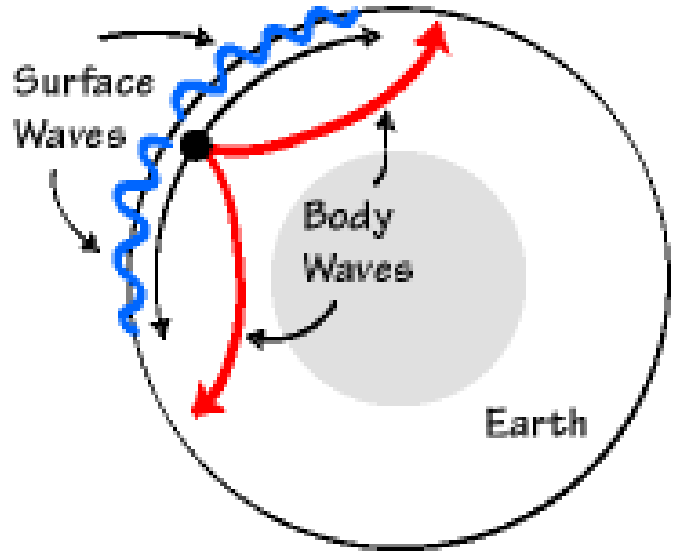
SEISMIC WAVES AND EARTHQUAKE

Seismic Waves

- **Seismic waves** are the waves of energy released by the sudden breaking of rock within the earth or an explosion. They are the energy that travels through the earth and is recorded on seismographs.
- There are several different kinds of seismic waves, and they all move in different ways. The two main types of waves are **body waves** and **surface waves**.
  - **Body Waves (Travel Through the earth)**
    - Primary or p-wave
      - Compression wave
    - Secondary/shear or s-wave
      - Transverse wave
  - **Surface (Travel Primarily on surface)**
    - Love wave
    - Rayleigh wave



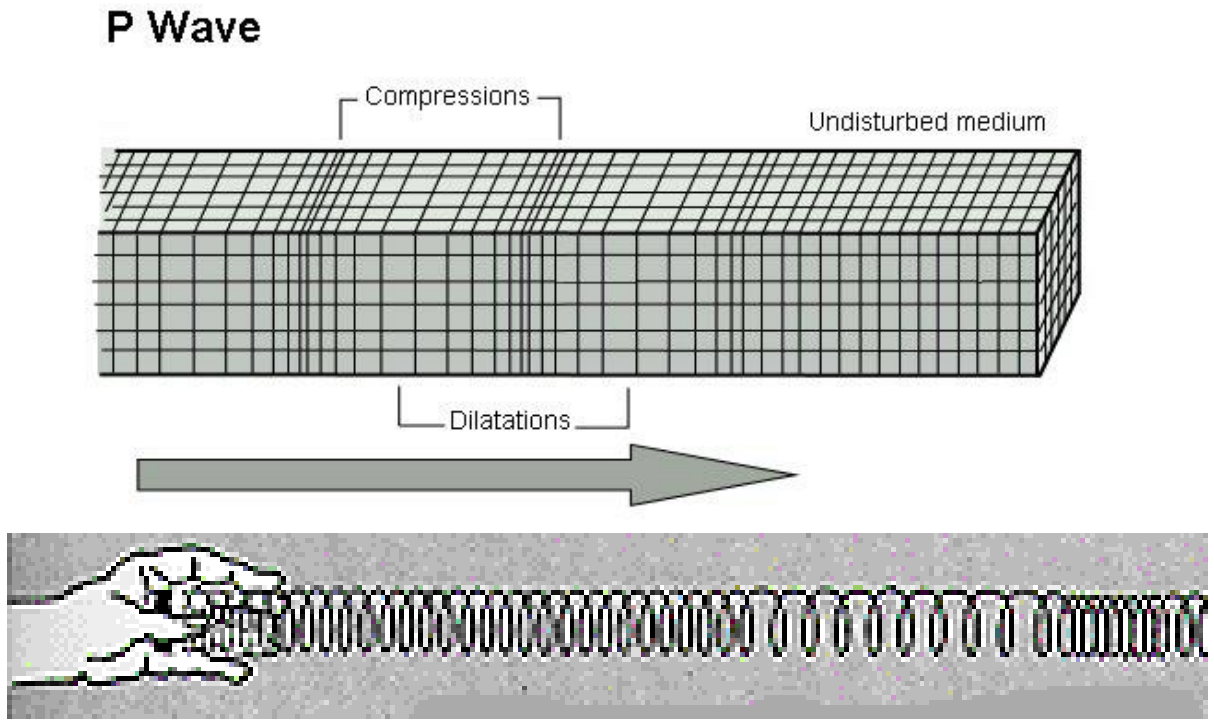
Body Waves

P Waves (compression wave)

- This is the fastest seismic wave (Hence **Primary**). They can be used for earthquake warning because they arrive first at the seismograph stations.
- They can **travel in all mediums,** and their velocity depends on the shear strength **(elasticity)** of the medium.
- Hence, the velocity of the P-waves in **Solids** > **Liquids** > **Gases**
- These waves are of relatively high frequency and are the **least destructive** among the earthquake waves.
- P-wave velocity in earthquakes is in the range of **5 to 8 km/s**.
- 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.
- The trembling on the earth's surface caused due to these waves is in the **up-down direction (vertical)**

Body Waves

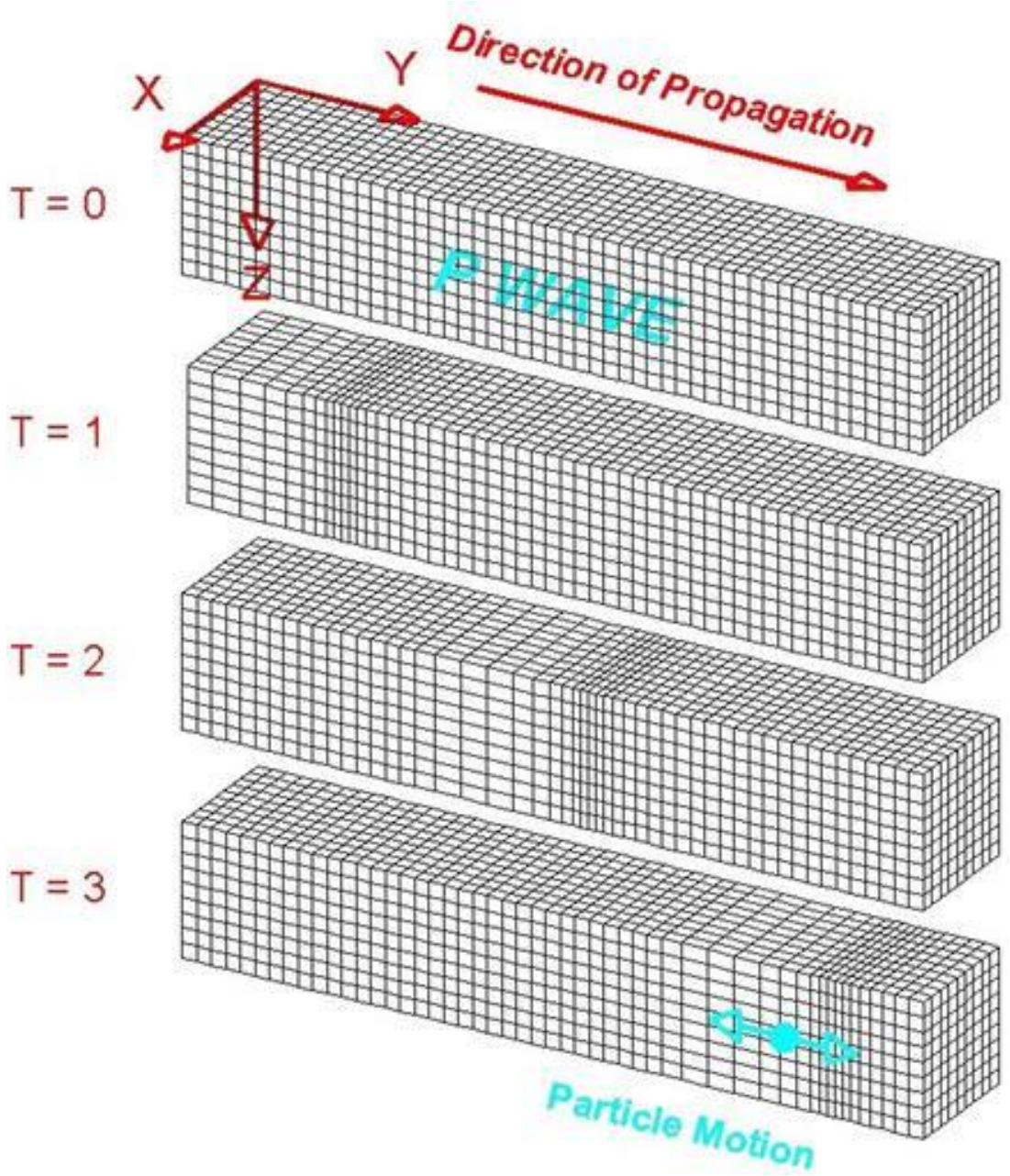
- **P Waves (compression wave)**
- **longitudinal** in nature — wave propagation is similar to sound waves. The displacement of the medium is parallel to the direction of propagation of the wave.
- **compressional waves** because they produce compression and rarefaction when travelling through a medium- causes density differences.



P Wave

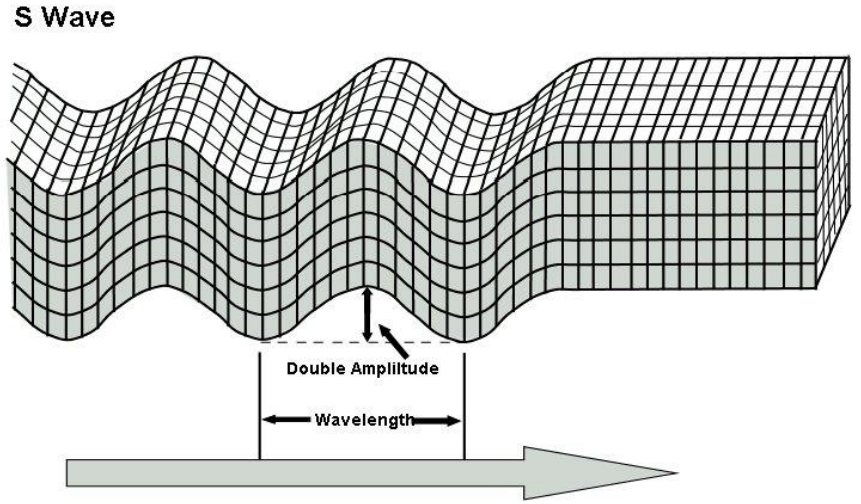
$$P_V = \sqrt{[\{\kappa+(4/3)\mu\}/\rho]}$$

P_V – P wave velocity
κ – bulk modulus
μ – shear modulus
ρ – density



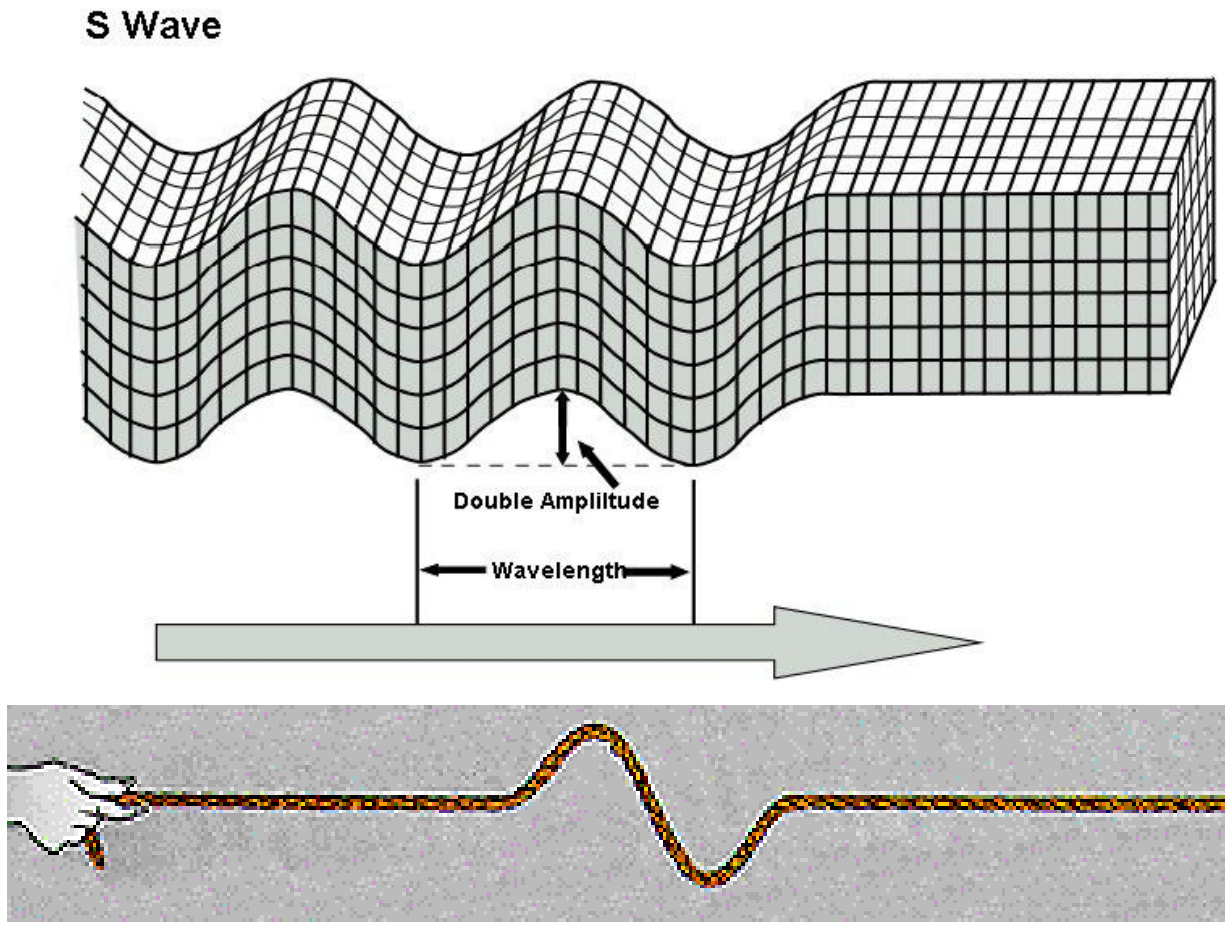
S wave (transverse wave)

- **Secondary waves** (recorded second on the seismograph) or S-waves are also called as **transverse waves or shear waves or distortional waves.**
- S-waves **cannot pass through fluids (liquids and gases)** as fluids do not support **shear stresses.**
- These waves are of high frequency and possess **slightly higher destructive power** compared to P-waves.
- **Transverse waves or shear waves** mean that the direction of vibration 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).
- The trembling on the earth's surface caused due to these waves is from **side to side (horizontal).**



S wave (transverse wave)

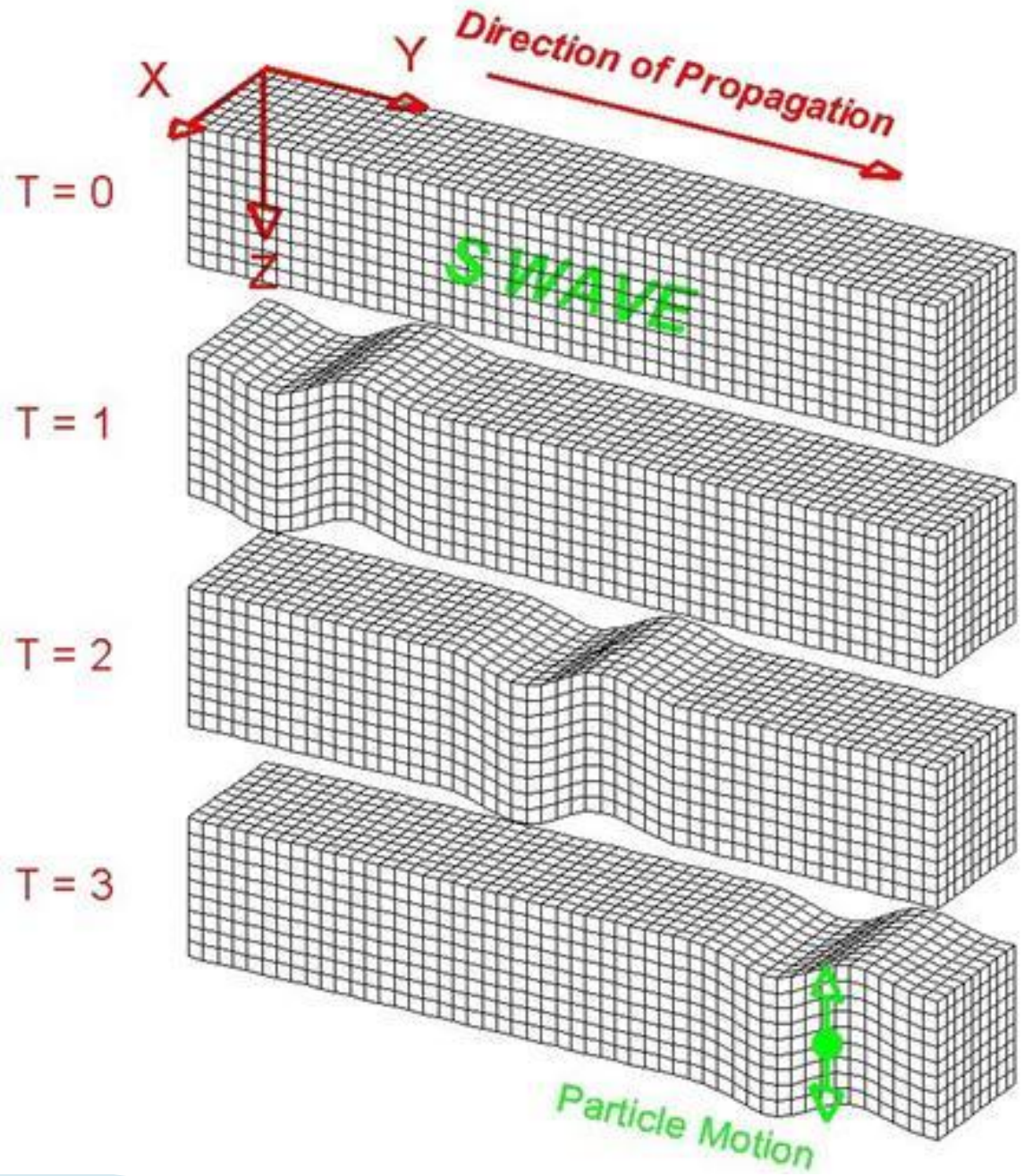
- **Transverse waves or shear waves** mean that the direction of vibration of the particles in the medium is perpendicular to the direction of propagation of the wave.
- S-wave propagation is similar to that of light.



S Wave

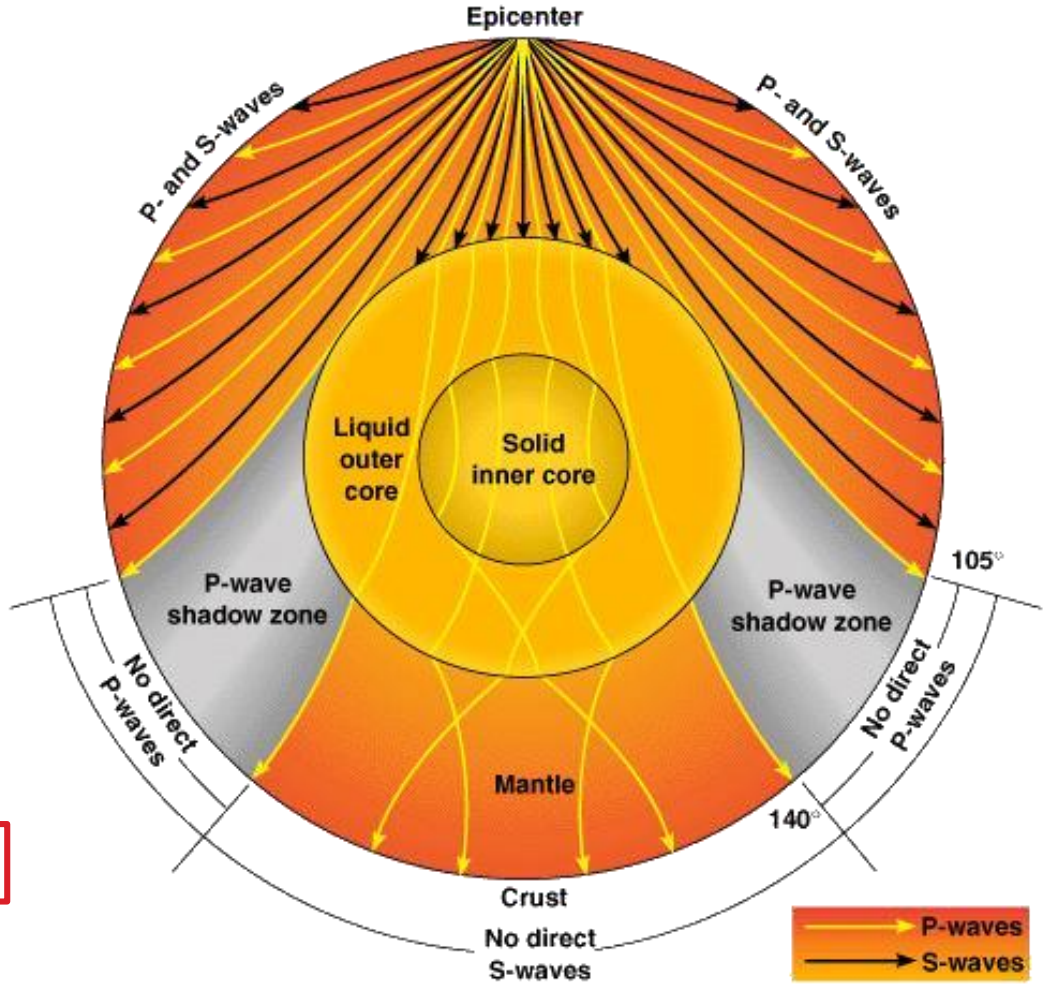
$S_V = \sqrt{(\mu/\rho)}$

S_V – S wave velocity
μ – shear modulus
ρ – density

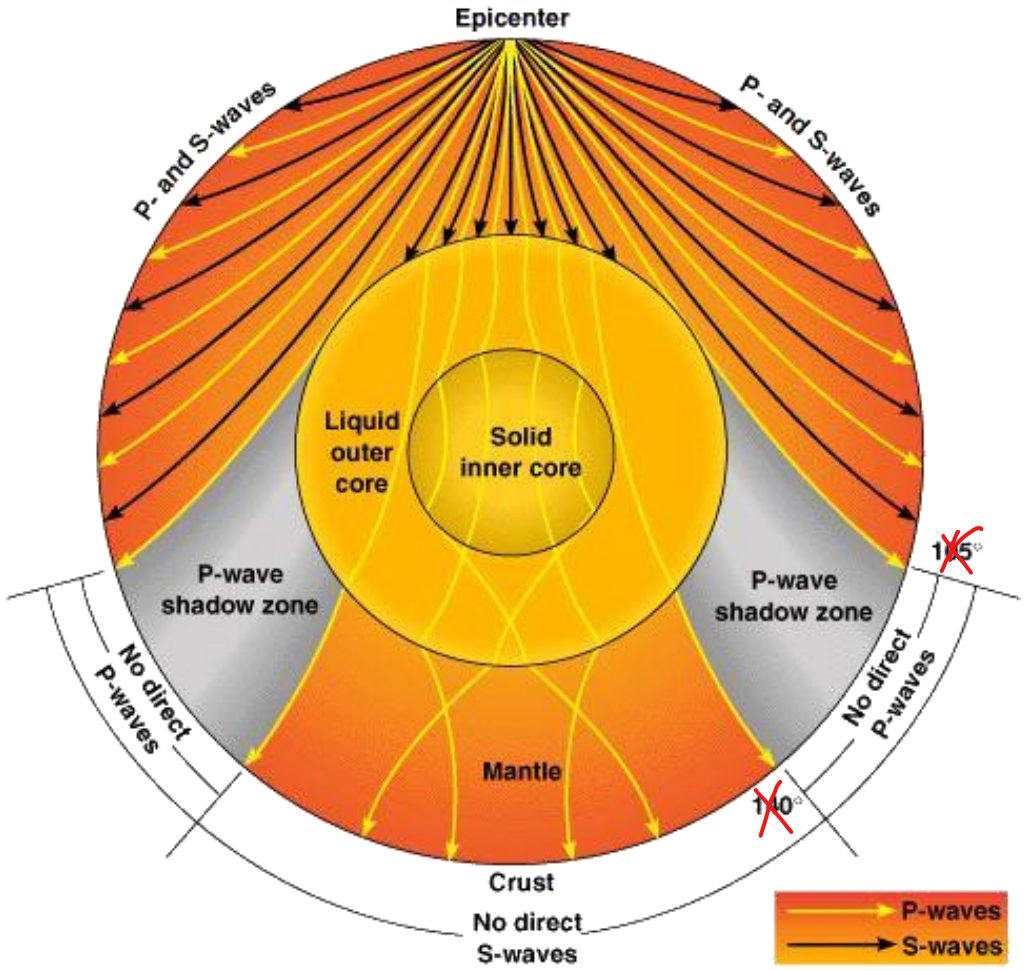


- S-waves do not travel through liquids (they are **attenuated**).
- The entire zone beyond 103° does not receive S-waves, and hence this zone is identified as the **S-wave Shadow zone**. This observation led to the discovery of the **liquid outer core**.

Span of S-wave shadow zone = 154°



- The **P-wave Shadow zone** appears as a band around the earth between **103° and 142°** away from the epicenter.
- 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 epicenter, 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 epicenter was identified as the shadow zone for both the types of waves.



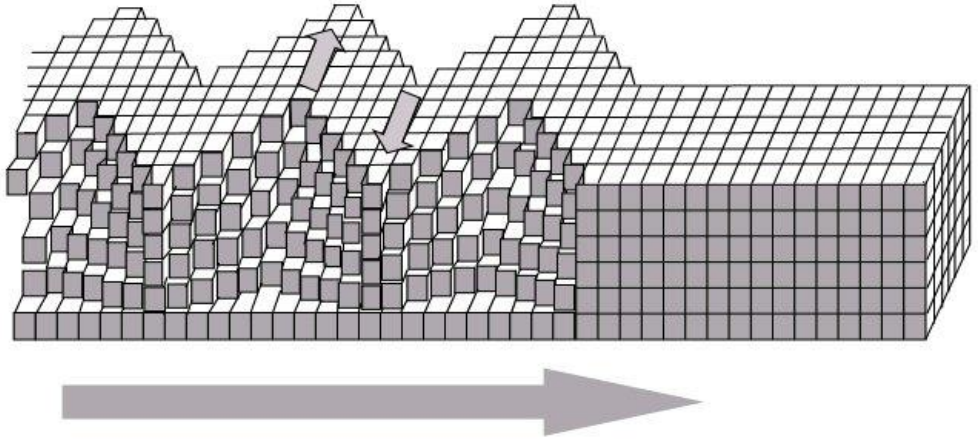
Span of P-wave shadow zone = 78°

Surface Waves (Long or L-waves)

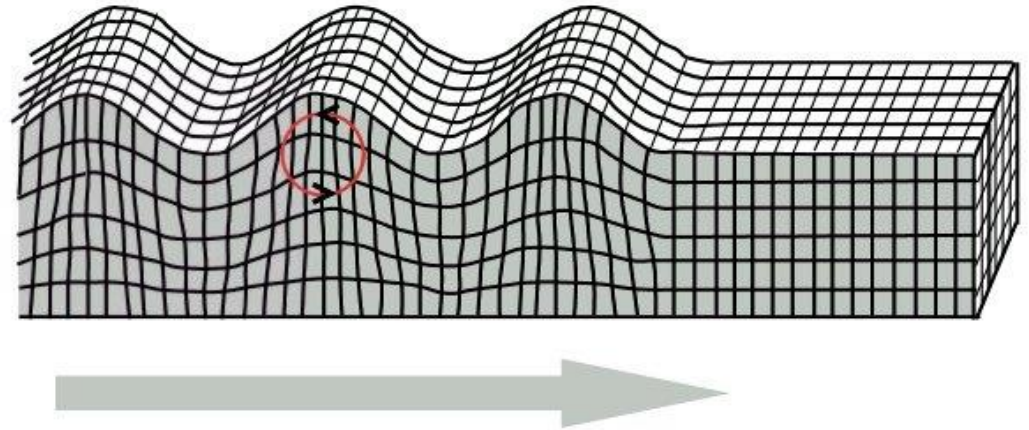
- The body waves **interact with the surface rocks and generate new set of waves called surface waves** (long or L-waves)**. These waves move only along the surface.**
- Surface Waves are also called long period waves because of their **long wavelength.**
- They are **low-frequency transverse waves (shear waves).**
- They develop in the **immediate vicinity 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 the **slowest** among the earthquake waves and are recorded last on the seismograph.

Surface Waves

Love Wave



Rayleigh Wave

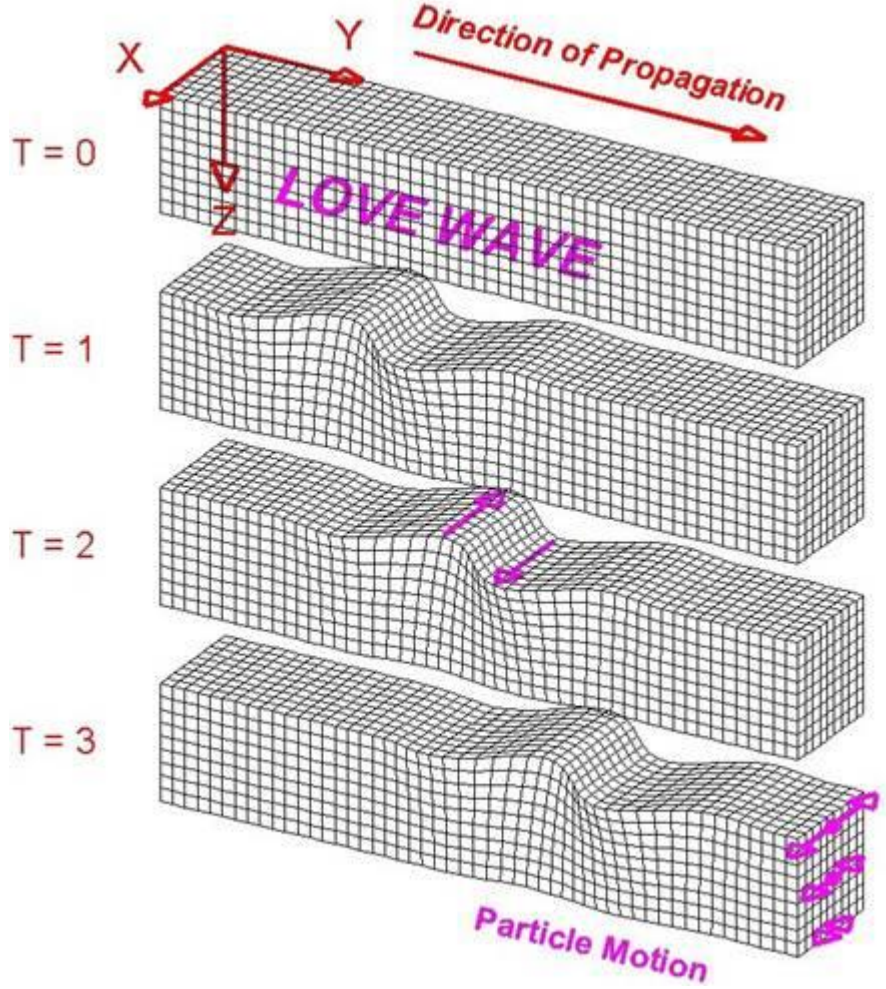


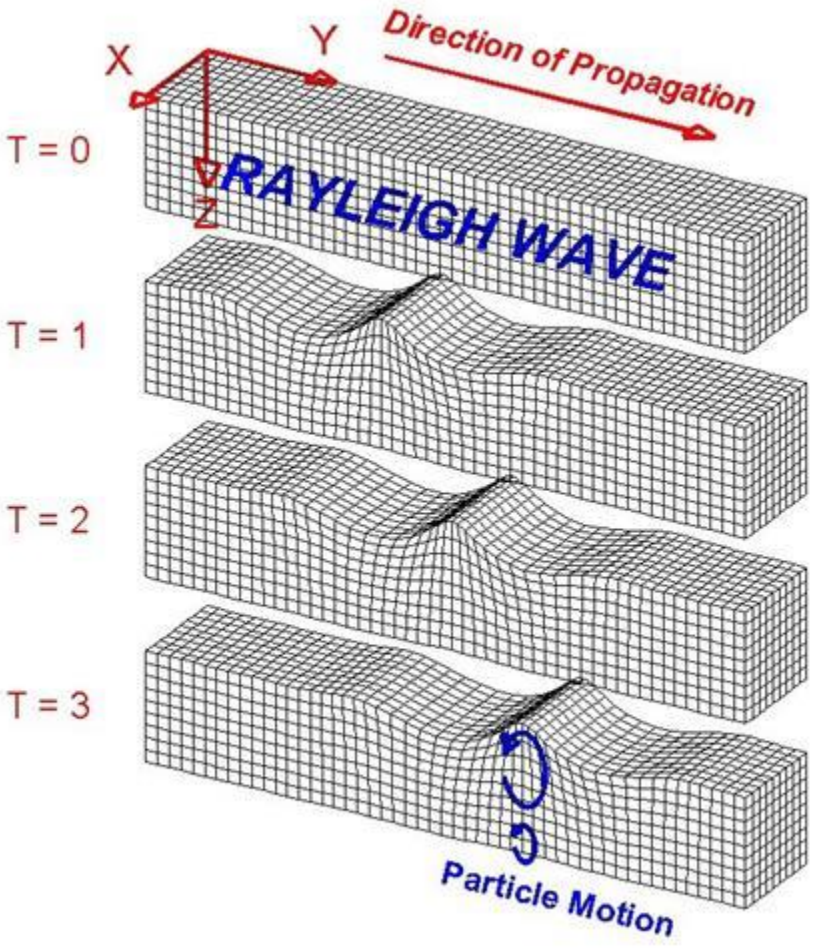
- **Love Waves**
- It's the fastest surface wave and moves the ground from side-to-side.

Rayleigh Waves

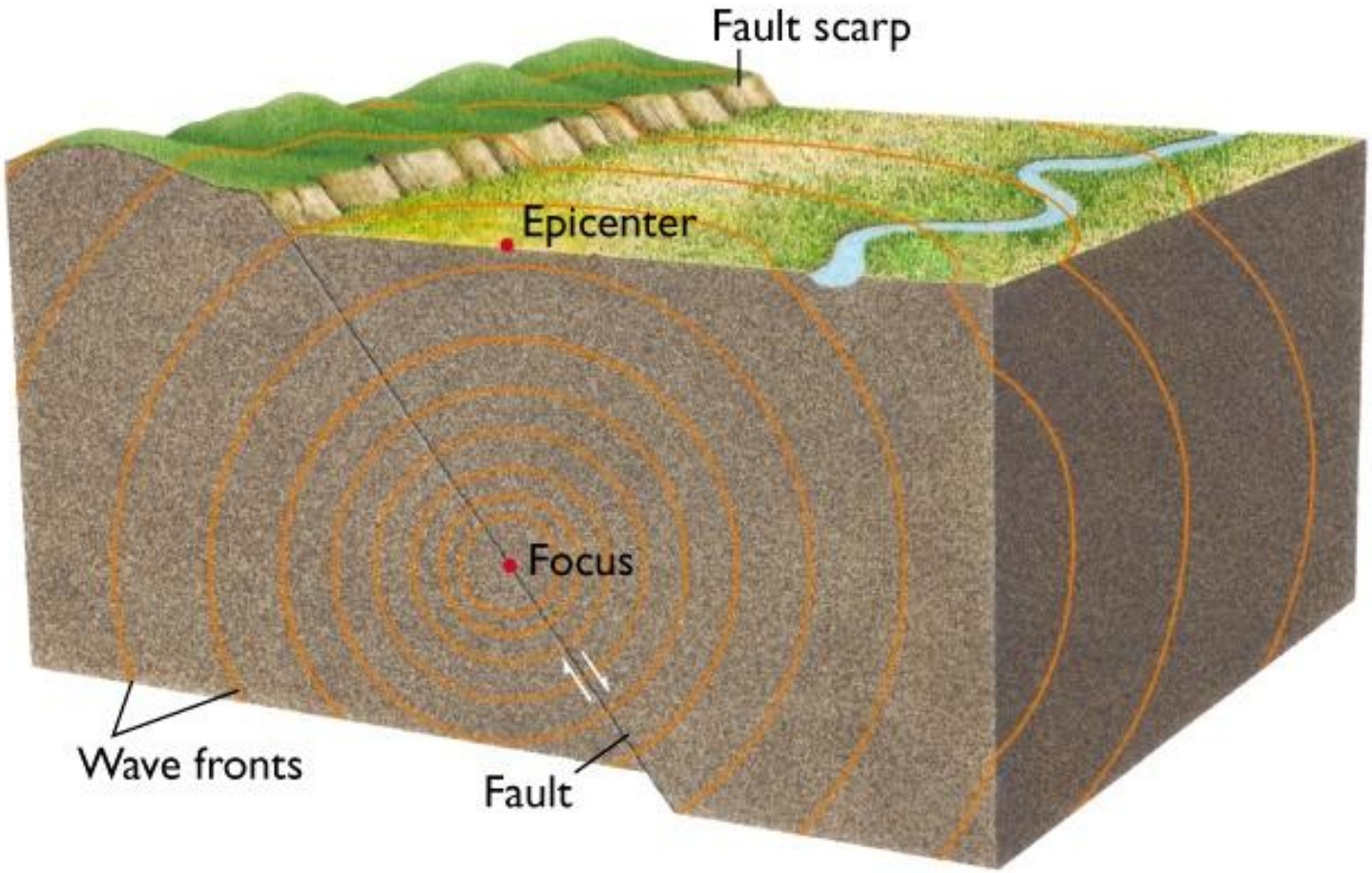
- A Rayleigh wave rolls along the ground just like a wave rolls across a lake or an ocean.
- Because it rolls, it moves the ground up and down, and side-to-side in the same direction that the wave is moving.
- Most of the shaking felt from an earthquake is due to the Rayleigh wave, which can be much larger than the other waves.

Surface Waves

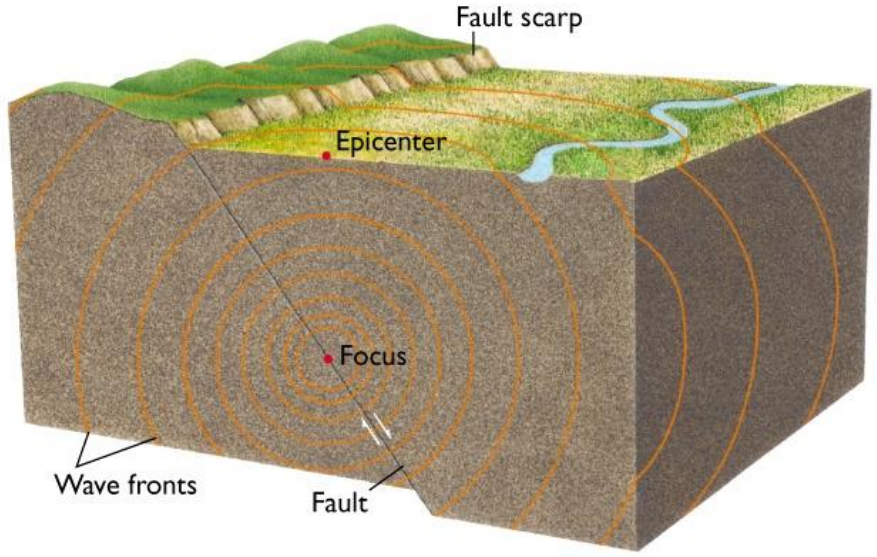




EARTHQUAKE – TREMOR or a TREMBLER



- An earthquake is the shaking or trembling of the earth's surface, caused by the release of **seismic waves** or earthquake waves that are generated due to a sudden movement (sudden release of energy) in the earth's crust or upper mantle.
- A **seismograph**, or seismometer, is an instrument used to detect and record earthquakes.
- 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** (first surface point to experience the earthquake waves).
- A line connecting all points on the surface where the intensity is the same is called an **isoseismic line.**



Foreshocks and aftershocks

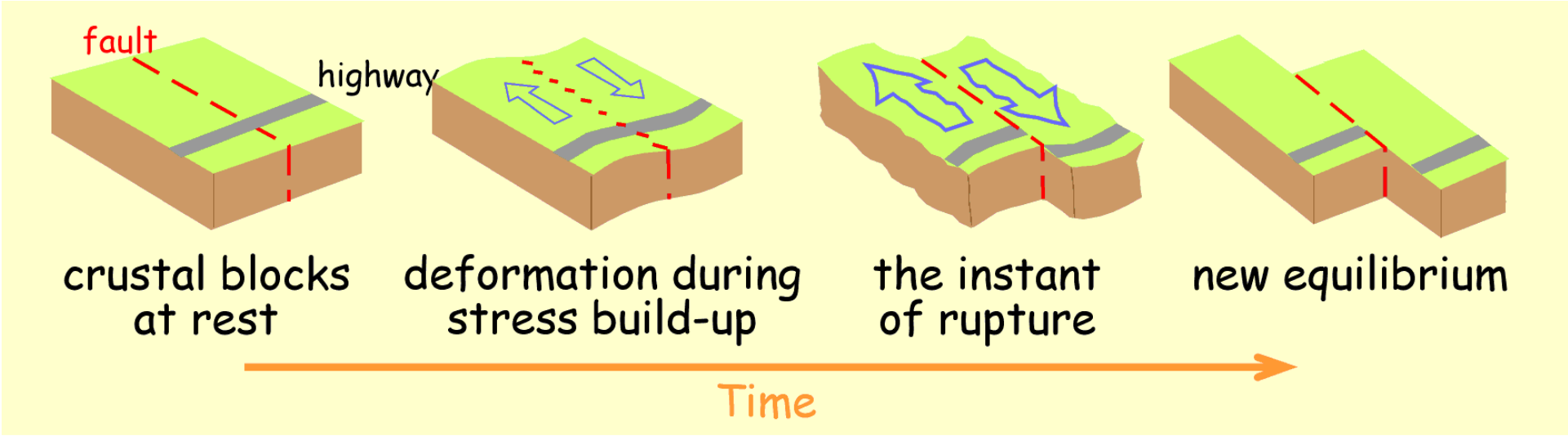
- A mild earthquake preceding the violent shaking movement of an earthquake is known as a **foreshock**.
- Usually, a major or even moderate earthquake of shallow focus is followed by many lesser-sized earthquakes known as **aftershocks**.

Swarms

- Large numbers of small earthquakes may occur in a region for months without a major earthquake.
- Such series of earthquakes are called **earthquake swarms**.
- Earthquakes associated with **volcanic activity** often occur in swarms.
- Earthquake swarms can serve as markers for the location of the flowing magma throughout the volcanoes.

Causes of Earthquake

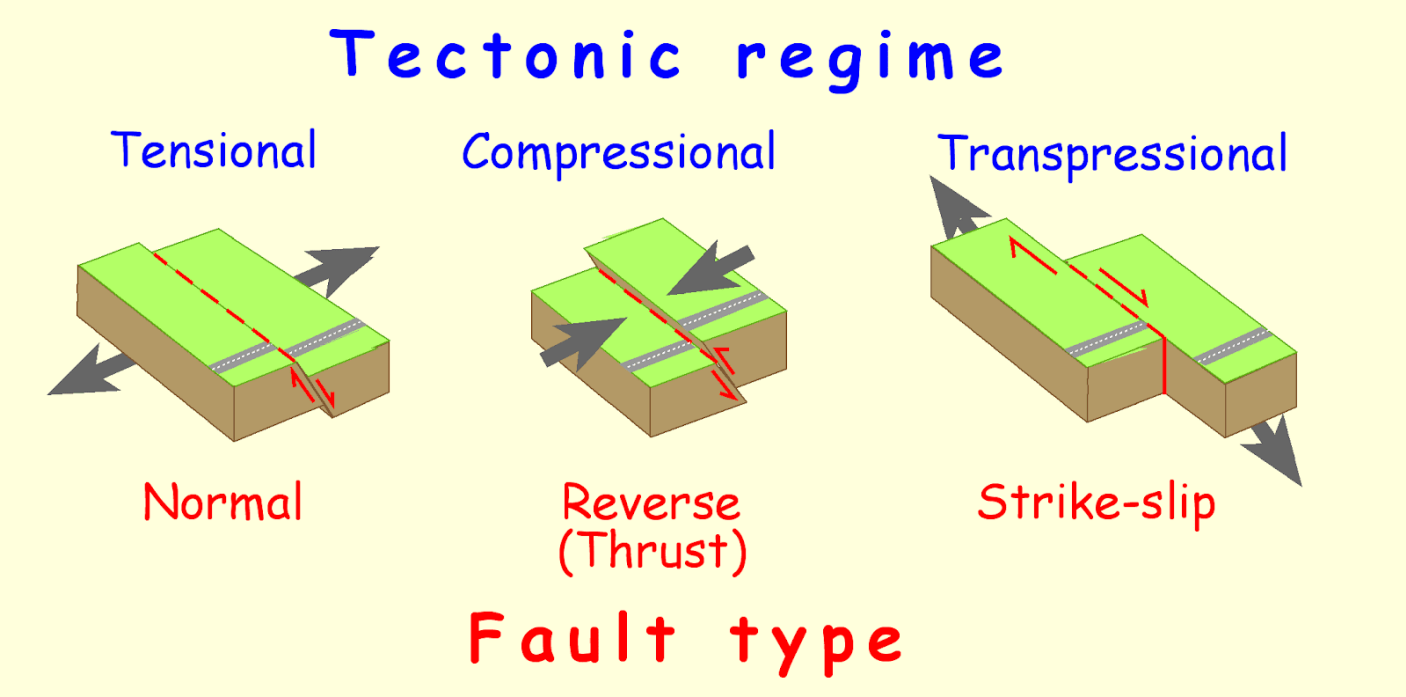
- **Fault Zones**
- The immediate cause of most shallow earthquakes is the sudden release of stress along a **fault rupture** (crack) in the earth's crust.
- The longer the length and the wider the width of the faulted area, the larger the resulting magnitude.



The elastic rebound model

Causes of Earthquake

- **Fault Zones**
- The longest earthquake ruptures along **thrust faults (convergent boundary)** are approximately 1,000 km.
- The longest earthquake ruptures on **strike-slip faults (transform fault)** are about half to one third as long as the lengths along the thrust fault.
- The fault ruptures along normal faults (divergent boundary) are **shorter.**



Causes of Earthquake

- **Plate tectonics**
- Slipping of land along the faultline along convergent, divergent and transform boundaries cause earthquakes.
- **Reverse faults (convergent boundary) are associated with the most powerful earthquakes**, **megathrust earthquakes**, including almost **all of those of magnitude 8 or more.**
- **Megathrust earthquakes** occur at subduction zones, where one tectonic plate is forced underneath another. E.g. 2004 Indian Ocean earthquake.
- Strike-slip faults, particularly **continental transforms**, can produce major earthquakes **up to about magnitude 8**.
- **San Andreas Fault** is a **transform fault** where Pacific plate and North American plate move horizontally relative to each other causing earthquakes along the fault lines.
- Earthquakes associated with normal faults (divergent boundary) are generally less than magnitude 7.

Causes of Earthquake

- **Volcanic Activity**
- Volcanic activity also can cause an earthquake, but **the earthquakes of volcanic origin are generally less severe and more limited in extent** than those caused by fracturing of the earth's crust.
- Earthquakes in volcanic regions are caused by the consequent release of elastic strain energy both by tectonic faults and the movement of magma in volcanoes.
- Such earthquakes can serve as an **early warning of volcanic eruptions**, as during the 1980 eruption of Mount St. Helens.
- There is a clear correspondence between the geographic distribution of volcanoes and major earthquakes, particularly in the Circum-Pacific Belt and along mid-oceanic ridges.

Causes of Earthquake

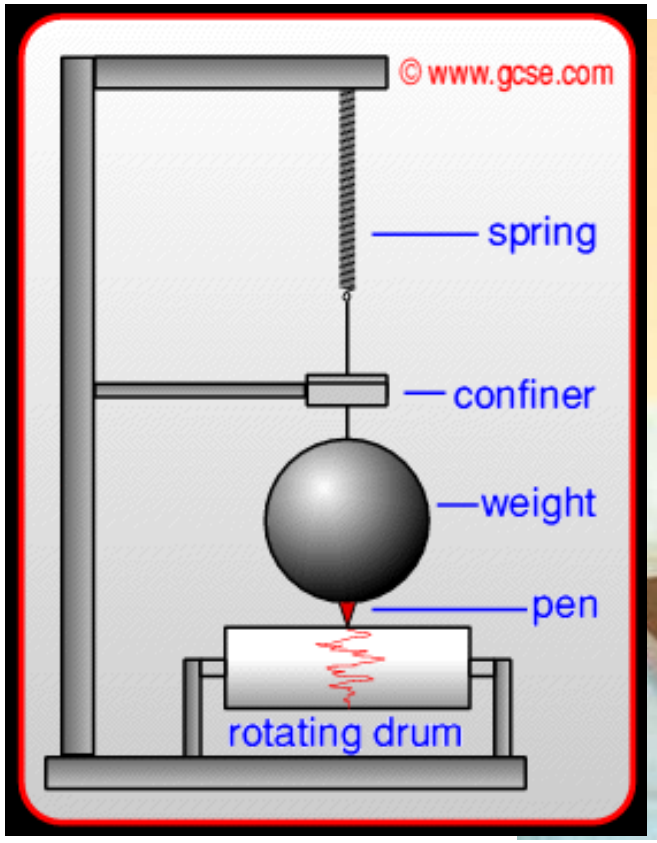
Human Induced Earthquakes

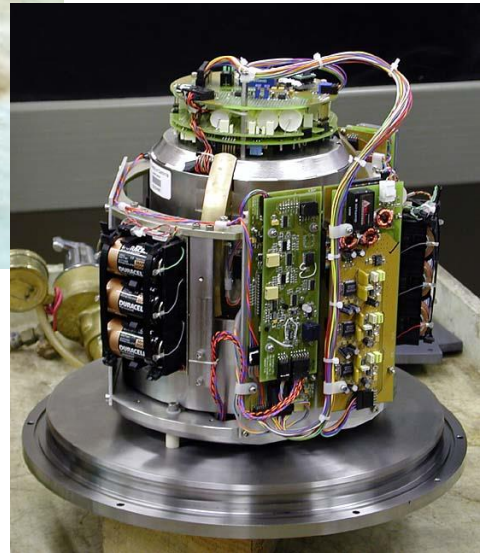
- Human Induced Earthquakes refers to typically minor earthquakes and tremors that are caused by human activity like **mining**, large scale petroleum extraction, artificial lakes (reservoirs), **nuclear tests** etc.
- **Reservoir-induced seismicity**- The pressure offered by a column of water in a large and **deep** artificial lake alter stresses along an existing fault or fracture. Also, the percolation of water weakens the soil structure and lubricates the faults.
- The 6.3 magnitude 1967 **Koynanagar earthquake** occurred near the Koyna Dam reservoir in Maharashtra and claimed more than 150 lives.
- The **2008 Sichuan earthquake**, which caused approximately 68,000 deaths, is another possible example.

Types of Earthquakes

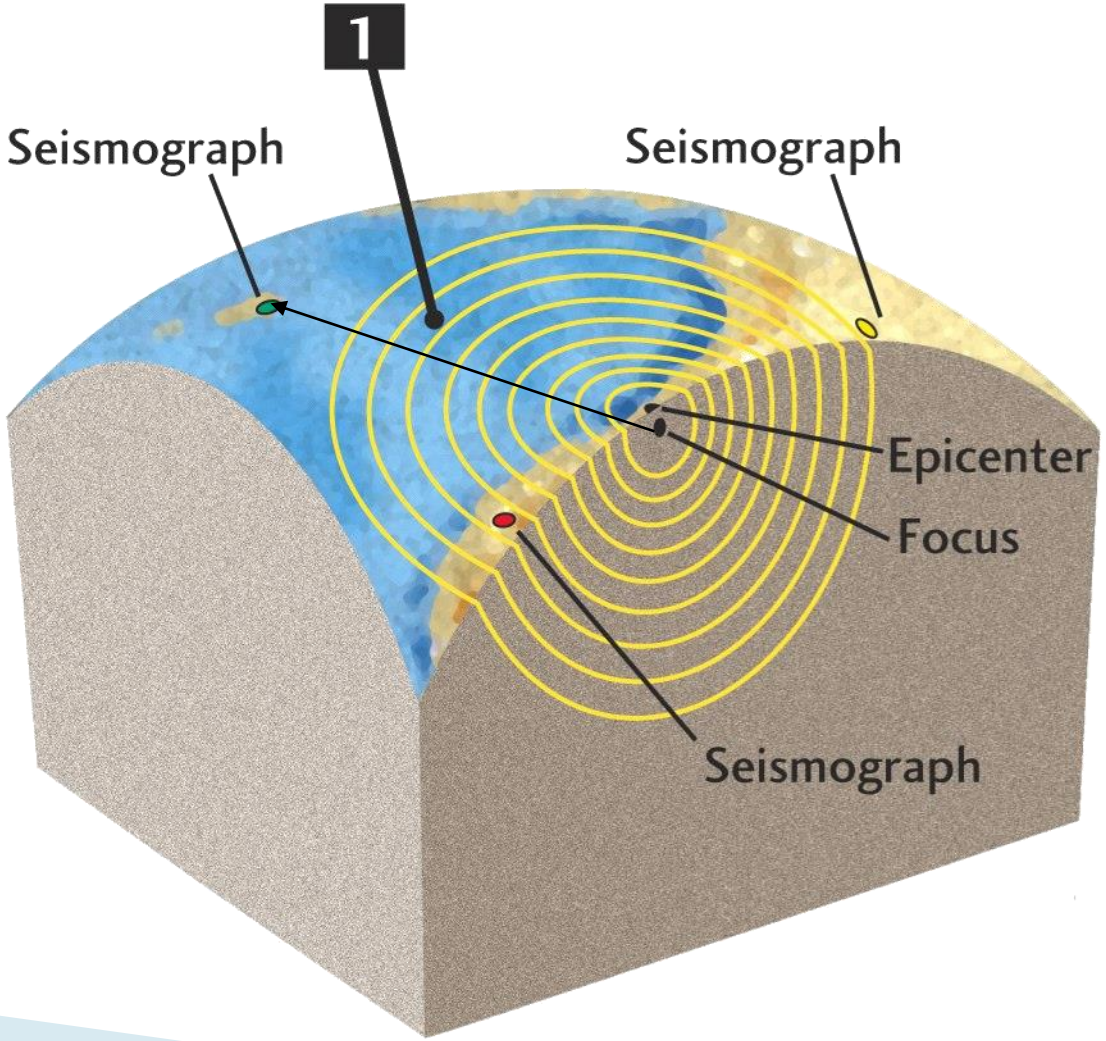
- **Shallow focus earthquakes**-Seismic shocks originate at a depth of 70 kilometres or less, below the earth surface
- **Intermediate earthquakes**-Shock originates at a depth between 70-300 km
- **Deep focus earthquakes**-Origin of the shock is at a depth between 300-700 km.
- A quake's destructive force depends not only on the energy released but also on location, distance from the epicentre and depth.
- On 24 August 2016, a 6.2 earthquake rocked Central Italy killing about 300 people. An even bigger 6.8 hit Myanmar the same day killing just a few people.
- Italy's quake was very shallow, originating within 10 kilometers underground. By contrast, the quake in Myanmar was deeper — 84 kilometers.

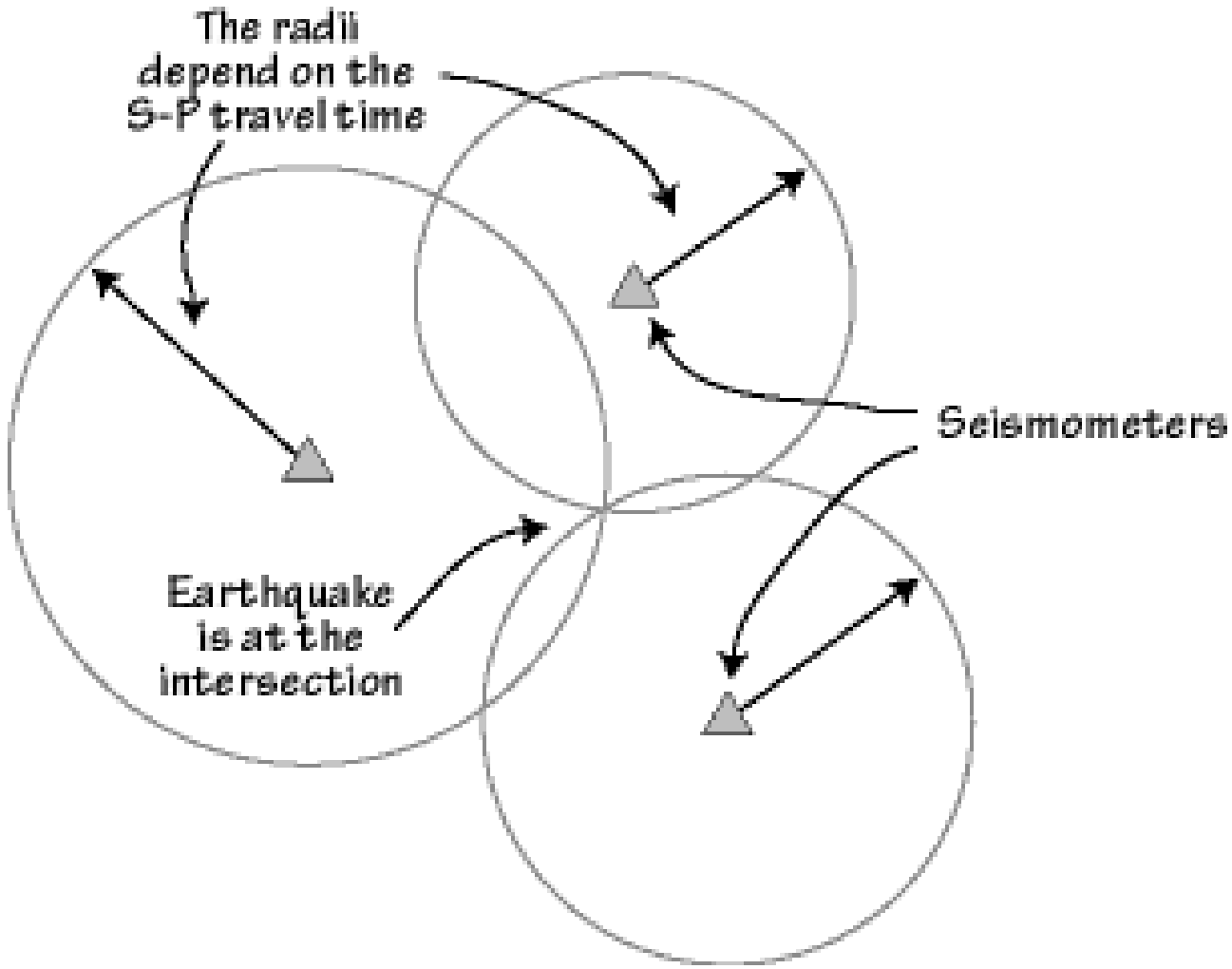
SEISMOGRAPH
SEISMOMETER





READINGS AT DIFFERENT SEISMOGRAPHIC STATIONS REVEAL THE LOCATION OF THE EARTHQUAKE EPICENTER




The radii
depend on the
S-P travel time
Seismometers
Earthquake
is at the
intersection

Let

d – distance from earthquake

P_v *– P-wave speed*

S_v *– S-wave speed*

- The travel time of the P wave is d/P_v
- The travel time of the S wave is d/S_V
- The difference in the arrival times of the waves is

$$d/S_V - d/P_v$$
$$= d(1/S_V - 1/P_V)$$

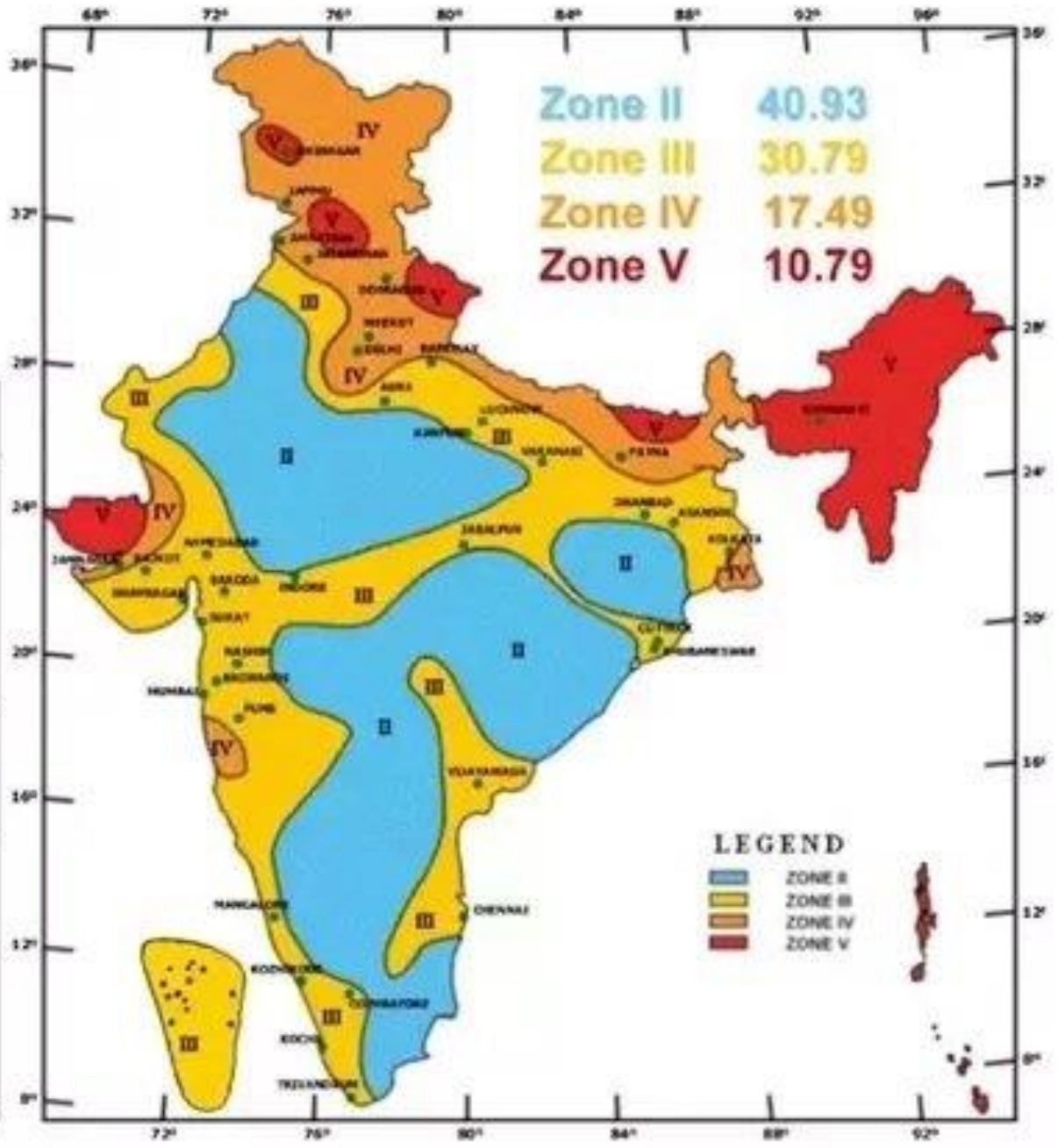
Magnitude of Earthquake

- Richter Scale- A logarithmic scale used to measure the strength (amount of energy released) of an earthquake.
- Under the Richter magnitude scale, an **increase of one step corresponds to about 32 times increase in the amount of energy released**, and **an increase of two steps corresponds to 1,000 times increase in released energy.**
- Thus, **an earthquake of magnitude of 7.0 releases about 32 times as much energy as one of 6.0 and nearly 1,000 times (~ 32 X 32) one of 5.0.**
- The scale varies from 1 to 10.

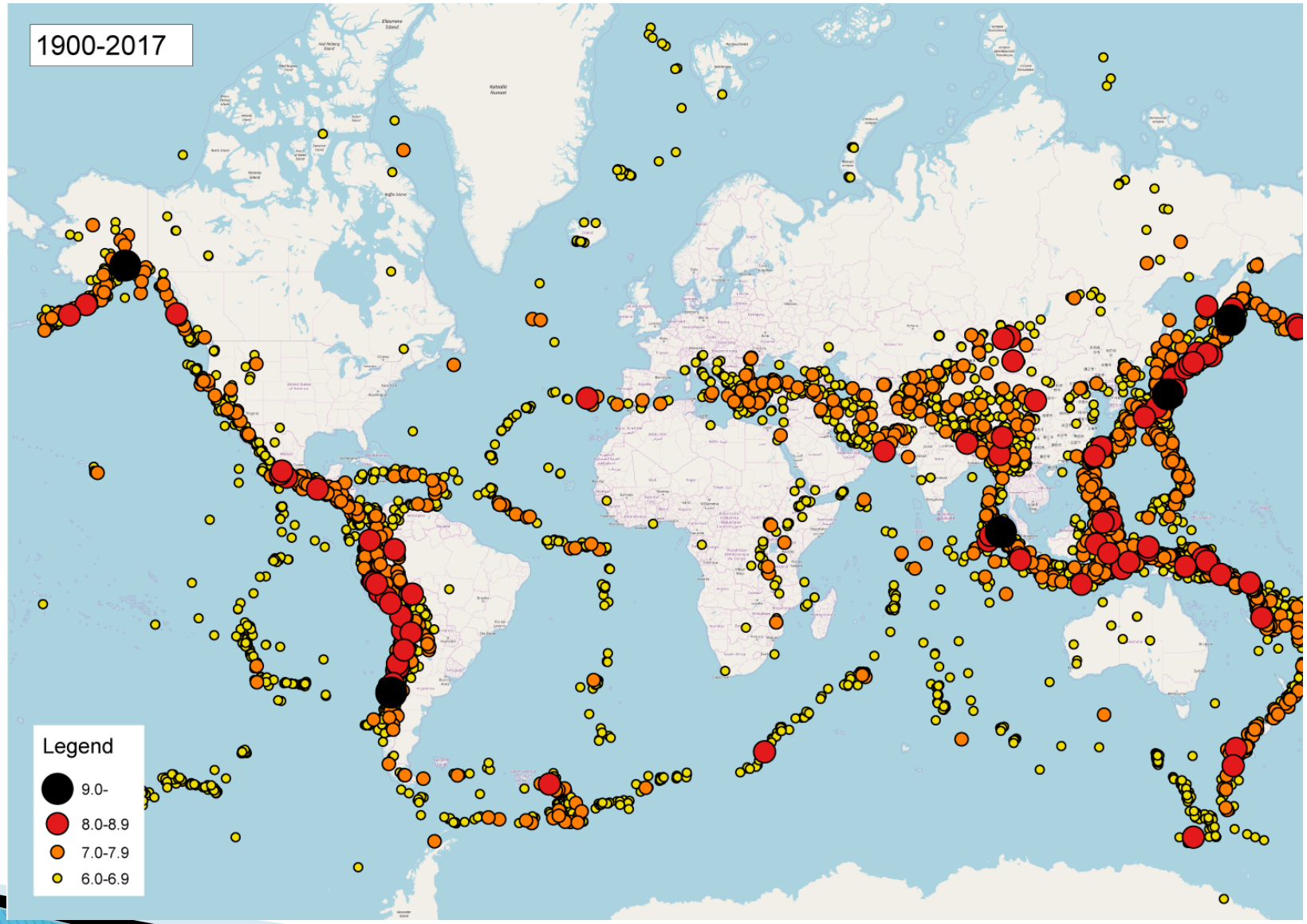
Seismic Zone Map of India: -2002

About 59 percent of the land area of India is liable to seismic hazard damage

Zone	Intensity
Zone V	Very High Risk Zone Area liable to shaking Intensity IX (and above)
Zone IV	High Risk Zone Intensity VIII
Zone III	Moderate Risk Zone Intensity VII
Zone II	Low Risk Zone VI (and lower)



Global Distribution of Earthquakes



Global Distribution of Earthquakes

- Earth's major earthquakes occur mainly in belts coinciding with the margins of **tectonic plates.**
- The most important earthquake belt is the **Circum-Pacific Belt**, which affects many populated coastal regions around the Pacific Ocean—for example, those of New Zealand, New Guinea, Japan, the Aleutian Islands, Alaska, and the western coasts of North and South America.
- Because at many places the Circum-Pacific Belt is associated with volcanic activity, it has been popularly dubbed the "**Pacific Ring of Fire**."
- **The Pacific Ring of Fire accounts for about 68 per cent of all earthquakes.**
- A second belt, known as the **Alpine Belt (Himalayas and Alps).** The energy released in earthquakes from this belt is about 15 per cent of the world total.
- The **mid-world mountain belt (Alpine Belt)** extends parallel to the equator from Mexico across the Atlantic Ocean, the Mediterranean Sea from Alpine-Caucasus ranges to the Caspian, Himalayan mountains and the adjoining lands.
- There also are striking connected belts of seismic activity, mainly along oceanic ridges—including those in the Arctic Ocean, the Atlantic Ocean, and the western Indian Ocean—and along the **rift valleys of East Africa.**