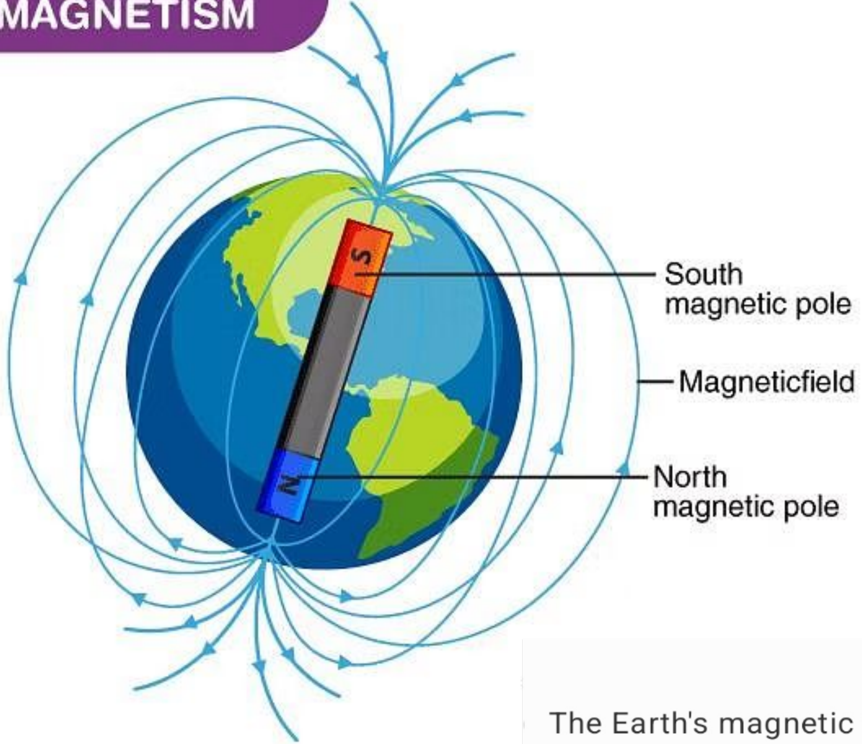
Direct & Indirect Sources for Understanding the Earth's Interior

The Earth's surface is shaped by geological processes, driven by forces from above and below:

- Endogenous Processes: These are caused by forces from within the Earth (endogenous meaning "in"). They lead to major features like mountains, plateaus, and lakes. These processes include folding and faulting, primarily driven by internal forces.
- Exogenous Processes: These result from forces on or above the Earth's surface (exogenous meaning "out"). While they also influence the surface, endogenous processes have a more significant role in shaping it.
- Geophysical Phenomena: Catastrophic events like earthquakes and volcanic eruptions are primarily caused by forces deep below the Earth's surface. For instance, earthquakes result from tectonic plate movements, fueled by mantle convection currents. Volcanism, on the other hand, occurs through vents and fissures created by tectonic activity.

EARTH'S MAGNETISM



The Earth's magnetic field is generated by convection currents in its outer core, crucial for protecting our atmosphere from harmful solar wind. Solar system objects share a common formation process from a single nebular cloud, resembling Earth's formation.

Earth's magnetic field

The Earth's magnetic field is generated by the movement of molten iron and nickel in its outer core. This movement creates convection currents, which, combined with the Earth's rotation, generate the magnetic field through a process known as the dynamo effect. This magnetic field is crucial because it protects the Earth from harmful solar wind and cosmic radiation by deflecting charged particles away from the planet, ensuring that our atmosphere remains stable and life can thrive.

Aspect	Convection	Conduction
Definition	Transfer of heat through fluid (liquid or gas) movement	Transfer of heat through direct contact between molecules
Medium	Occurs in fluids (liquids and gases)	Occurs in solids, liquids, and gases
Mechanism	Involves the bulk movement of the fluid	Involves transfer of energy through molecular collisions
Heat Transfer	Circulates within the fluid, creating currents	Heat moves from hot to cold regions within the material
Example	Boiling water, atmospheric circulation	Heating a metal rod from one end

Evolution and present composition of the atmosphere

The Earth's atmosphere, vital for life, contains oxygen, CO_2, greenhouse gases, ozone, and the right pressure, all released by volcanic eruptions. Mineral exploration relies on comprehending volcanic activity and rock properties since valuable minerals like diamonds form deep within the Earth's mantle and reach the surface through volcanic processes.

Mineral exploration

Deep earth mining and drilling provide insights into subsurface rocks, but practical limitations restrict their depth reach. Mponeng and TauTona gold mines in South Africa, the world's deepest, extend only 3.9 km deep. The Soviet Union's deepest drilling reached approximately 12 km in the 1970s on the Kola Peninsula.


Mponeng gold mine, located at Johannesburg, South Africa, is the deepest mine in the world with an operating depth of 4kms.

Indirect methods to learn about the Earth's interior include:

NDA CDS COACHING CENTRE

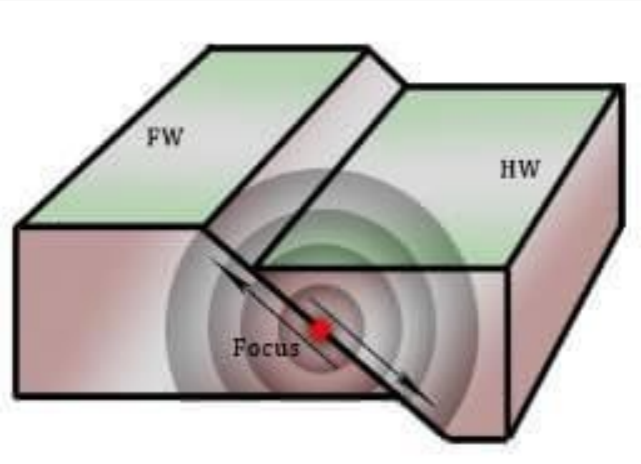
- Pressure and temperature rise with depth.
- Seismic waves.
- Meteorites.
- Gravitational effects and Earth's size for pressure estimates.
- Volcanic eruptions and hot springs indicate a hot interior.

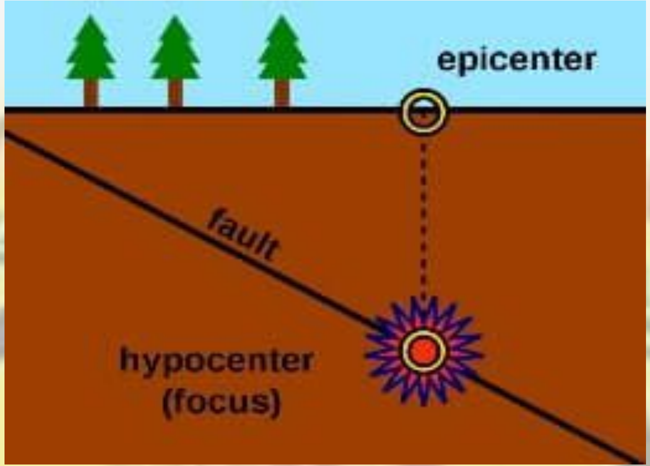
Seismic waves

- Seismic waves: Energy waves caused by earthquakes, volcanic eruptions, magma flow, significant landslides, and large human-made explosions.
- They traverse Earth's layers and provide insights into its internal structure through refraction and reflection.
- Seismic waves and earthquake waves are frequently used interchangeably.

How are earthquake waves produced?

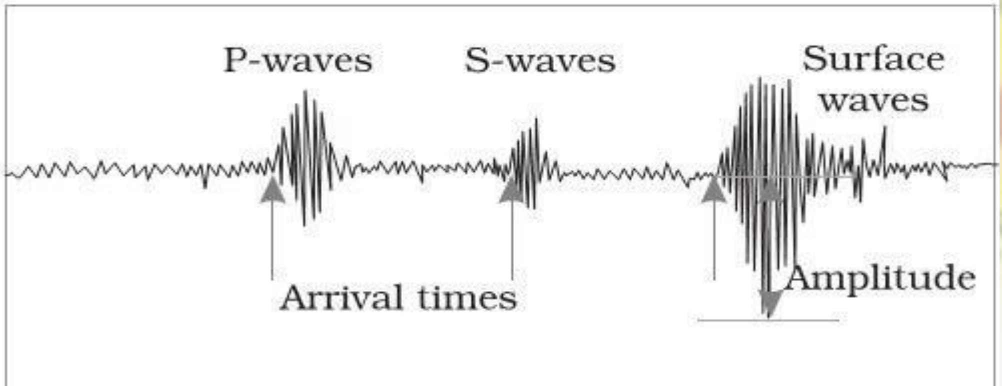
- Earthquake waves originate from the sudden release of energy at a fault, which is a sharp break in the Earth's crust.
- Rock layers near the fault move in opposite directions, constrained by friction from overlying rocks.
- When this friction is overcome, it results in a seismic release of energy, creating earthquake waves.
- The pressure on the rock layers builds up over a period and overcomes the frictional force resulting in a sudden movement generating shockwaves (seismic waves) that travel in all directions.
- The point where the energy is released is called the **focus** or the **hypocentre** of an earthquake.
- The point on the surface directly above the focus is called **epicentre**.
- An instrument called 'seismograph' records the waves reaching the surface.





Types of Seismic waves or earthquake waves

- The seismic waves or earthquake waves are basically of two types — **body waves** and **surface waves**.



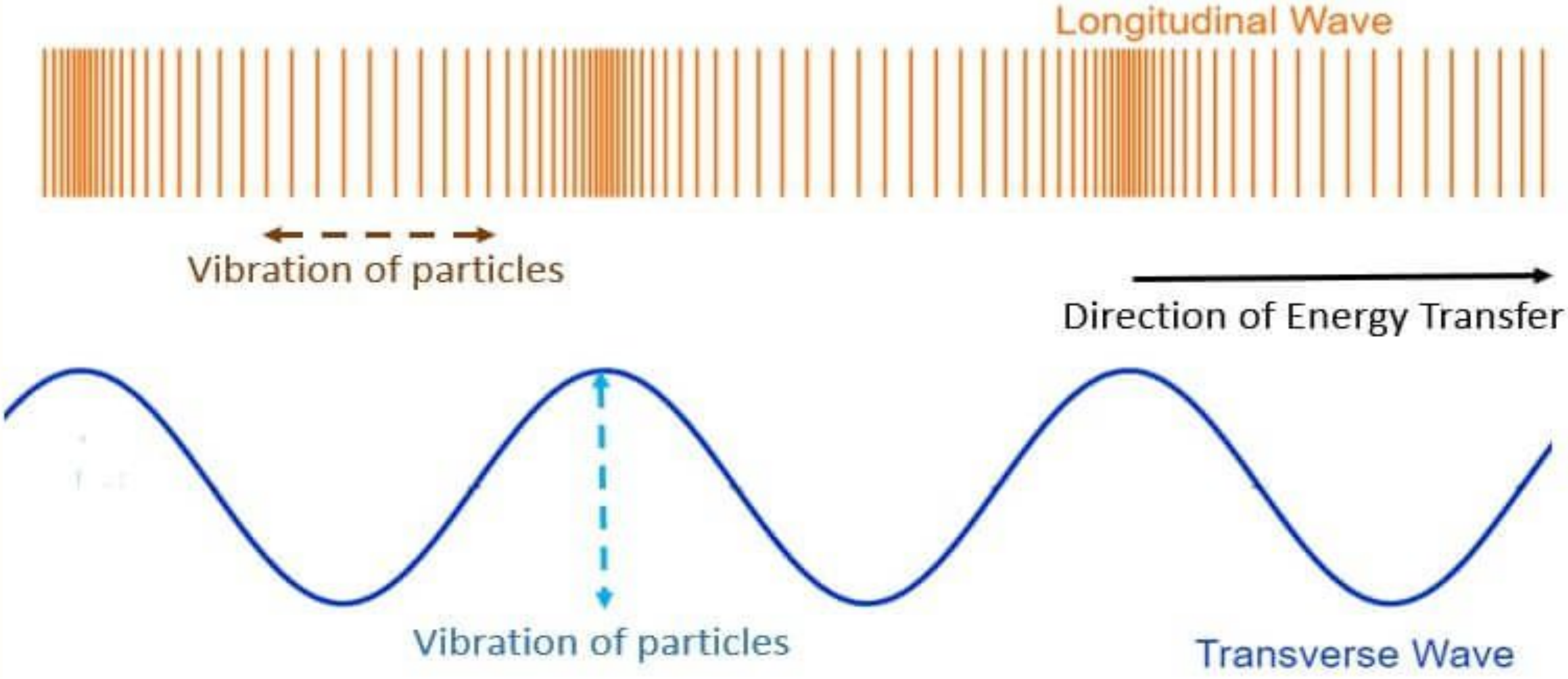
Body waves

- Body waves originate at the earthquake focus and travel in all directions through the Earth's interior.
- Two types of body waves exist:
  - P-waves (primary waves), which are longitudinal like sound waves.
  - S-waves (secondary waves), which are transverse, resembling ripples on water's surface.

Primary Waves (P-waves)

- Primary waves (P-waves) earned their name due to being the fastest seismic waves, detected first on seismographs.
- P-waves are also known as:
- Longitudinal waves because they displace the medium parallel or antiparallel to their propagation direction.
- Compressional waves for causing compression and rarefaction in the medium.
- Pressure waves for creating variations in pressure within the medium.
- P-waves induce density changes in materials, resulting in stretching (rarefaction) and squeezing (compression).

Longitudinal and Transverse Wave



- P-waves have a relatively high frequency and are the least destructive among earthquake waves.
- They cause vertical trembling on the Earth's surface.
- P-waves can travel through all mediums, with velocity depending on the medium's shear strength (elasticity).
- Velocity order: Solids > Liquids > Gases.
- In the atmosphere, they resemble sound waves.
- Earthquake P-wave velocity varies: 5-8 km/s, with regional differences (e.g., <6 km/s in the crust, 13.5 km/s in the lower mantle, and 11 km/s in the inner core).

Why do P-waves travel faster than S-waves?

- P-waves outpace S-waves by approximately 1.7 times.
- P-waves are compression waves that transmit energy efficiently in the direction of propagation, leading to their higher speed.
- S-waves, as shear waves with motion perpendicular to the wave's direction, are less easily transmitted through the medium, resulting in slower travel.

P-waves as an earthquake warning

- P-waves serve as an early earthquake warning.
- They travel faster through the Earth's crust than destructive secondary and surface waves.
- The delay between P-wave arrival and destructive waves varies (typically 60 to 90 seconds), depending on the earthquake's depth of focus.

Secondary Waves (S-waves)

- Secondary waves (S-waves) are the second seismic waves recorded on seismographs.
- They are also known as transverse, shear, or distortional waves.
- S-waves resemble water ripples or light waves.
- These waves create troughs and crests in the medium, as vibrations are perpendicular to the wave's direction.
- S-waves follow P-waves in arrival.
- They have higher frequency and slightly greater destructive power than P-waves.
- S-waves cause side-to-side (horizontal) trembling on the Earth's surface.
- They cannot pass through fluids (liquids and gases) due to their need for shear stresses.
- S-wave velocity varies depending on the Earth's solid materials and their shear strength.

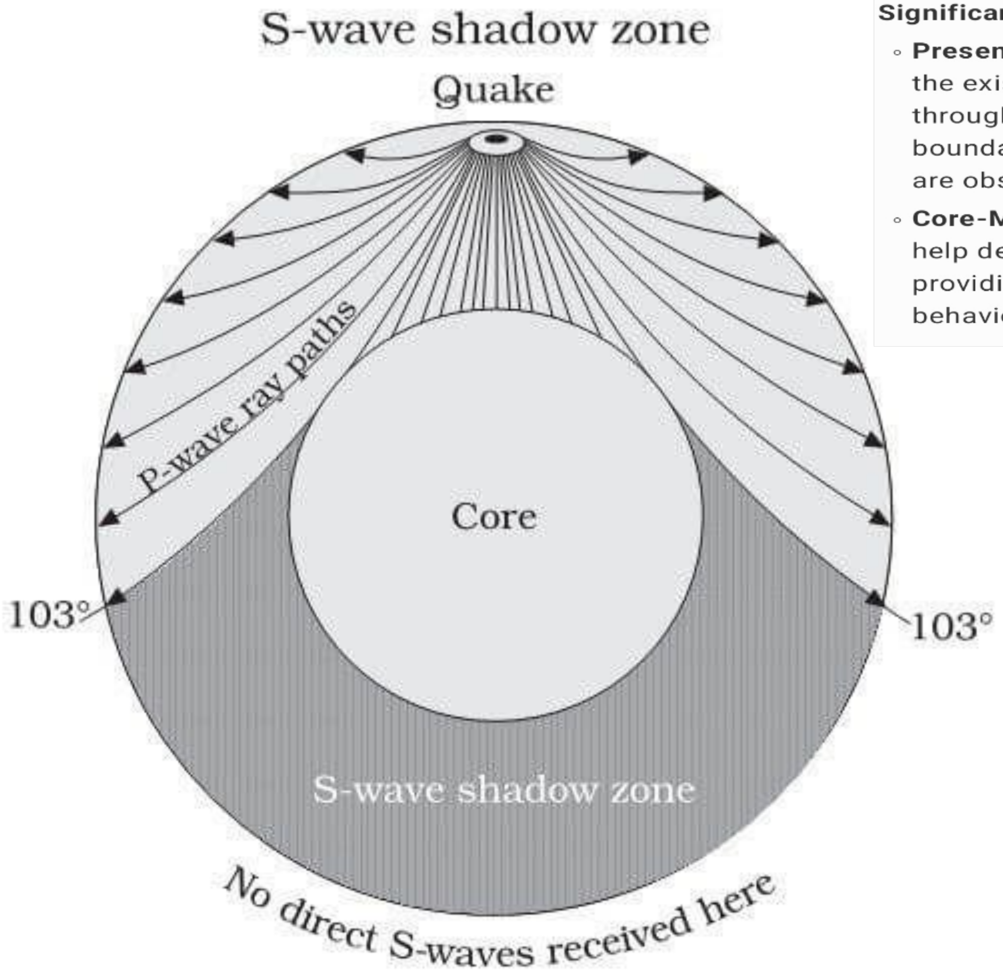
Feature	P Waves (Primary Waves)	S Waves (Secondary Waves)
Nature	Compressional (longitudinal)	Shear (transverse)
Motion	Push-pull motion; particles move parallel to the wave direction	Side-to-side motion; particles move perpendicular to the wave direction
Speed	Faster; the fastest seismic waves	Slower; second fastest seismic waves
Propagation	Travel through solids, liquids, and gases	Only travel through solids
Arrival	Arrive first at seismic recording stations	Arrive after P waves
Effect	Cause less ground displacement	Cause more ground displacement
Use	Useful for initial detection of earthquakes and determining the depth of the focus	Useful for determining the nature of the materials in the Earth's interior

How do seismic waves help in understanding the earth's interior?

- Seismic waves are recorded by seismographs at distant locations.
- Variations in arrival times, unexpected wave paths (refraction), and seismic wave absence in specific regions (shadow zones) aid in Earth's interior mapping.
- Velocity changes with depth indicate alterations in composition and density.
- Observing velocity changes helps estimate the Earth's interior composition and density.
- Wave motion changes with depth reveal phase variations, helping identify different layers.

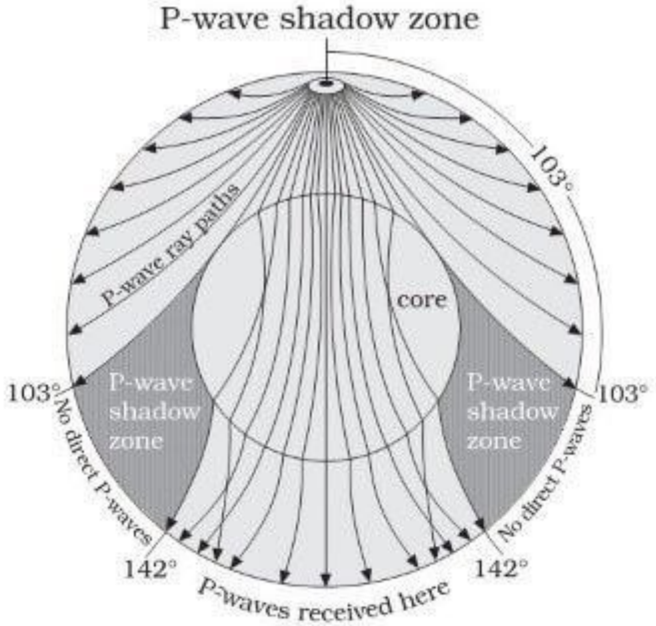
The emergence of Shadow Zone of P-waves and S-waves

- S-waves do not travel through liquids (they are **attenuated**).
- The entire zone beyond 103° does not receive S-waves, and hence this zone is identified as the shadow zone of S-waves. This observation led to the discovery of the **liquid outer core**.
- The shadow zone of P-waves appears as a band around the earth between 103° and 142° away from the epicentre.
- This is because P-waves are refracted when they pass through the transition between the semisolid mantle and the liquid outer core.
- However, the seismographs located beyond 142° from the epicentre, record the arrival of P-waves, but not that of S-waves. This gives clues about the **solid inner core**.
- Thus, a zone between **103° and 142°** from epicentre was identified as the **shadow zone for both the types of waves**.



Significance:

- **Presence of Liquid Outer Core:** The P-wave shadow zone confirms the existence of a liquid outer core. Although P waves can pass through liquids, they slow down and bend significantly at the boundary, creating a shadow zone where no direct P-wave arrivals are observed.
- **Core-Mantle Boundary:** The size and shape of the shadow zone help determine the size and properties of the Earth's outer core, providing insights into the Earth's internal structure and the behavior of seismic waves through different layers.



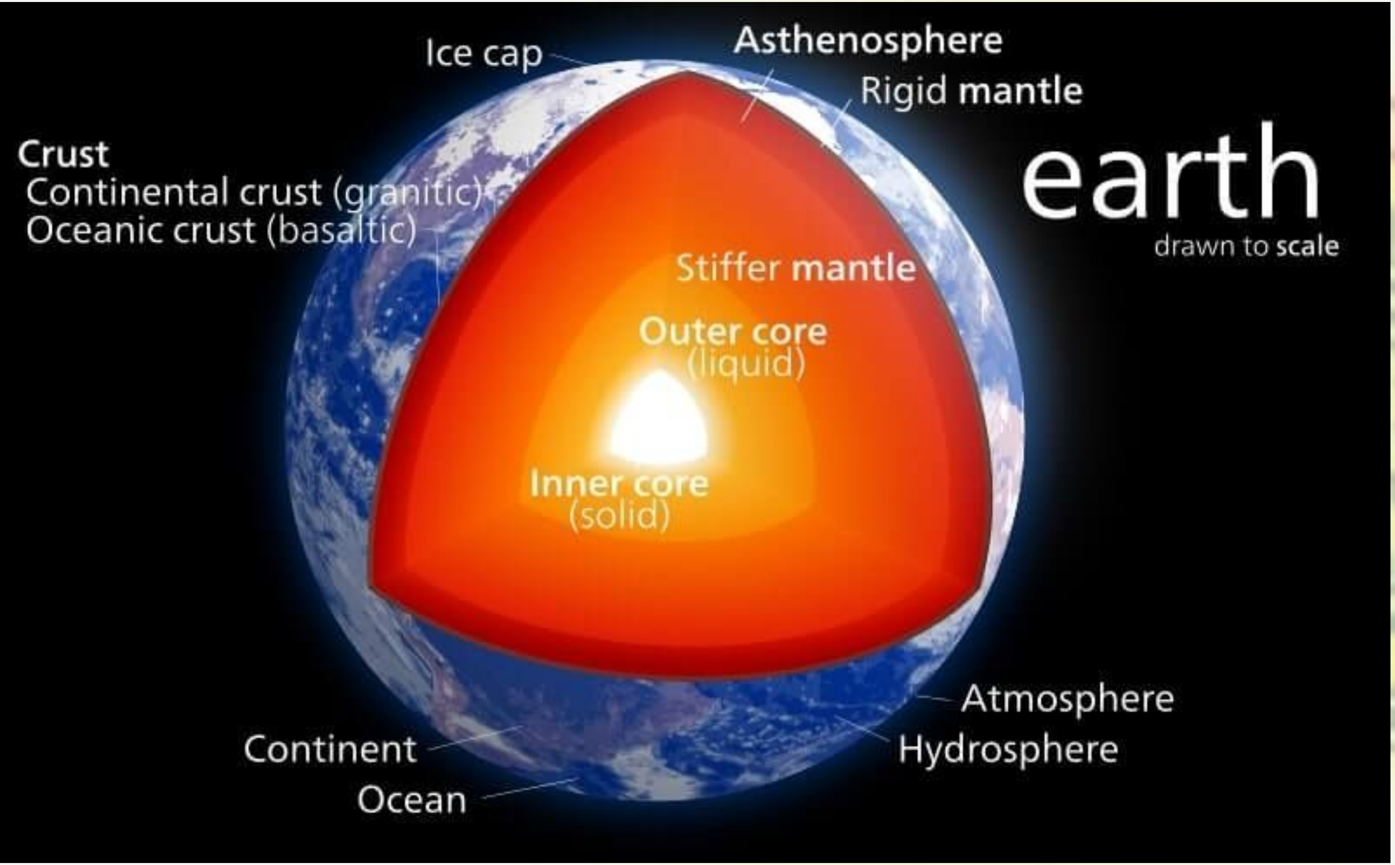
Inside Our Earth

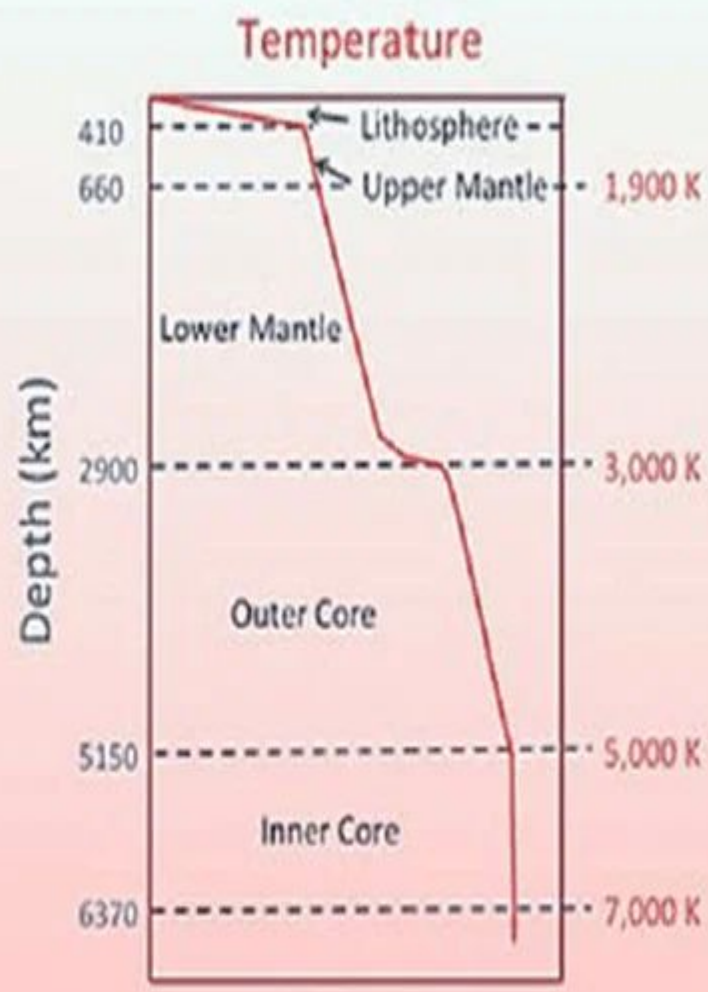
SUMMARY

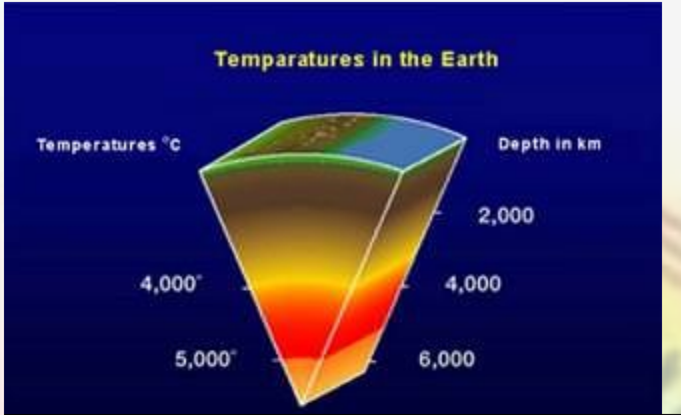
- **Interior of the Earth**
  - **The Core**
    - Innermost layer.
    - Radius of about 3500 km.
    - Made up of nickel and iron.
    - The central care has very high temperature and pressure
  - **The Mantle**
    - Situated just beneath the crust.
    - Has a depth of 2900 km.
  - **The Crust**
    - Uppermost layer
    - Thinnest of all the layers
    - About 35 kms
    - Main Minerals
      - **Continental mass-** Silica & Aluminium
      - **Ocenic crust-** Silica and Magnesium

- **Rocks and Minerals**
  - **Minerals**
    - Very useful to mankind.
    - For example : coal, natural gas and petroleum.
  - **Rocks**
    - Metamorphic Rocks – Slate and Marble
    - Sedimentary Rocks – Sandstone
    - Igneous Rocks
      - Intrusive Rocks- Granite
      - Extrusive Rocks- Basalt

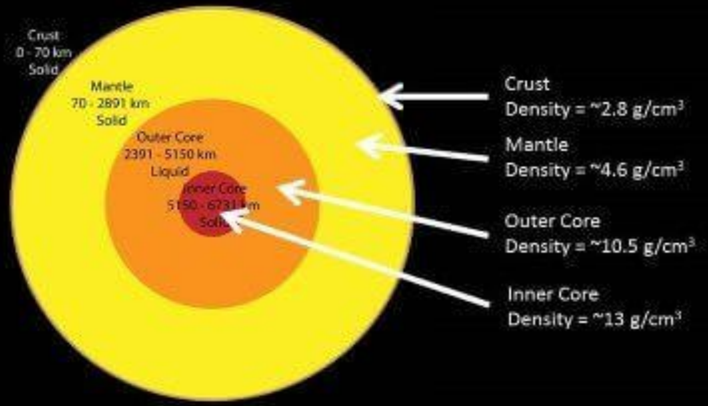
Earth's Layers (The internal structure of the Earth)





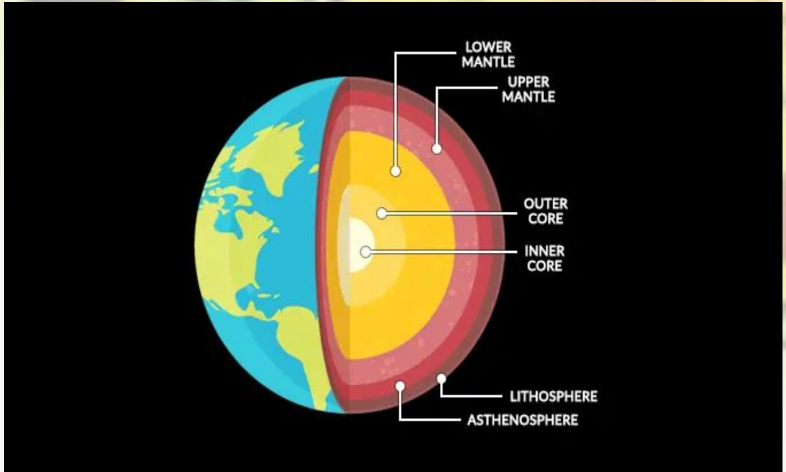


Density increases as you travel from the crust to the inner core.

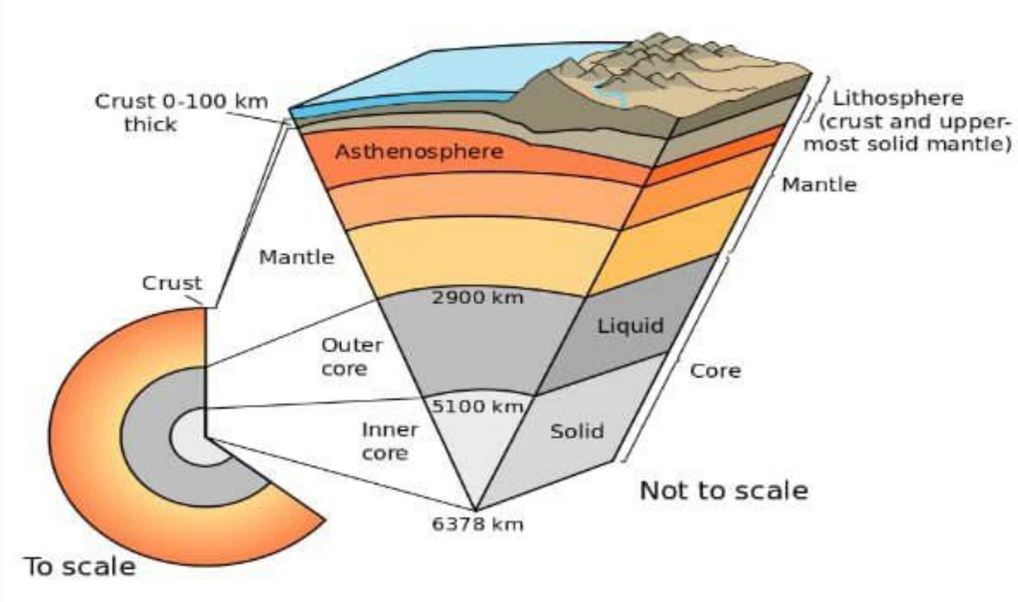


The Crust

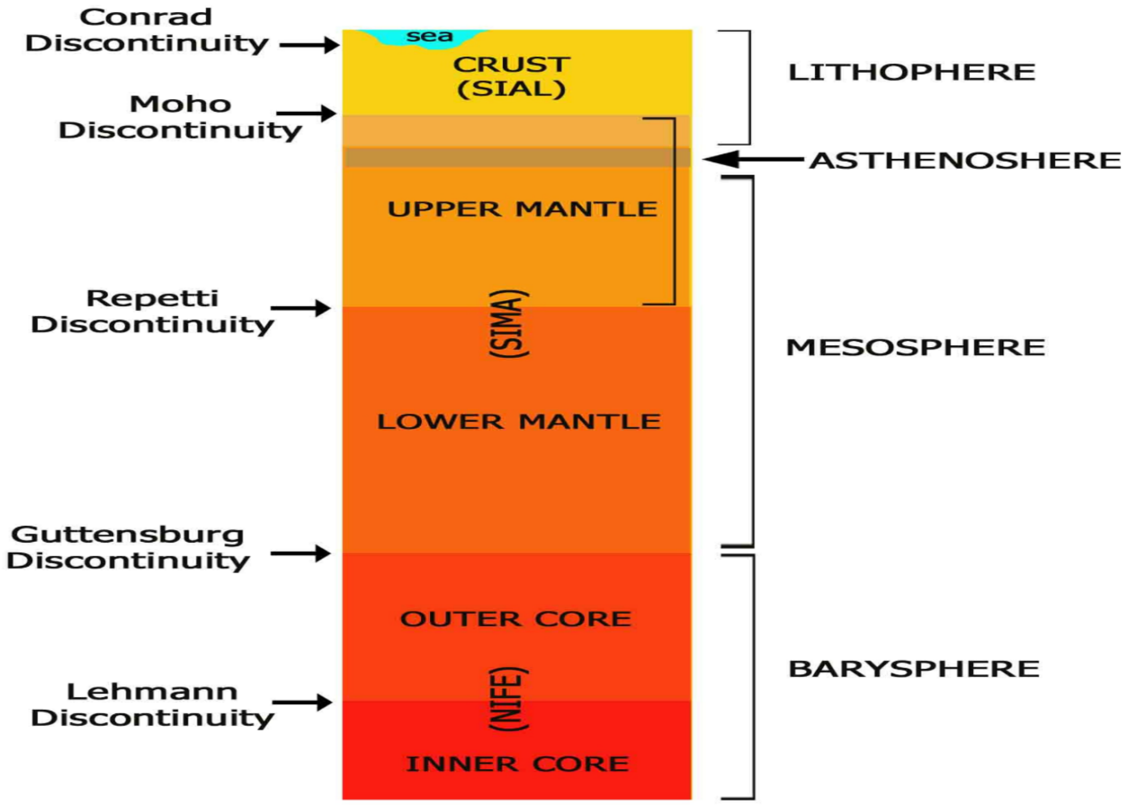
- The crust is Earth's outermost layer, accounting for 0.5-1.0% of its volume and less than 1% of its mass.
- It has an average density of about 2.7 g/cm^3, compared to Earth's average density of 5.51 g/cm^3.
- Oceanic crust ranges from 5-30 km thick, while continental crust varies from 50-70 km, with thicker sections near major mountain systems (up to 70-100 km in the Himalayas).
- Crust temperature increases with depth, typically from 200°C to 400°C at the boundary with the mantle, with a 30°C increase per kilometer in the upper part.
- The crust comprises sedimentary material on the surface, followed by acidic igneous and metamorphic rocks beneath.
- The lower crust contains basaltic and ultra-basic rocks.
- Continents consist of lighter silicates (sial) like granite, while oceans contain heavier silicates (sima) like basalt.



- The interior of the earth is made up of several concentric layers of which the crust, the mantle, the outer core and the inner core are significant because of their unique physical and chemical properties.
- The crust is a silicate solid, the mantle is a viscous molten rock, the outer core is a viscous liquid, and the inner core is a dense solid.



- Mechanically, the earth's layers can be divided into **lithosphere**, **asthenosphere**, **mesospheric mantle** (part of the Earth's mantle below the lithosphere and the asthenosphere), **outer core**, and **inner core**.
- Chemically, Earth can be divided into the **crust**, **upper mantle**, **lower mantle**, **outer core**, **and inner core**.



Conrad Discontinuity
Moho Discontinuity
Repetti Discontinuity
Guttensburg Discontinuity
Lehmann Discontinuity
sea
CRUST (SIAL)
UPPER MANTLE
(SIMA)
LOWER MANTLE
OUTER CORE
(NIFE)
INNER CORE
LITHOPHERE
ASTHENOSHERE
MESOSPHERE
BARYSPHERE

Seismic Discontinuities:

Definition: Regions in the Earth exhibiting distinct seismic wave behavior due to significant changes in physical or chemical properties.

Mohorovicic Discontinuity (Moho):

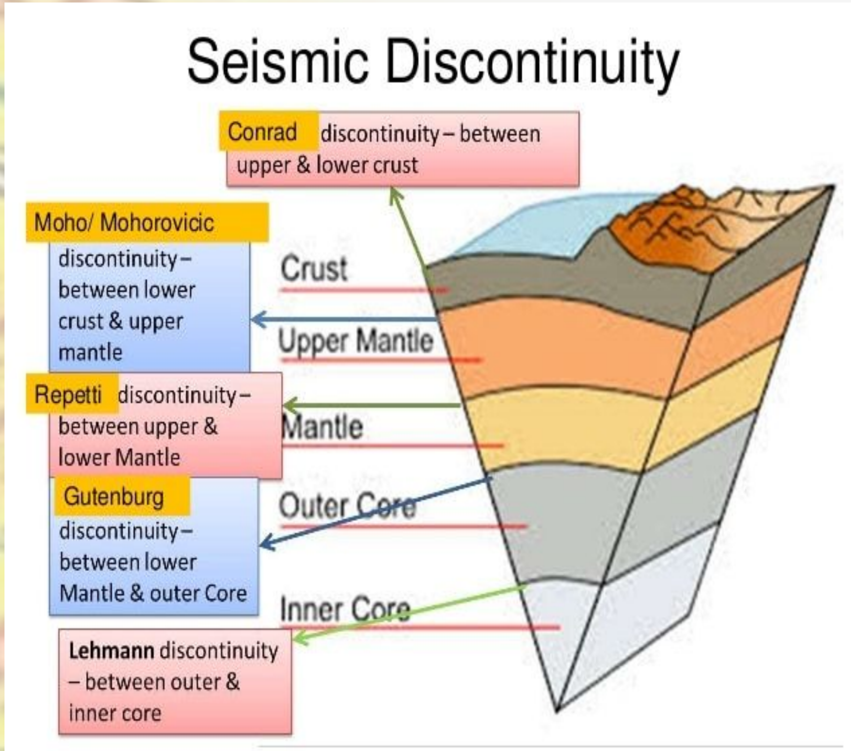
- Separates Earth's crust from the mantle.

Asthenosphere:

- Highly viscous, mechanically weak, and ductile portion of the mantle.

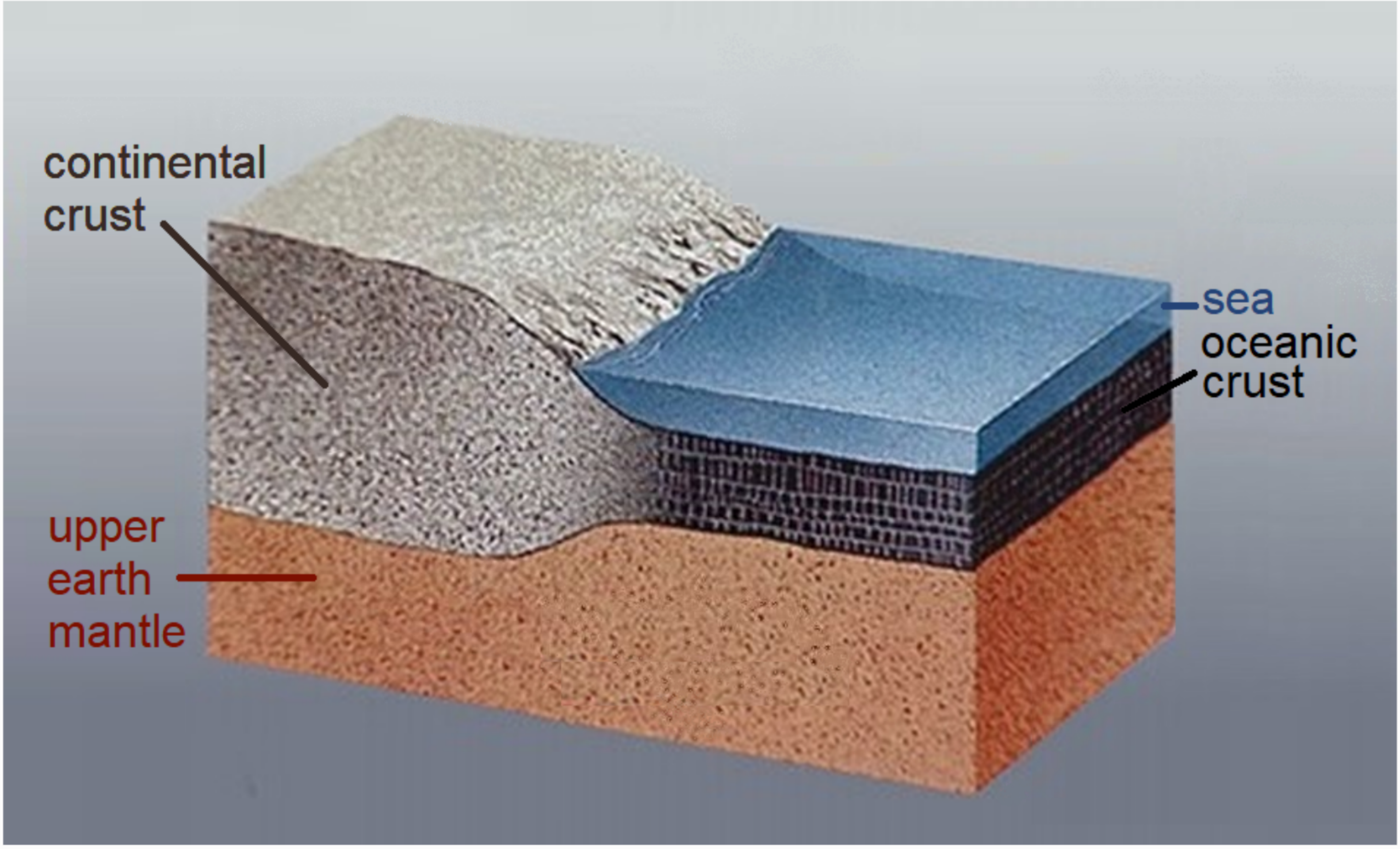
Gutenberg Discontinuity:

- Located between the mantle and the outer core.



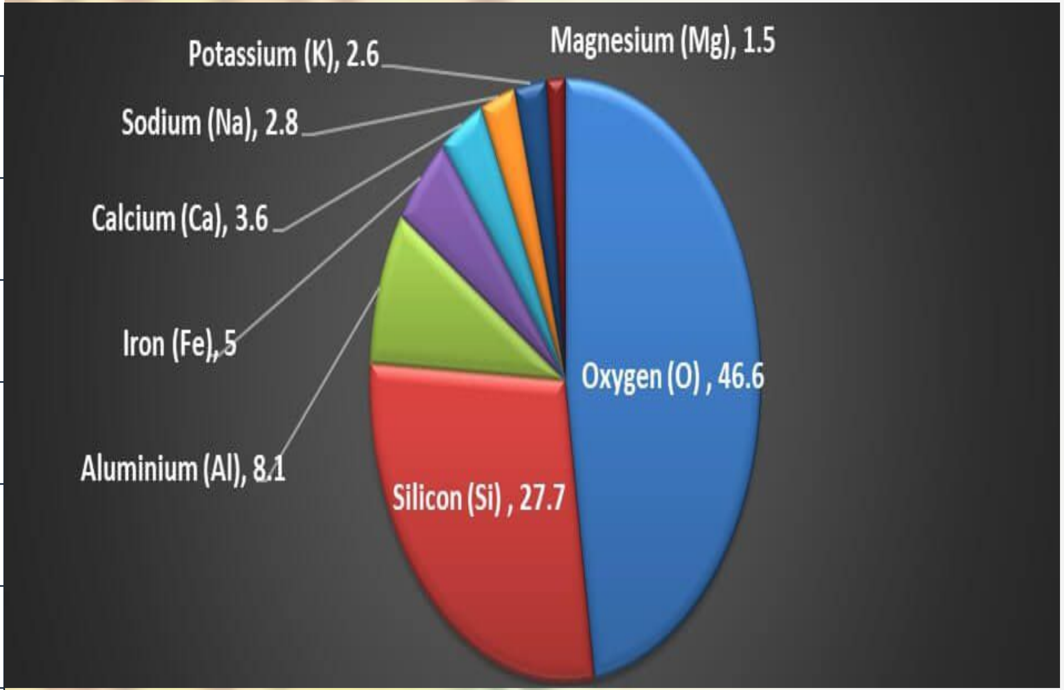
This format provides a clear and concise overview of seismic discontinuities and their respective locations within the Earth.

Discontinuity	Location	Depth	Characteristics
Conrad Discontinuity	Within the Earth's crust	~15-20 km below the surface	Marks a transition within the crust; often between granitic and basaltic compositions.
Moho Discontinuity	Between the crust and the mantle	~5-10 km (oceanic crust), ~20-70 km (continental crust)	Transition from less dense crustal rocks to denser mantle rocks; increase in seismic wave velocity.
Repetti Discontinuity	Between the upper mantle and lower mantle	~410 km below the surface	Marks a transition between the upper and lower mantle; associated with changes in mineral
Gutenberg Discontinuity	Between the mantle and the outer core	~2,900 km below the surface	Transition from solid mantle to liquid outer core; seismic waves slow down significantly.
Lehmann Discontinuity	Between the outer core and the inner core	~5,150 km below the surface	Transition from liquid outer core to solid inner core; seismic waves speed up as they enter the inner core.

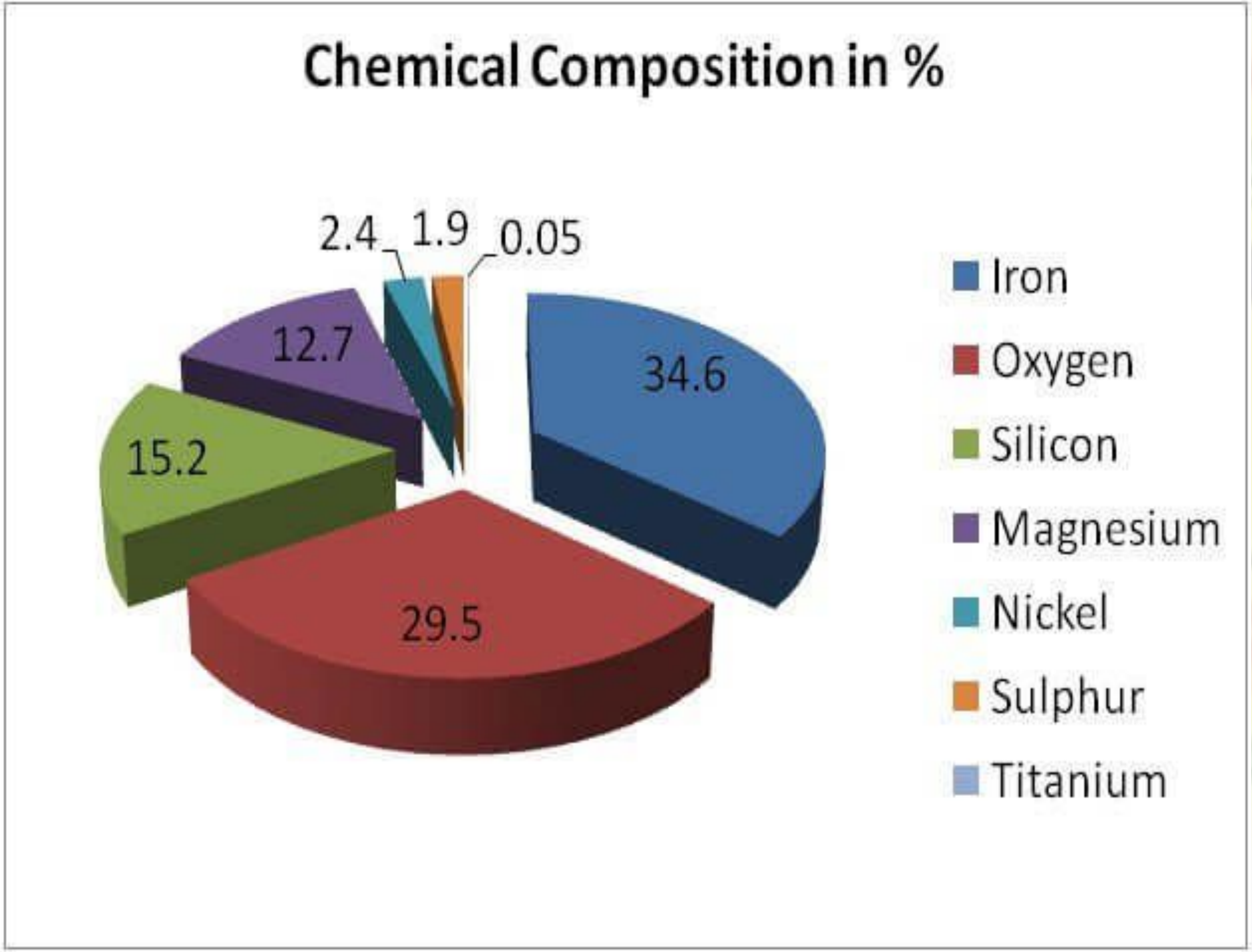

continental
crust
sea
oceanic
crust
upper
earth
mantle

Most Abundant Elements of the Earth's Crust

Element	Approximate % by weight	
1	**Oxygen (O)**	**46.6**
2	**Silicon (Si)**	**27.7**
3	**Aluminium (Al)**	**8.1**
4	**Iron (Fe)**	**5.0**
5	**Calcium (Ca)**	**3.6**
6	Sodium (Na)	2.8
7	Potassium (K)	2.6
8	Magnesium (Mg)	1.5



Most Abundant Elements of the Earth

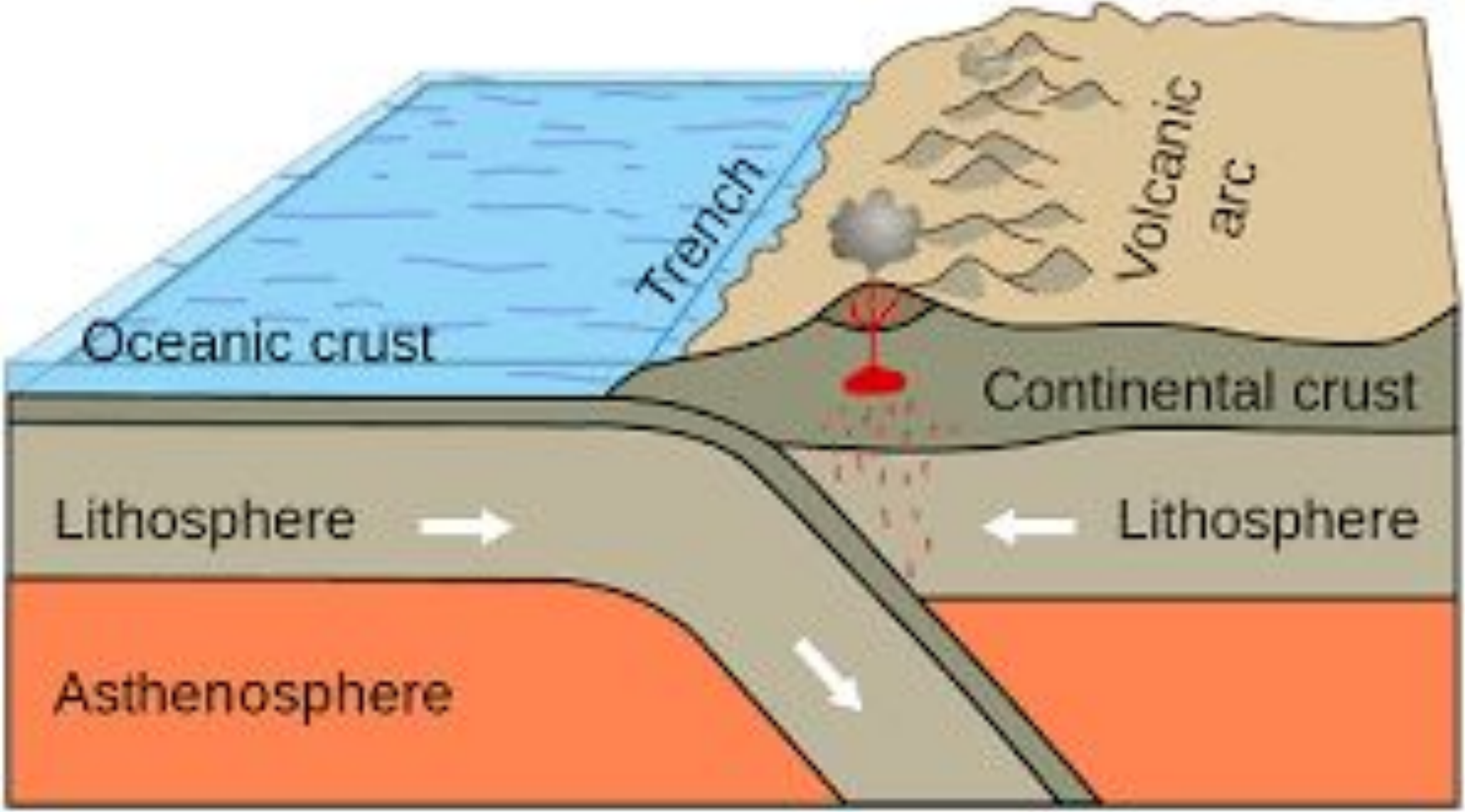


The Mohorovicic (Moho) discontinuity

- The Mohorovicic (Moho) discontinuity marks the boundary between the crust and the upper mantle's asthenosphere.
- It's characterized by a seismic velocity change.
- The Moho lies roughly 8 km below ocean basins and 30 km beneath continents.
- It's attributed to a transition from feldspar-containing rocks in the upper layers to feldspar-free rocks in the lower layers.

Lithosphere

- The lithosphere, ranging from 10-200 km thick, comprises both the crust and upper mantle.
- Tectonic plates form within the lithosphere and their movement drives significant geological changes like folding and faulting.
- Plate tectonics are powered by heat from the Earth's formation and the radioactive decay of elements like uranium, thorium, and potassium in the crust and mantle.

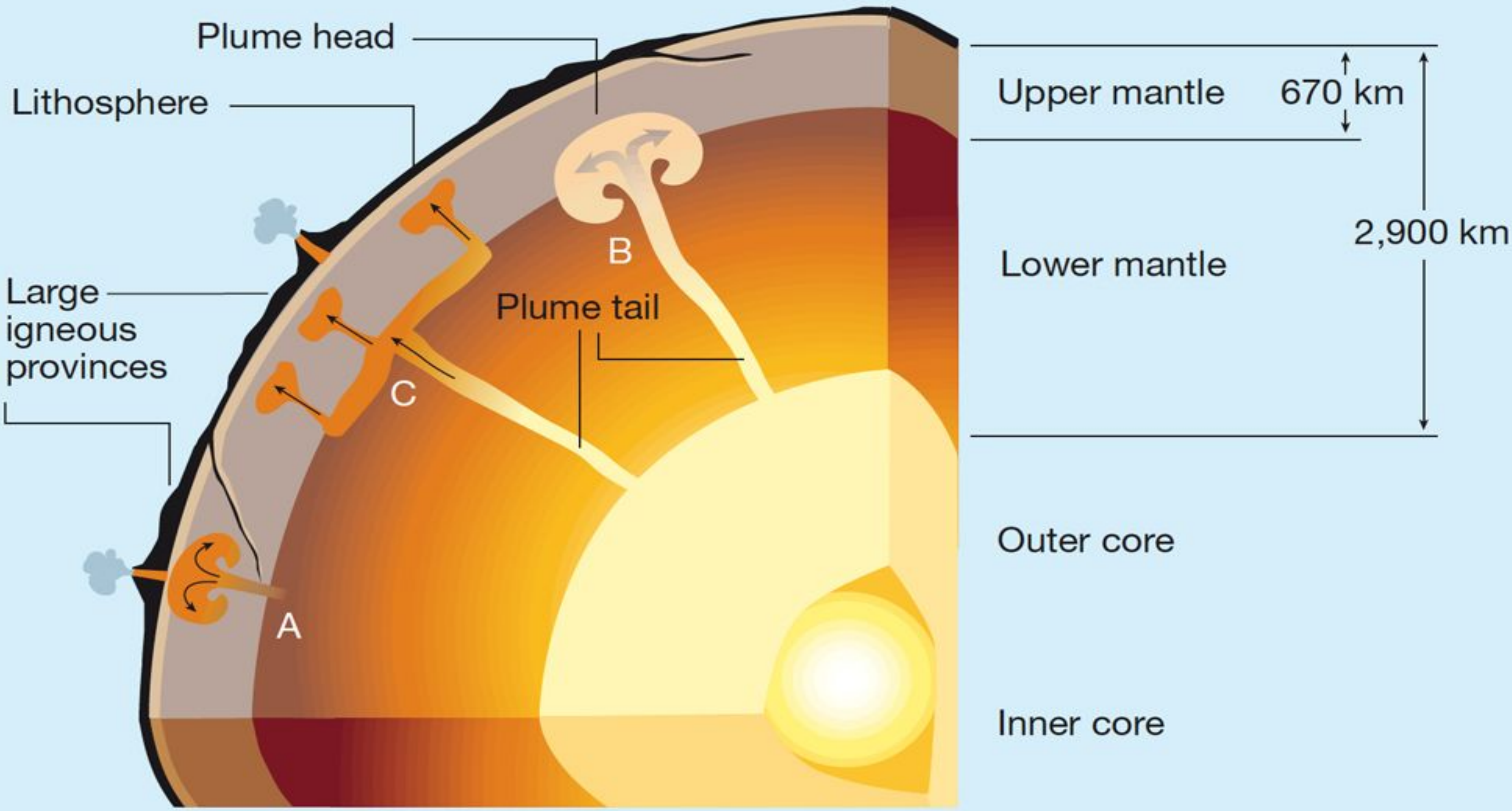

Trench
Volcanic arc
Oceanic crust
Continental crust
Lithosphere
Lithosphere
Asthenosphere

The Mantle

- The mantle constitutes 83% of Earth's volume and 67% of its mass, extending from the **Moho Discontinuity** to 2,900 km deep.
- Upper mantle density varies from 2.9 g/cm^3 to 3.3 g/cm^3.
- The lower mantle is solid, with densities ranging from 3.3 g/cm^3 to 5.7 g/cm^3.
- It's composed of iron and magnesium-rich silicate rocks.
- Constituent elements: 45% oxygen, 21% silicon, and 23% magnesium (OSM).
- Mantle temperatures range from 200°C at the upper boundary to 4,000°C at the core-mantle boundary.
- High temperatures allow ductile material circulation, causing mantle convection.
- Surface effects of mantle convection are seen in tectonic plate movements.
- Despite high pressure, earthquakes occur in subduction zones down to 670 km depth.

Asthenosphere

- The upper mantle upper portion is called the asthenosphere (astheno means weak).
- It lies just below the lithosphere, extending 80-200 km deep.
- The asthenosphere is highly viscous, mechanically weak, and ductile, with a density higher than the crust.
- These properties facilitate plate tectonic movement and isostatic adjustments.
- It serves as the primary source of magma for volcanic erruptions.


Plume head
Lithosphere
Large igneous provinces
Upper mantle
670 km
2,900 km
Lower mantle
B
Plume tail
C
A
Outer core
Inner core

Outer Core:

- Located between 2900 km and 5100 km below Earth's surface.
- Composition: Iron mixed with nickel (NiFe) and trace amounts of lighter elements.
- State: Liquid due to lack of sufficient pressure despite its composition.
- Density: Ranges from 9.9 g/cm^3 to 12.2 g/cm^3.
- Temperature: Varies from 4400°C in outer regions to 6000°C near the inner core.
- Generates Earth's magnetic field through dynamo theory involving convection and the Coriolis effect.

Inner Core:

- Extends from Earth's center to 5100 km below the surface.
- Composition: Predominantly iron (80%) with some nickel (NiFe).
- State: Solid and capable of transmitting shear waves (S-waves).
- Rotates slightly faster than Earth's surface.
- Too hot to maintain a permanent magnetic field.
- Density: Ranges from 12.6 g/cm^3 to 13 g/cm^3.

Layer	Location	Composition	State	Thickness	Key Characteristics
Crust	Outermost layer	Silicate rocks (granite, basalt)	Solid	5-70 km (varies)	Thin, solid, composed of continental and oceanic crusts.
Mantle	Beneath the crust	Silicate minerals (peridotite)	Solid (plastic flow)	2,900 km (approx.)	Composed of silicate minerals; convective flow drives plate
Outer Core	Beneath the mantle	Liquid iron and nickel	Liquid	2,200 km (approx.)	Generates Earth's magnetic field; convective currents create the dynamo effect.
Inner Core	Center of the Earth	Solid iron and nickel	Solid	1,220 km (approx.)	Extremely hot, solid due to high pressure; center of Earth's magnetic field.

Lets Try Some PYQ

The mantle occupies _____ of the Earth.

a. 15%
b. 1%
c. 84%
d. 48%

The outermost solid part of the Earth is known as ______.

a. Core
b. Mantle
c. Crust
d. None of the options

Which among the following is made of solid rocks?

a. Core
b. Mantle
c. Crust
d. None of the options

The uppermost part of the mantle and crust are called the ________

a. Hydrosphere
b. Atmosphere
c. Lithosphere
d. Exosphere

In the structure of planet Earth, below the mantle, the core is mainly made up of which one of the following? (2009)

(a) Aluminium (b) Chromium (c) Iron (d) Silicon

What is the thickness of the Outer Core?

a. 2000km b. 2500km c. 2900km d. 3200km