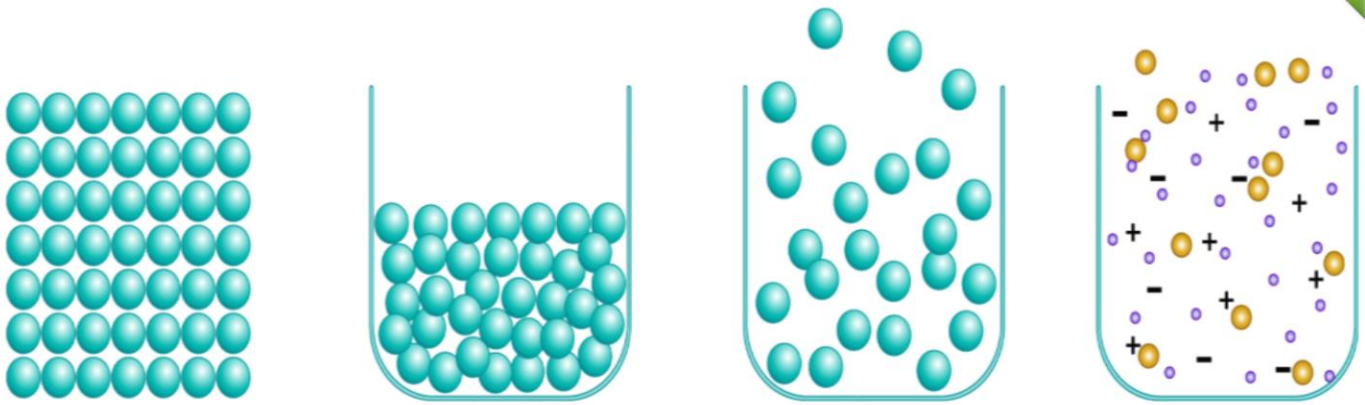
- From 2900 km to 6371 km,
- Also called NiFe (Nickel + ferrous/ iron)
- Contains 16% of Total volume of earth And 32% of total mass of Earth
- **Gutenberg discontinuity** :- Found between mental and Core
- Can be divided into 2 layer
  1. Outer core :- 2900-5150 km
  2. Inner core :- 5150- 6371 km
- **Lehmann discontinuity** :- found between upper Core and lower Core
- S-wave does not passes through outer Core thus it is believed that it is in molten state.
- Inner core is in plastic or semi liquid state And matters are in in plasma state.





Physical states

increasing energy



Solid

The molecules that make up a solid are arranged in regular, repeating patterns. They are held firmly in place but can vibrate within a limited area.

Liquid

The molecules that make up a liquid flow easily around one another. They are kept from flying apart by attractive forces between them. Liquids assume the shape of their containers.

Gas

The molecules that make up a gas fly in all directions at great speeds. They are so far apart that the attractive forces between them are insignificant.

Plasma

At the very high temperatures of stars, atoms lose their electrons. The mixture of electrons and nuclei that results is the plasma state of matter.

Earth's Discontinuities

- The Earth's interior is divided into several layers: the crust, mantle, outer core, and inner core. These layers are separated by **discontinuities**, which are boundaries where seismic wave velocities change due to differences in material composition, density, or state.
- **Discontinuities are signs of changes in structure and composition** within the Earth's interior.

Discontinuity	Location	Separates
Mohorovičić (Moho) Discontinuity	~5–70 km below surface	Crust and Upper Mantle
Conrad Discontinuity	~15–20 km depth in continental crust	Upper Crust and Lower Crust (Continental)
Repetti Discontinuity	~660 km below surface	Upper Mantle and Lower Mantle
Gutenberg Discontinuity	~2,900 km below surface	Mantle and Outer Core
Lehmann Discontinuity	~5,100 km below surface	Outer Core and Inner Core

Discovery of Subterranean Water Reservoir

- In 2014, scientists made a groundbreaking discovery of a vast reservoir of water trapped deep beneath the Earth's surface. This subterranean ocean is estimated to be three times larger than all the world's surface oceans combined!
- The discovery was made by analyzing seismic waves generated by earthquakes.
- By studying how these waves traveled through the Earth's interior, scientists were able to identify the presence of a large amount of water **trapped within a mineral called ringwoodite**, located at a **depth of about 700 kilometers** below the Earth's surface.