INTERIOR OF THE EARTH

AND

EARTH'S SEISMICITY

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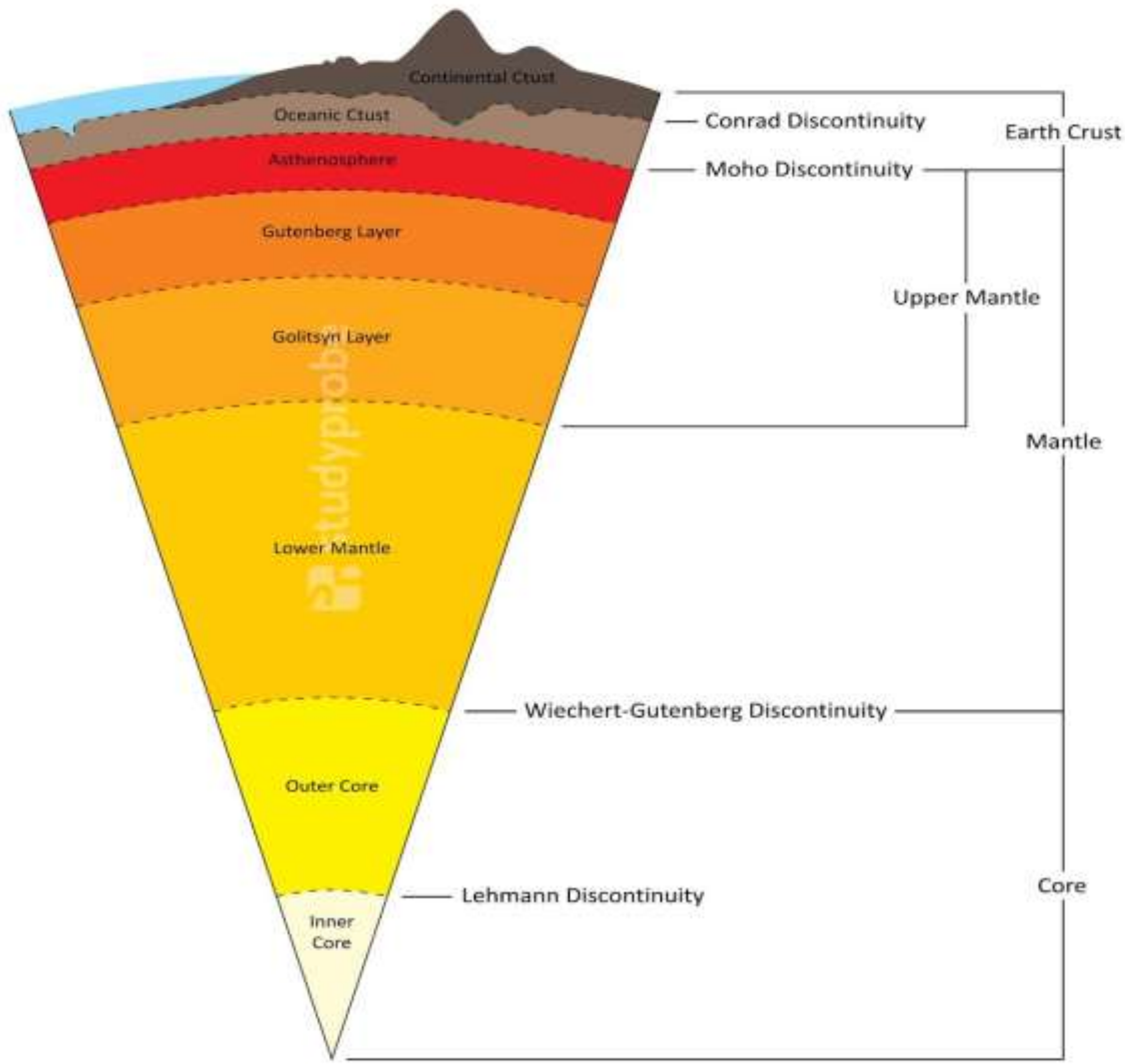
LAYERS OF THE EARTH

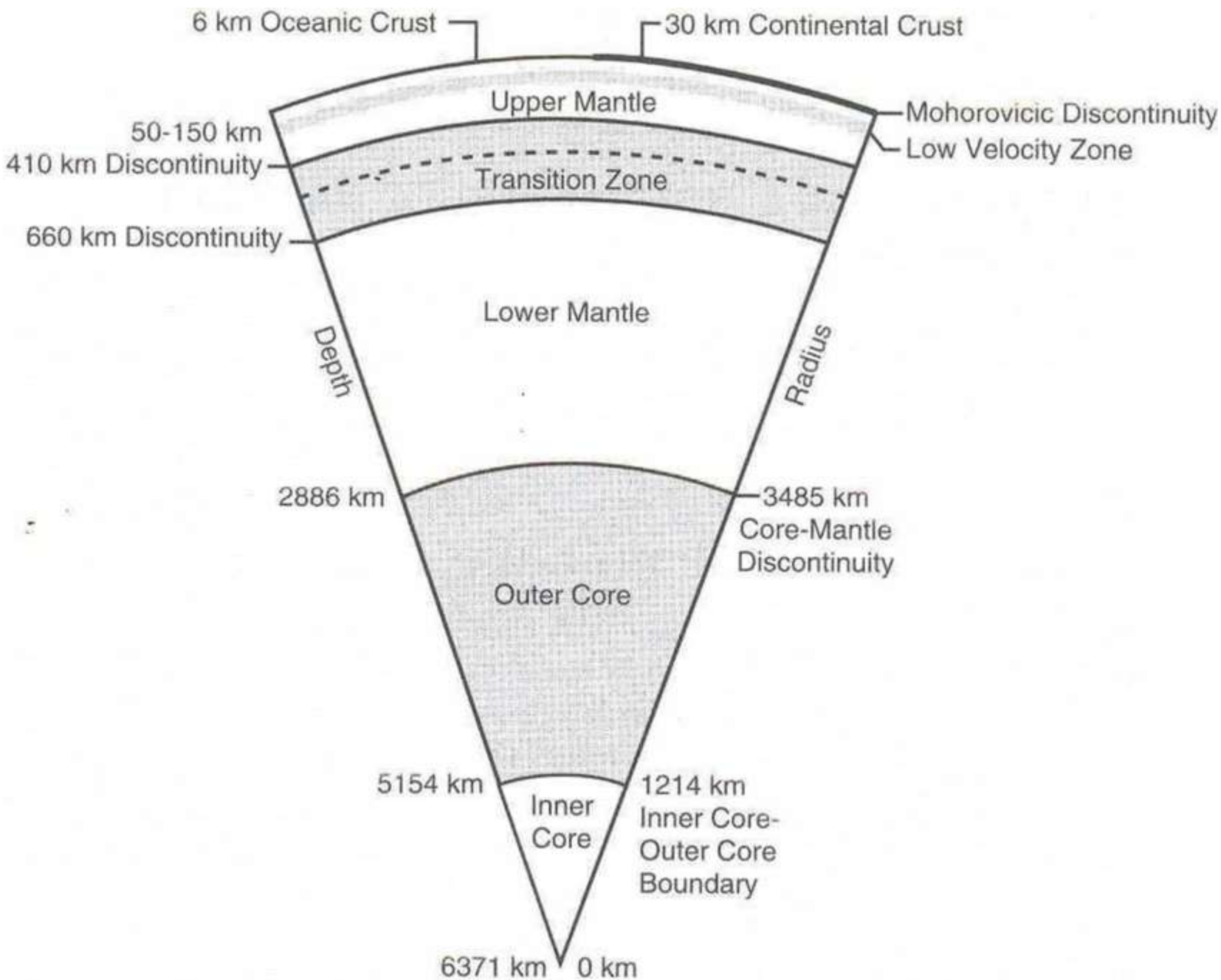
- **1. CRUST**
  a) CONTINENTAL CRUST
  b) OCEANIC CRUST
- **2. MANTLE**
  a) UPPER MANTLE
  b) LOWER MANTLE
- **3. CORE**
  a) OUTER CORE
  b) INNER CORE

Interior Structure of the Earth



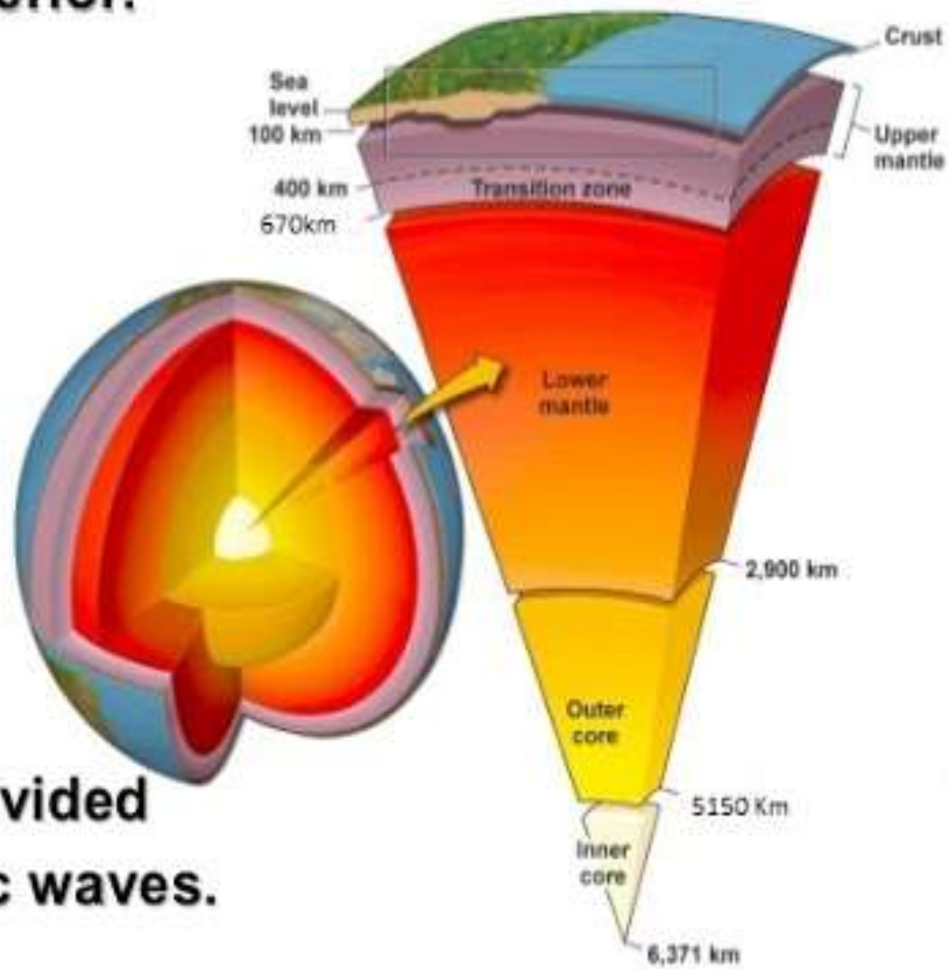
Sources of information about the layers of the earth

- **Direct sources**
  - Mining.
  - Deep oceanic drilling projects.
  - Volcanic eruption.
- **Indirect sources**
  - Temperature and pressure increase with the increasing distance from the surface towards the Earth's interior.
  - The density of the material.
  - Gravitational Anomaly.
  - Seismic activities.


6 km Oceanic Crust
30 km Continental Crust
Upper Mantle
Mohorovicic Discontinuity
Low Velocity Zone
50-150 km
410 km Discontinuity
Transition Zone
660 km Discontinuity
Lower Mantle
Depth
Radius
2886 km
3485 km
Core-Mantle
Discontinuity
Outer Core
5154 km
1214 km
Inner Core-
Outer Core
Boundary
Inner
Core
6371 km
0 km

Summarizing Earth's Layers

- Earth has a layered interior.
  - Crust
    - Continental
    - Oceanic
  - Mantle
    - Upper
    - Transitional
    - Lower
  - Core
    - Outer—liquid
    - Inner—solid
- These layers are subdivided on the basis of seismic waves.



DISCONTINUITY

- Earth's interior is made of different kinds of materials. Each of those materials are different from each other by their physical and chemical properties, such as temperature, density etc. Unique layers are there according to their characteristics inside the earth. All those layers are separated from each other through a transition zone. These transition zones are called discontinuities.

DISCONTINUITIES

- There are five discontinuities inside the earth.
- **Conrad Discontinuity**: Transition zone between SIAL and SIMA.
- **Mohorovicic Discontinuity**: Transition zone between the Crust and Mantle.
- **Repiti Discontinuity**: Transition zone between Outer mantle and Inner mantle.
- **Gutenberg Discontinuity**: Transition zone between Mantle and Core.
- **Lehman Discontinuity**: Transition zone between Outer core and Inner core.
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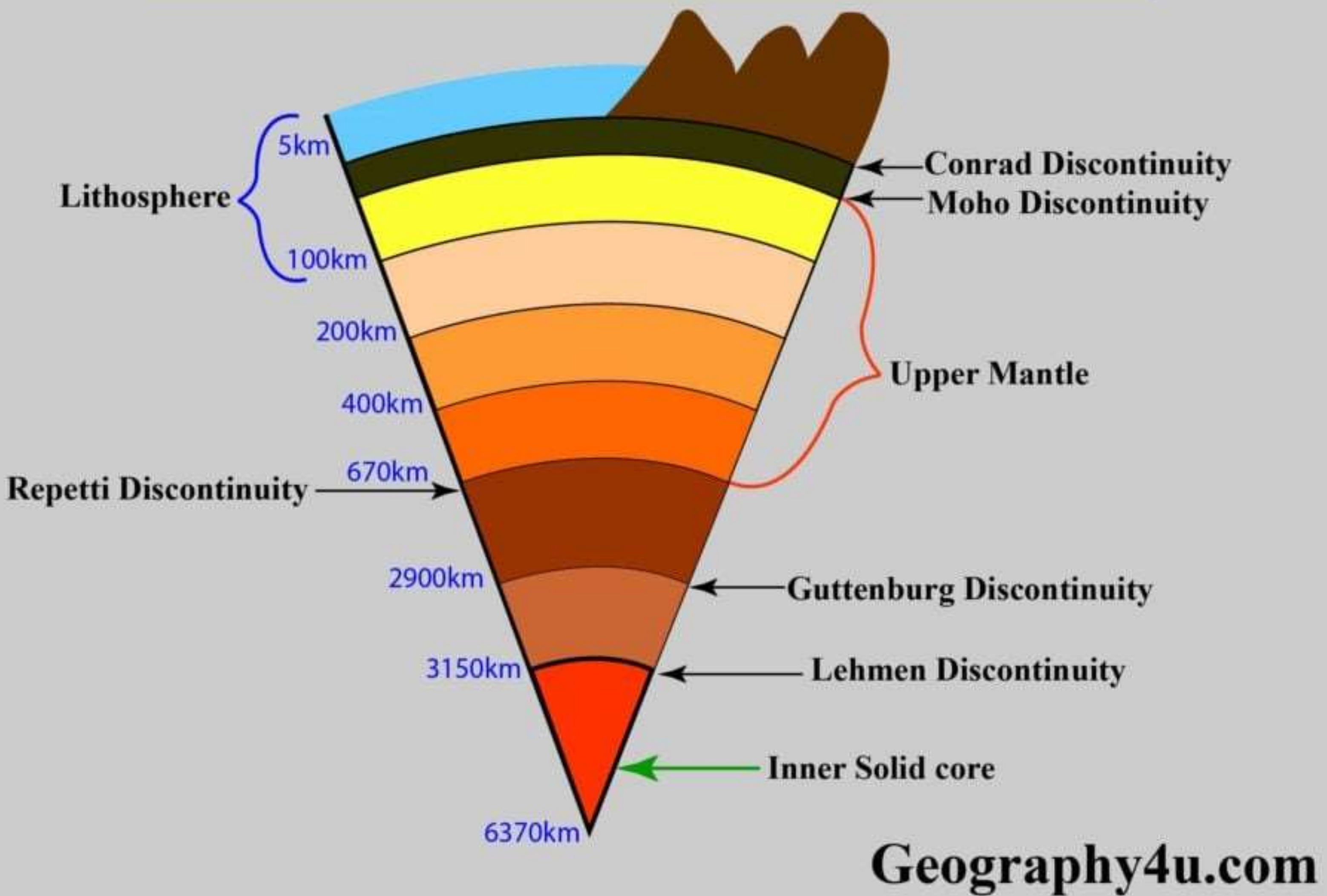
Discontinuities in the layers of the earth



LAYERS OF THE EARTH

Crust

- It is the uppermost and the thinnest layer of the earth.
- The average thickness of the crust is about 35 km.
- Moreover, the crust can be further divided into the Continental crust and Oceanic crust.

Continental crust

- In terms of structure, composition, density and thickness, the continental crust differs from the oceanic crust.
- It is composed of granitic and andesitic rocks.
- The continental crust is rich in Feldspar mineral.
- Moreover, the density of the continental crust is about 2.6gm/cm3.
- The average thickness is about 40km.
- However, under the mountainous regions, the thickness reaches up to 100 Km.

Oceanic crust

- The oceanic crust is made up of the Basalt.
- It is rich in ferro-magnesia.
- Its density is about 3 gm/cm^{3}.
- The **Conrad discontinuity** divides the continental crust and the oceanic crust.
- **Moho discontinuity**
- The moho discontinuity separates the crust and mantle.

MANTLE

- The mantle extends from the base of the crust at a depth of 2900km.
- It comprises about 80% of the earth's total volume.
- Mantle contain Iron, magnesium and calcium.
- Because of increasing temperature and pressure inside the earth, it is hotter and denser than the crust.
- At the depth of about 670km, the mantle is divided into upper and the lower mantle.

➢ **Upper mantle**

- It comprises of Peridotite and Gabbro and Plagioclase minerals.
- The average density of the upper mantle is about 4.5 gm/cm3.
- The average temperature of this layer is about 1100 C ^{0}.
- The **Repetti Discontinuity** separates the upper mantle from the lower mantle.
- Due to Repetti discontinuity, there is a sharp increase in the velocity of the seismic waves.
- The **upper mantle is heterogeneous** in terms of density and composition.
- The thickness of the uppermost part of this stratum is about 80-100 km.
- The uppermost part of the upper mantle is as rigid as the crust.
- Both crust and upper mantle constitute the Lithosphere.

Asthenosphere

- The asthenosphere is that part of the layer of earth which is below the Lithosphere. It extends at a depth of 100 km to 400 km from the lithosphere. Due to the high temperature, this region is partially molten. Here the velocity of seismic wave slowdowns abruptly. This region is called Low-velocity region. Also, it is rich in Peridotite. Moreover, this region is popularly known as the **Magma Chamber**.

Lower mantle

- The lower mantle extends at a depth of 670 km to 2900km.
- The average density of this region is about 6.5gm/cm^3.
- It is composed of Olivine, Plagioclase and Orthoclase minerals.
- **Guttenberg Discontinuity** separates the lower mantle and the upper core of the earth.

CORE

- At the depth of 2900 km to 6371 km, lies the core of the earth. Because of metallic composition, its density is nearly twice as the mantle. It comprises of 15% to 16% of the total volume of the earth. The core is divided into two regions called the outer core and the inner core.

Outer core

- It extends between 2900 km to 5150 km.
- The density of the outer core is about 10gm/cm^3.
- It mainly consists of Iron and Nickle (about 85%).
- The outer core is always in the molten state.
- **Lehman Discontinuity** separates the outer core and the inner-core.

Inner core

- The inner-core extends between 5150 km to 6371 km.
- The average density of the inner core is about 13gm/cm3.
- Despite the high temperature, the inner-core is always in the solid-state due to very high pressure prevailing in this region.
- The temperature of the inner core is about 6000 C^0.

SEISMOLOGY

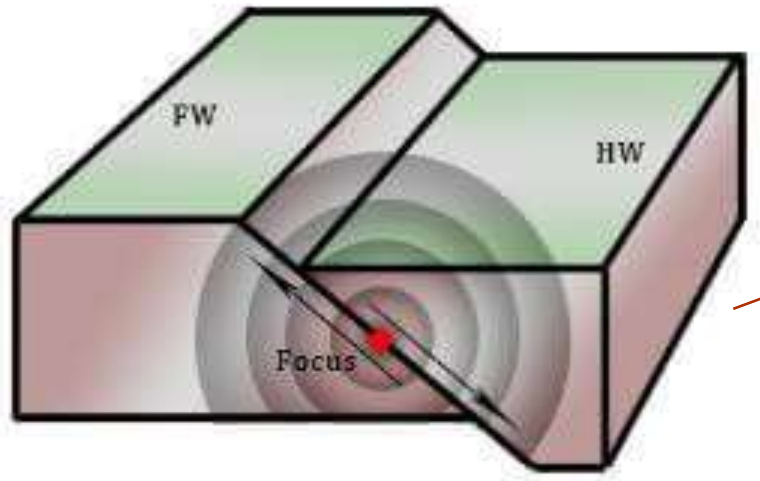
- **Seismology** is the study of earthquakes and associated phenomena, most notably the physical properties of the Earth's interior.
- Seismology is the science of earthquakes and studies the causes and effects from minute pulsations to the most catastrophic natural phenomenon inside Earth. The methods are classified into two divisions based on energy source of the seismic waves. **Earthquake seismology** is caused by natural shock waves of earthquakes and derives information on physical properties, composition, and the gross internal structure of Earth.
- A **seismograph**, or seismometer, is an instrument used to detect and record earthquakes

SEISMICITY

- **Seismic waves**
- Seismic: relating to earthquakes or other vibrations of the earth and its crust.
- Seismic waves are waves of energy that travel through the Earth's layers and are a result of earthquakes, volcanic eruptions, magma movement, large landslides and large human-made explosions.
- The refraction or reflection of seismic waves is used for research into the structure of the Earth's interior.
- The terms seismic waves and earthquake waves are often used interchangeably.

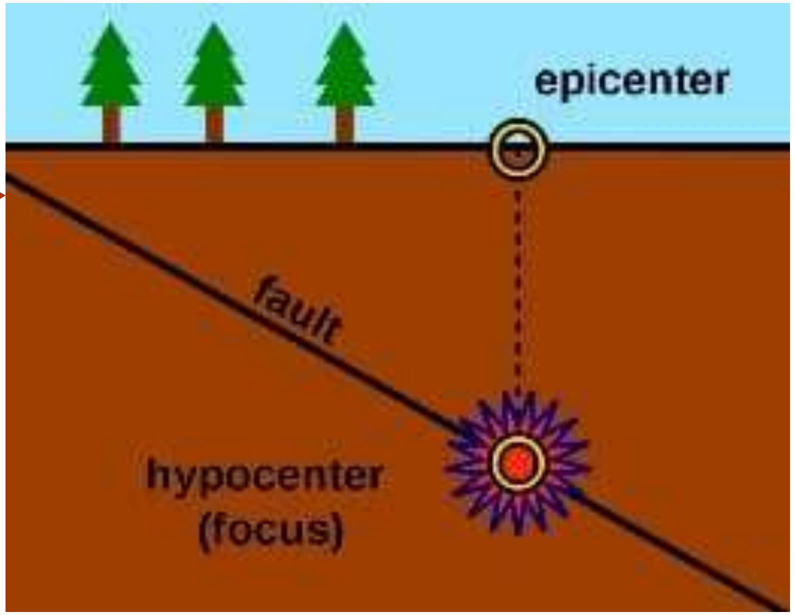
EARTHQUAKE

- **How are earthquake waves produced?**
- The abrupt release of energy along a fault (sharp break in the crustal layer) causes earthquake waves.
- Rock layers along a fault tend to move in opposite directions due to the force excreted on them but are held in place by counteracting frictional force exerted by the overlying rock strata.
- 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.



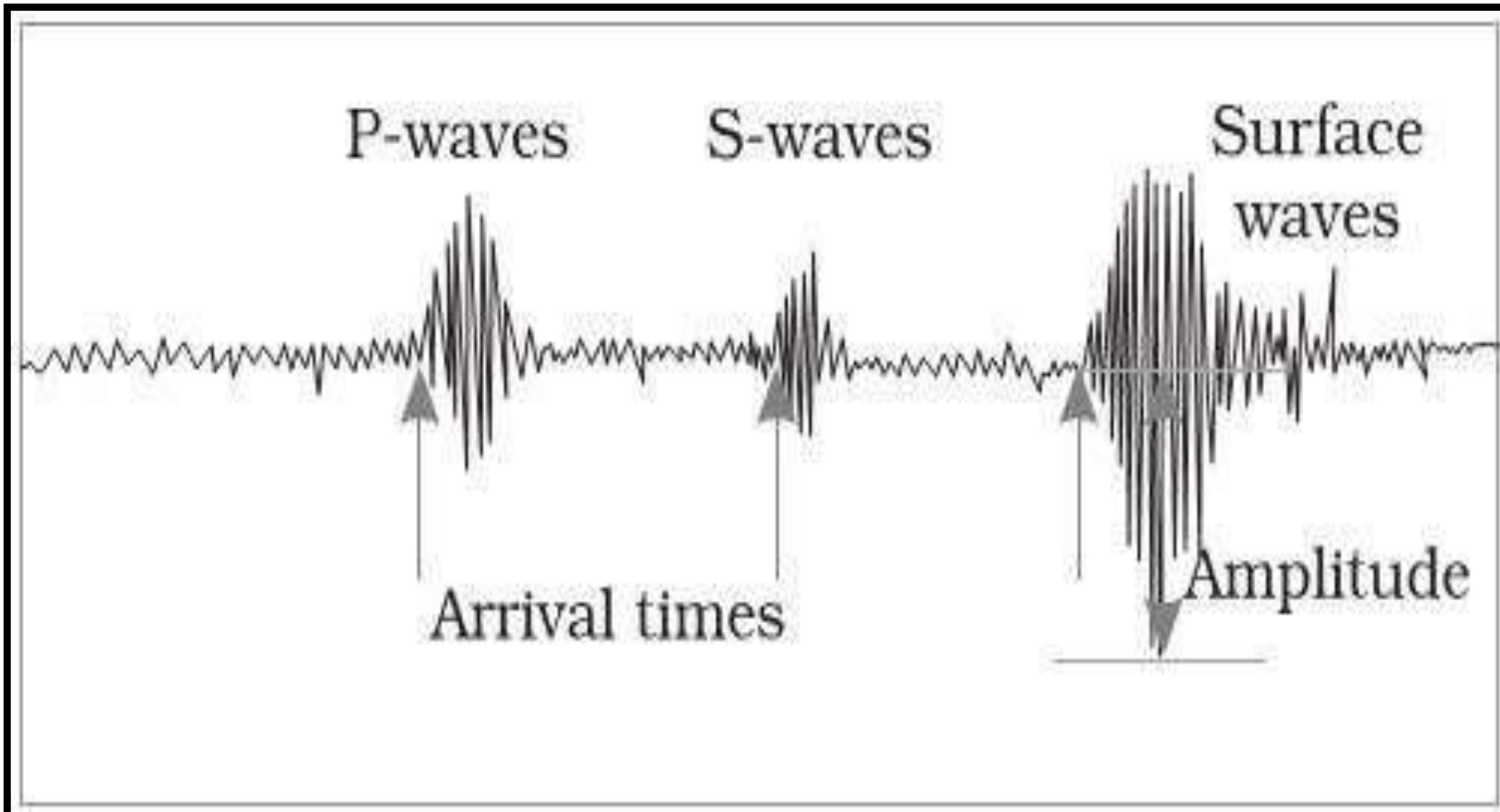
FOCUS- ORIGIN OF THE EARTHQUAK E

EPICENTRE



- **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 are generated due to the release of energy at the focus and **move in all directions** travelling through the interior of the earth. Hence, the name body waves.
- There are two types of body waves:
- the P-waves **or primary waves** (**longitudinal** in nature — wave propagation is similar to sound waves), and
- the **S-waves or** secondary waves (**transverse** in nature — wave propagation is similar to ripples on the surface of the water).

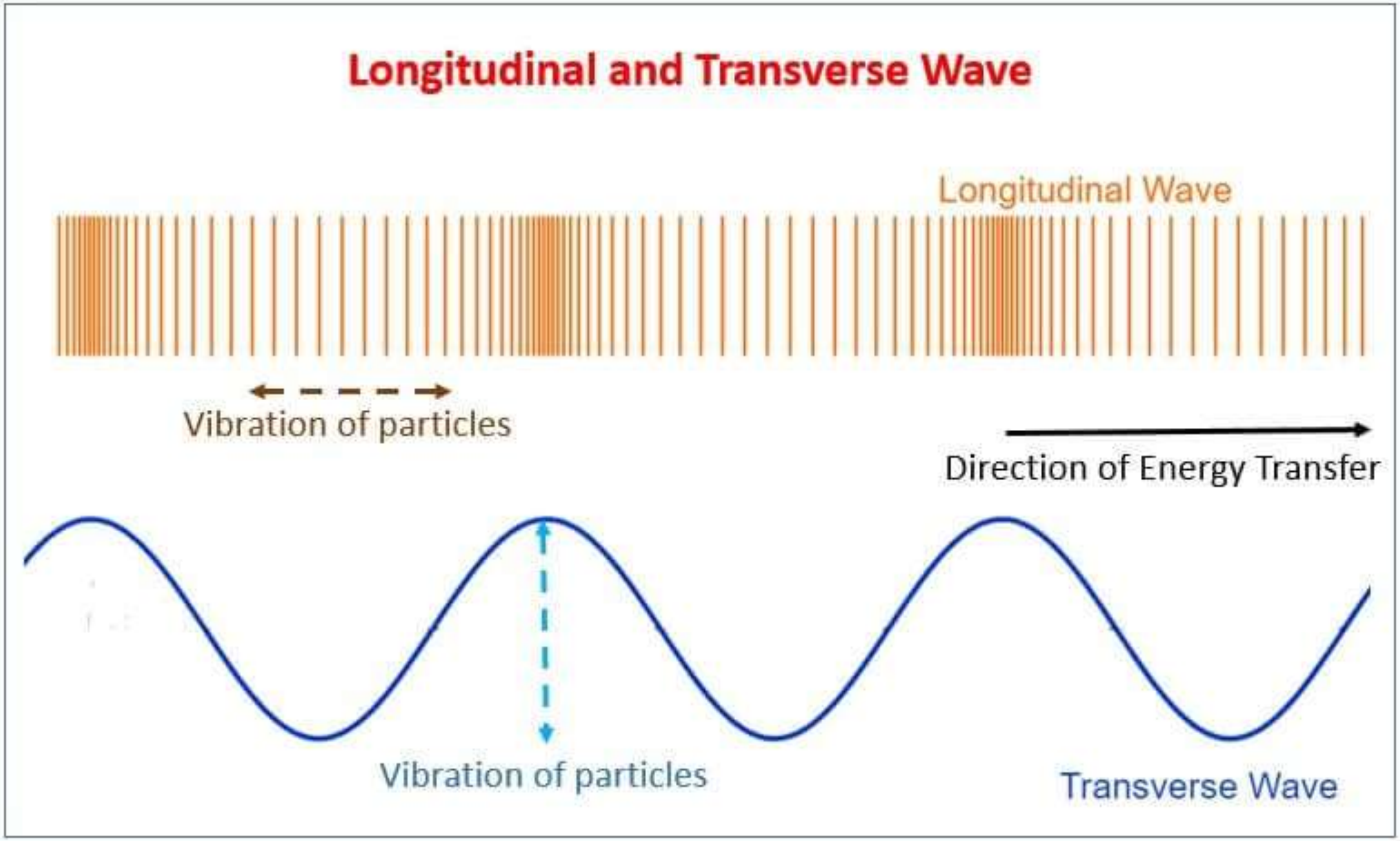
Types of Seismic waves or earthquake waves



P-WAVES

- Primary waves are called so because they are the **fastest** among the seismic waves and hence are **recorded first on the seismograph**.
- P-waves are also called as the
- **longitudinal waves** because the displacement of the medium is in the same direction as, or the opposite direction to, (parallel to) the direction of propagation of the wave; or
- **compressional waves** because they produce compression and rarefaction when travelling through a medium; or
- **pressure waves** because they produce increases and decreases in pressure in the medium.
- P-waves creates density differences in the material leading to stretching (rarefaction) and squeezing (compression) of the material.

Longitudinal wave and Transverse wave



Longitudinal wave and Transverse wave

- These waves are of relatively high frequency and are the **least destructive** among the earthquake waves.
- The trembling on the earth's surface caused due to these waves is in the **up-down direction (vertical)**.
- **They can travel in all mediums,** and their velocity depends on **shear strength (elasticity)** of the medium.
- Hence, the velocity of the P-waves in **Solids > Liquids > Gases**.
- These waves take the form of **sound waves** when they enter the atmosphere.
- P-wave velocity in earthquakes is in the range 5 to 8 km/s.
- The precise speed varies according to the region of the Earth's interior, from less than 6 km/s in the Earth's crust to 13.5 km/s in the lower mantle, and 11 km/s through the inner core.

Secondary Waves- (S-WAVES)

- Secondary waves (secondary they are recorded second on the seismograph) or S-waves are also called as **transverse waves or shear waves or distortional waves**.
- They are analogous to water ripples or light waves.
- **Transverse waves or shear waves** mean that the direction of vibrations of the particles in the medium is perpendicular to the direction of propagation of the wave. Hence, they create **troughs** and **crests** in the material through which they pass (they distort the medium).
- S-waves arrive at the surface after the P-waves.
- These waves are of high frequency and possess **slightly higher destructive power** compared to P-waves.
- The trembling on the earth's surface caused due to these waves is from **side to side (horizontal)**.
- S-waves **cannot pass through fluids (liquids and gases)** as fluids do not support **shear stresses**.
- They travel at varying velocities (proportional to shear strength) through the solid part of the Earth.

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

- **P-waves are about 1.7 times faster than the S-waves**.
- P-waves are compression waves that apply a force in the direction of propagation and hence transmit their energy quite easily through the medium and thus travel quickly.
- On the other hand, S-waves are **transverse waves** or **shear waves** (motion of the medium is perpendicular to the direction of propagation of the wave) and are hence less easily transmitted through the medium.
- **P-waves as an earthquake warning**
- Advance earthquake warning is possible by detecting the non-destructive primary waves that travel more quickly through the Earth's crust than do the destructive secondary and surface waves.
- Depending on the depth of focus of the earthquake, the delay between the arrival of the P-wave and other destructive waves could be up to about 60 to 90 seconds (depends of the depth of the focus).

SURFACE WAVES- (L-Waves)

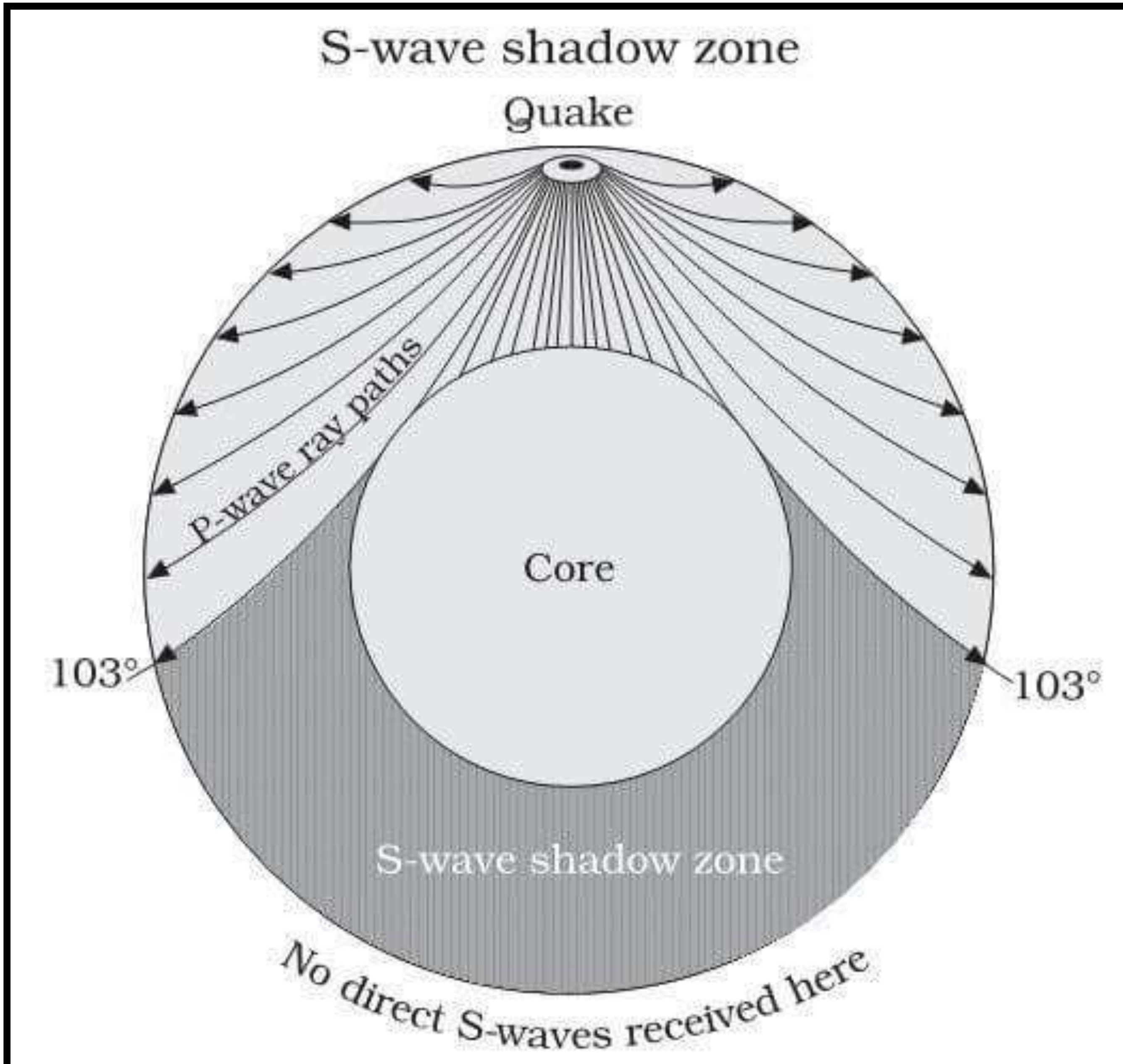
- The body waves **interact with the surface rocks and generate new set of waves called surface waves** (long or L-waves). **These waves move only along the surface**.
- Surface Waves are also called long period waves because of their **long wavelength**.
- They are **low–frequency transverse waves (shear waves)**.
- They develop in the **immediate neighbourhood of the epicentre** and affect only the surface of the earth and die out at smaller depth.
- **They lose energy more slowly with distance than the body waves** because they travel only across the surface unlike the body waves which travel in all directions.
- **Particle motion of surface waves (amplitude) is larger than that of body waves**, so surface waves are the **most destructive** among the earthquake waves.
- They are **slowest** among the earthquake waves and are recorded last on the seismograph.
- **Love waves**
- It's the fastest surface wave and moves the ground from side-to-side.
- **Rayleigh waves**
- A Rayleigh wave rolls along the ground just like a wave rolls across a lake or an ocean.
- Because it rolls, it moves the ground **up and down and side-to-side** in the same direction that the wave is moving.
- **Most of the shaking and damage** from an earthquake is due to the Rayleigh wave.

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

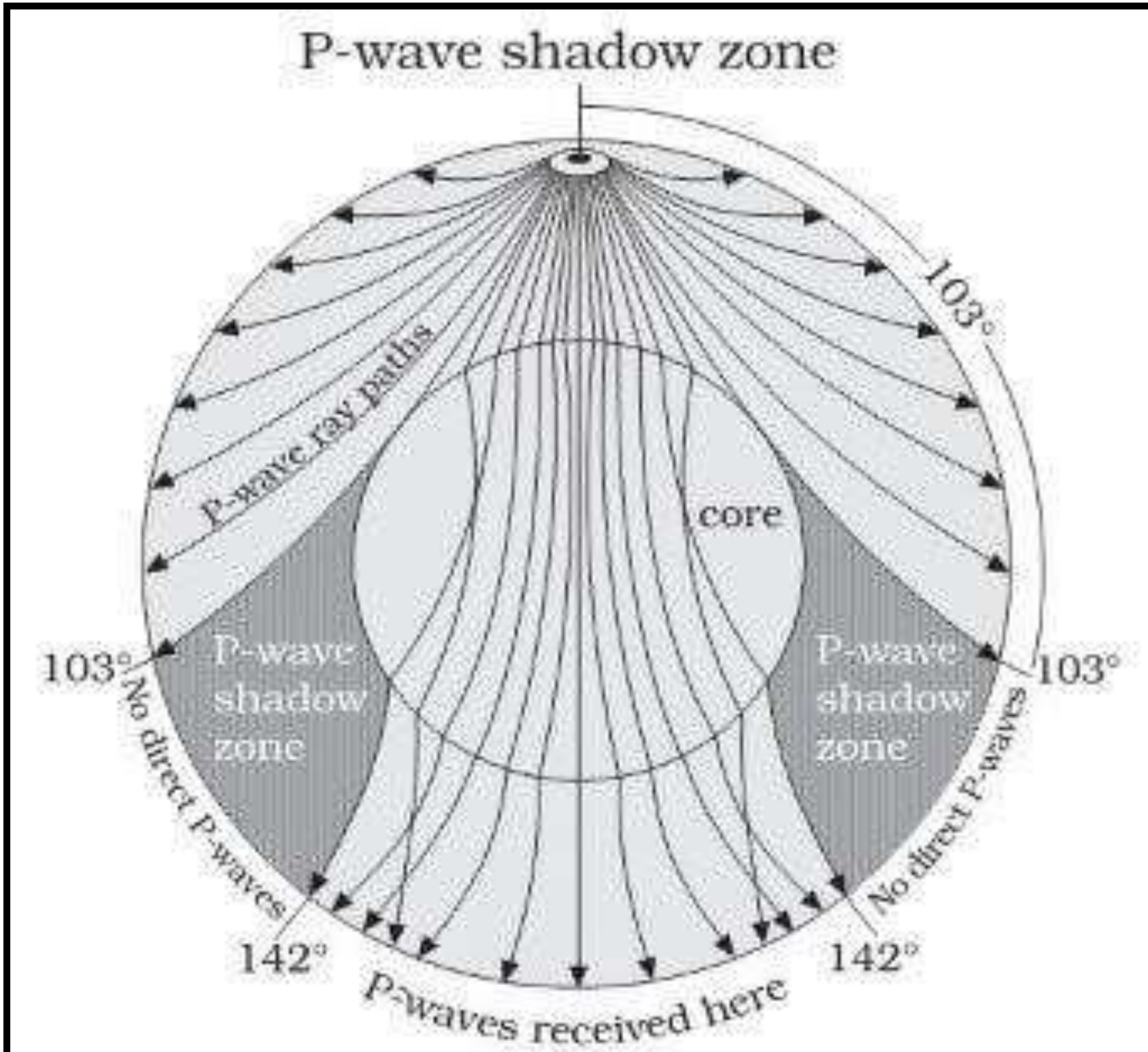
- Seismic waves get recorded in seismographs located at far off locations.
- Differences in arrival times, waves taking different paths than expected (due to refraction) and absence of the seismic waves in certain regions called as shadow zones, allow mapping of the Earth's interior.
- Discontinuities in velocity as a function of depth are indicative of changes in composition and density.
- That's is, by observing the changes in velocity, the density and composition of the earth's interior can be estimated (change in densities greatly varies the wave velocity).
- Discontinuities in wave motion as a function of depth are indicative of changes in phase.
- That is, by observing the changes in the direction of the waves, the emergence of shadow zones, different layers can be identified.

The Emergence of Shadow Zones 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**.
- The seismographs located at any distance within 103° from the epicentre, recorded the arrival of both P and S-waves.


S-wave shadow zone
Quake
P-wave ray paths
Core
103°
103°
S-wave shadow zone
No direct S-waves received here

- The span of the shadow zone of the P-Waves = 78° [2 x (142° – 103°)]
- The span of the shadow zone of the S-Waves = 154° [360° – (103° + 103°)]
- The span of the shadow zone common for both the waves = 78°


P-wave shadow zone
103°
P-wave ray paths
core
103°
P-wave shadow zone
103°
P-wave shadow zone
No direct P-waves
No direct P-waves
142°
142°
P-waves received here