# *Fundamentals of Earth Sciences (ESO 213A)*


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***Earthquakes***

***Previous Class: Stereonet problems***

# The most common question that is asked?

- Can earthquake be predicted?
- Will more earthquakes be felt after a strong earthquake? [aftershock]
- Can we generate an earthquake?
- Does a foreshock indicate a large earthquake?

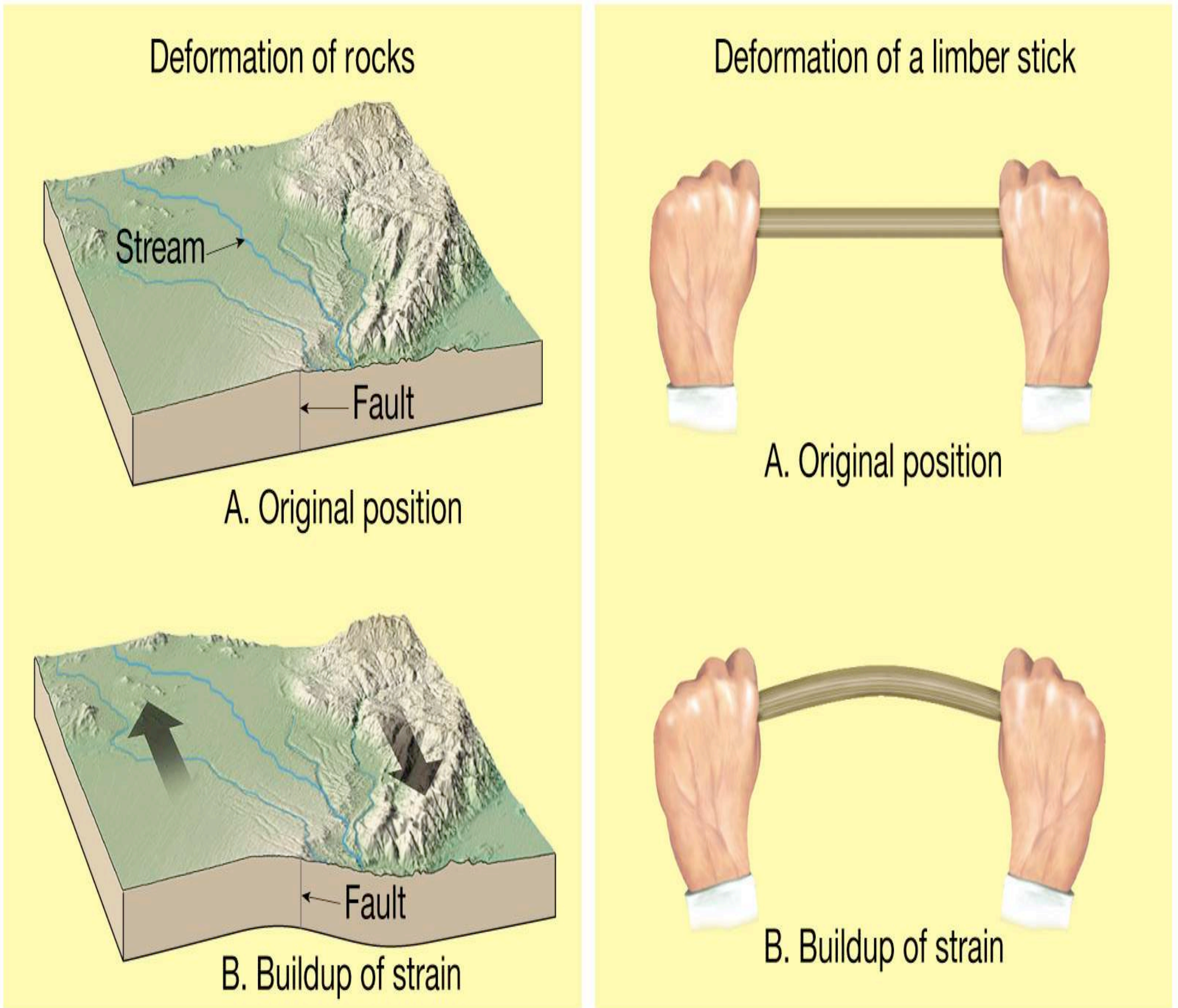
# *What Is an Earthquake?*

- An earthquake is the vibration of Earth, produced by the rapid release of energy.
    - Energy released radiates in all directions from its source, the focus or hypocenter.
    - Energy is in the form of waves.
    - Sensitive instruments around the world record the event.

# *How do earthquakes occur?*

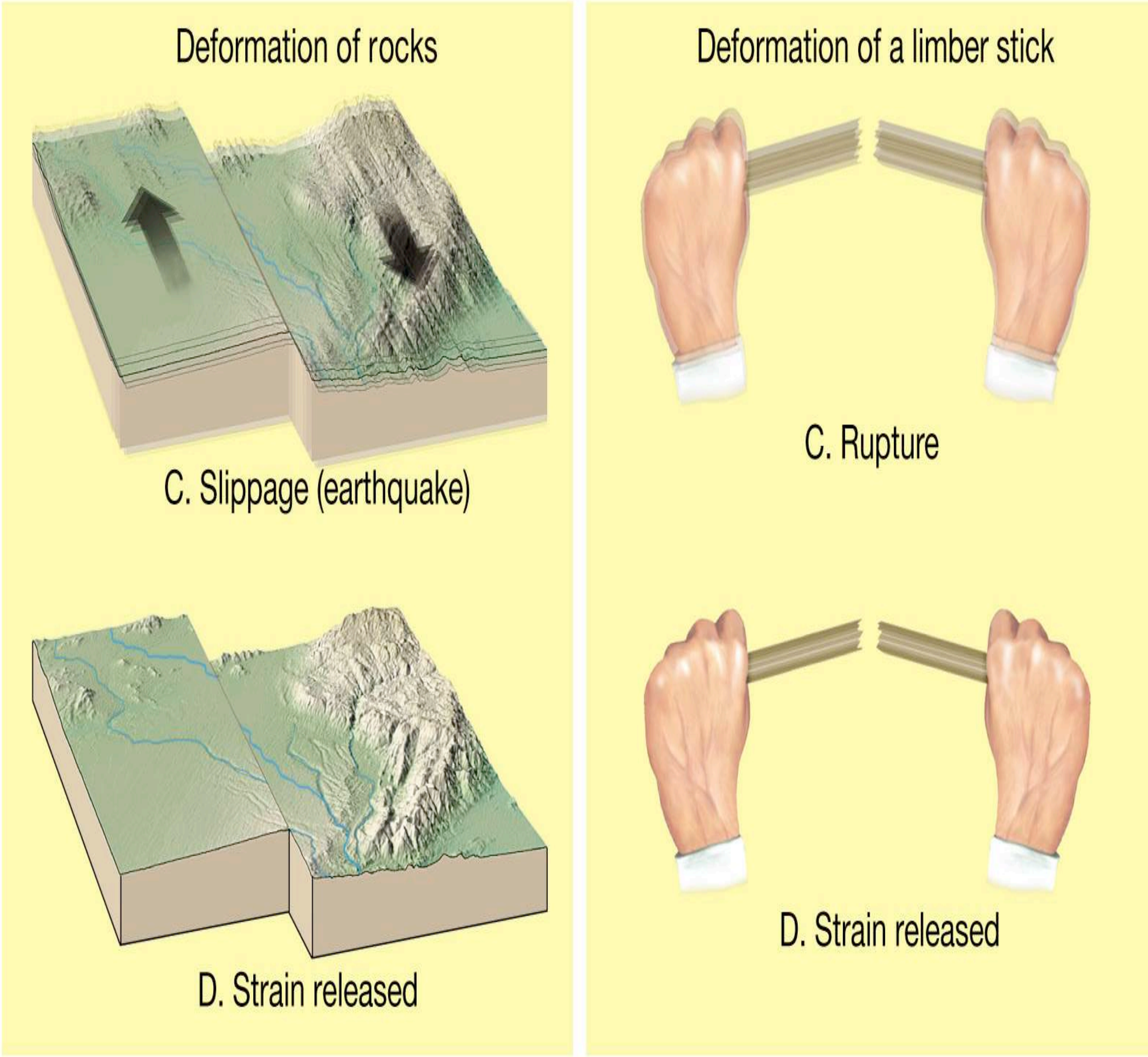
- Stresses build up in the crust, usually due to lithospheric plate motions

- Rock deform (strain) as the result of stress. The strain is energy stored in the rocks.



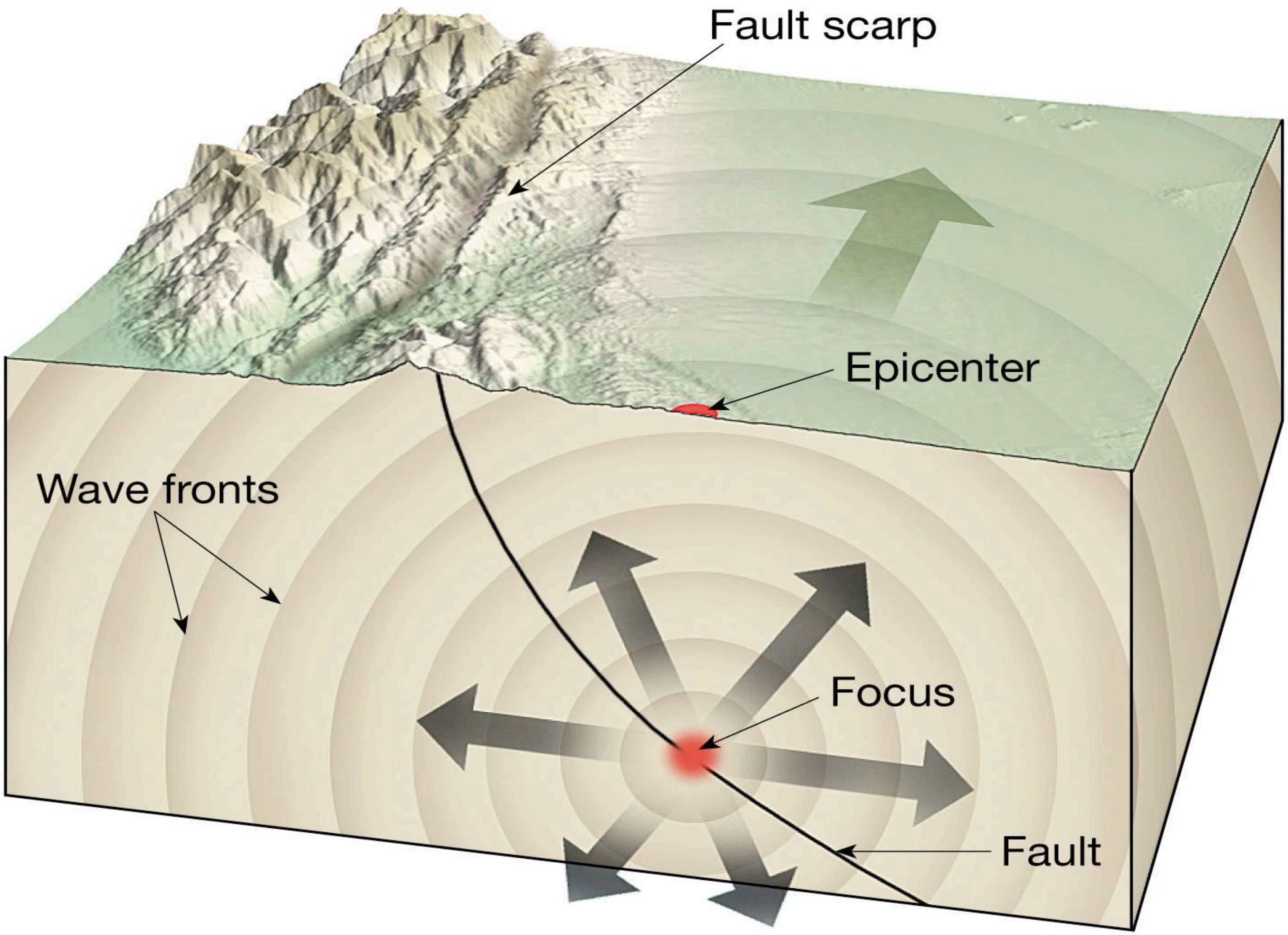
# *How do earthquakes occur?*

- When the rocks reach their elastic limit, they break, and energy is released in the form of seismic waves, radiating out from the earthquake focus
- The rocks return to their original shape, with a displacement (slip) along the fault



***Earthquake focus***: center of rupture or slip, seismic waves radiate out from the *focus*

*Earthquake* ***epicenter*** – the point on the Earth's surface over the focus

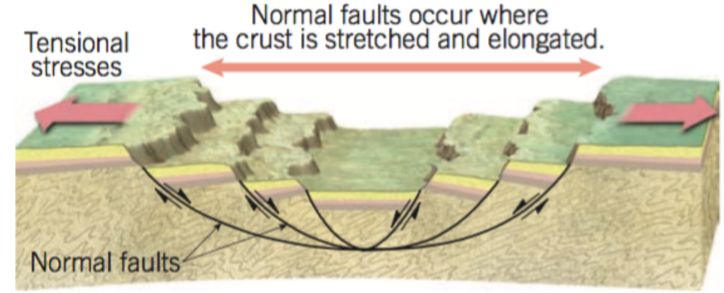


# Foreshocks and aftershocks

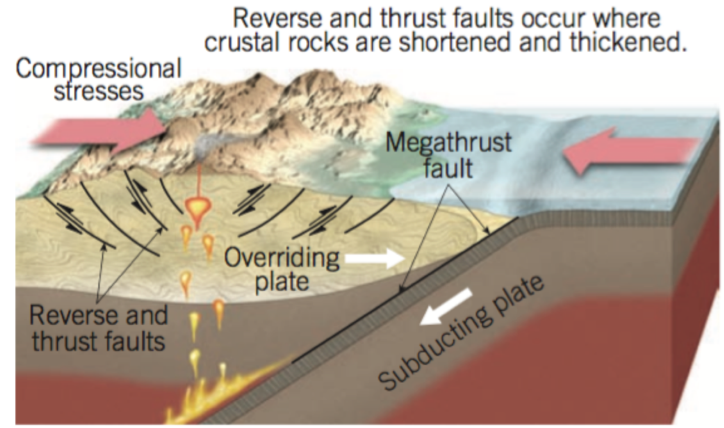
- **Foreshocks and aftershocks**
  - **Adjustments that follow a major earthquake often generate smaller earthquakes called aftershocks.**
  - **Small earthquakes, called foreshocks, often precede a major earthquake by days or, in some cases, by as much as several years.**

# *Where it occurs?*

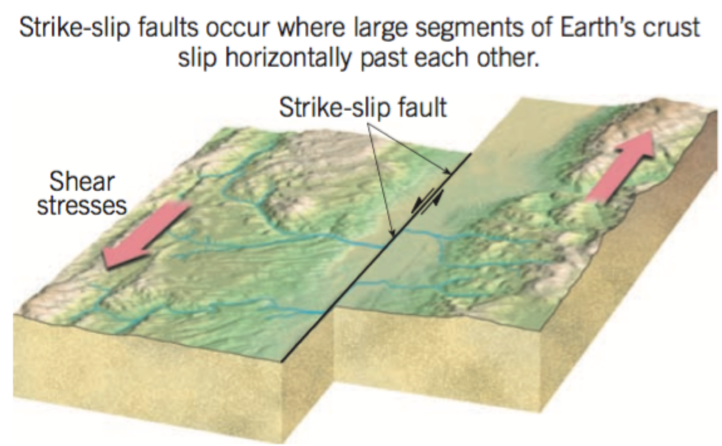
- Faults
  - Movements that produce earthquakes are usually associated with large fractures in Earth's crust called faults.
  - Most of the motion along faults can be explained by the plate tectonics theory.




**A. Normal faults are associated with divergent plate boundaries, mainly seafloor spreading centers and continental rifting.**




**B. Reverse and thrust faults are associated with subduction zones and continental collisions.**

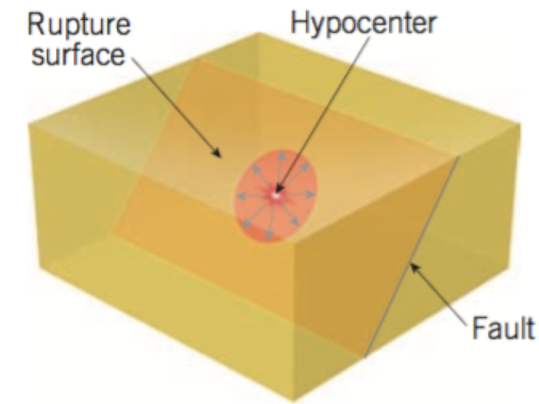



**C. Large strike-slip faults may form transform plate boundaries.**

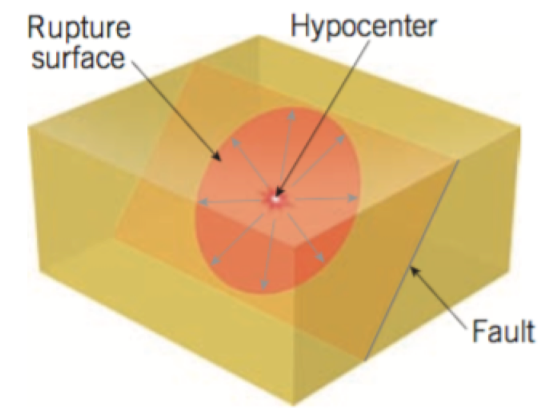
# Fault rupture and propagation

Most faults are locked. Faults do not slip at all once. The initial slip begins at the hypocenter and propagates (travels) along the fault surface, at 2 to 4 kilometers per second.
Slippage on one section of the fault adds stress to the adjacent segment that may also slip. As this zone of slippage advances, it can slow down, speed up, or even jump to a nearby fault segment. Earthquake waves are generated at every point along the fault as that portion of the fault begins to slip.

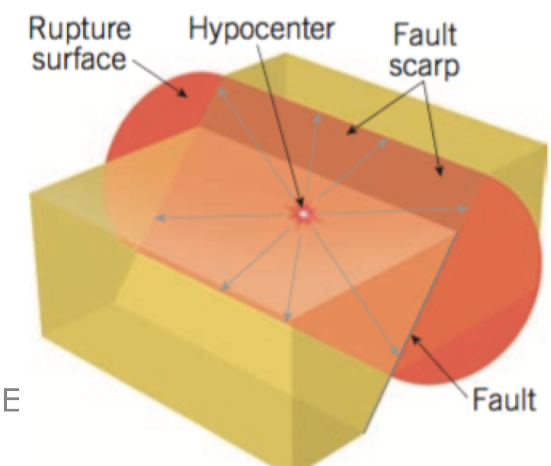
Displacement on the fault surface, called **fault slip**, is typically no more than a few meters. Slippage usually stops when the rupture reaches a section of the fault where the rocks have not been sufficiently strained to overcome frictional resistance, such as in a section of the fault that has recently experienced an earthquake. The rupture may also stop if it encounters a large kink, or an offset along the fault surface.




**During an earthquake the initial slippage begins at the hypocenter.**



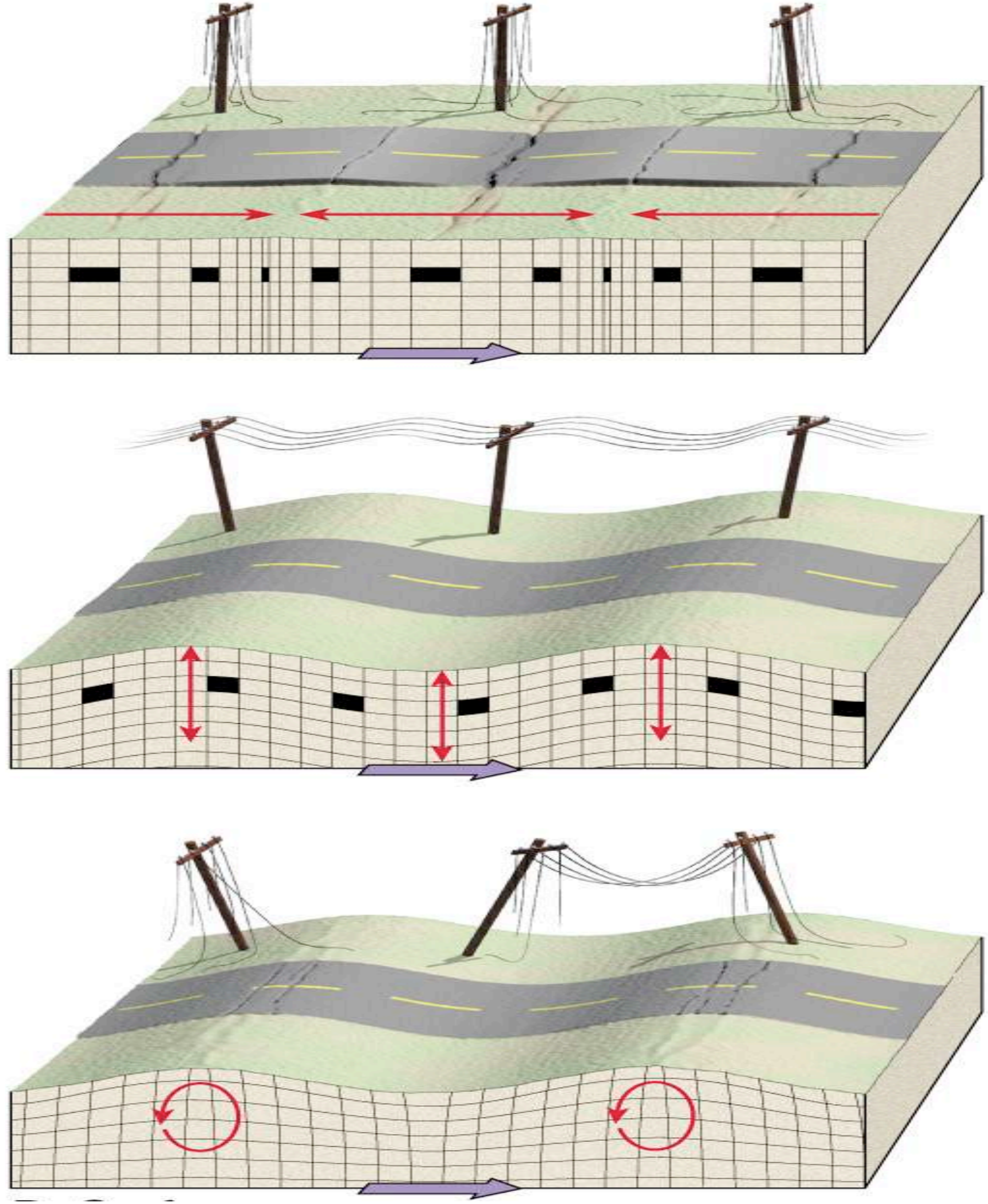

**The rupture surface propagates (travels) along the fault surface, at a rate of 2 to 3 kilometers per second.**



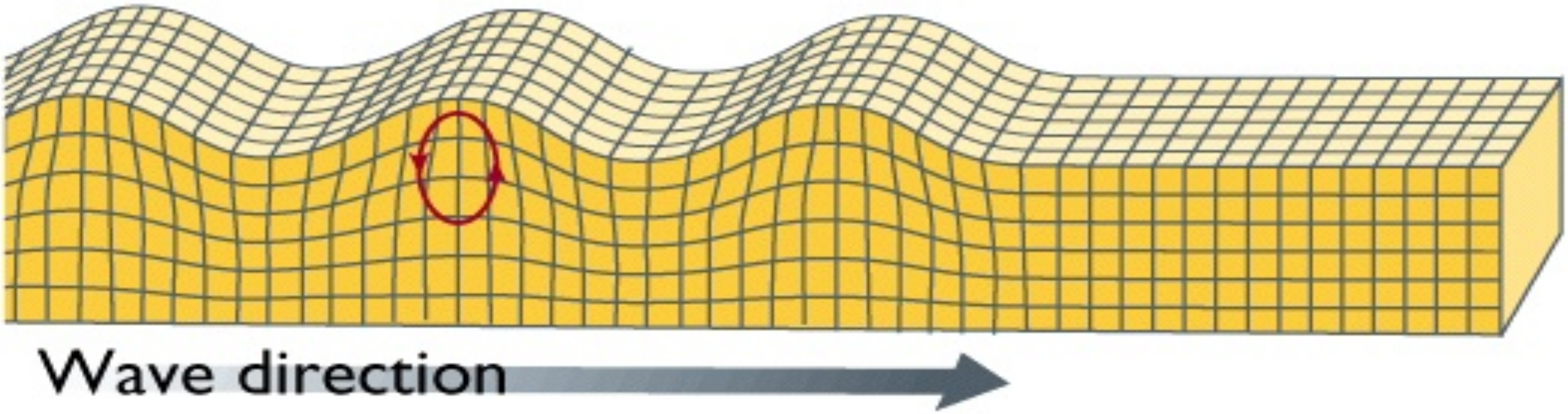

**The rupture surface continues to grow until it reaches a section of the fault where the rocks have not been sufficiently strained to rupture.**

# Kind of seismic waves

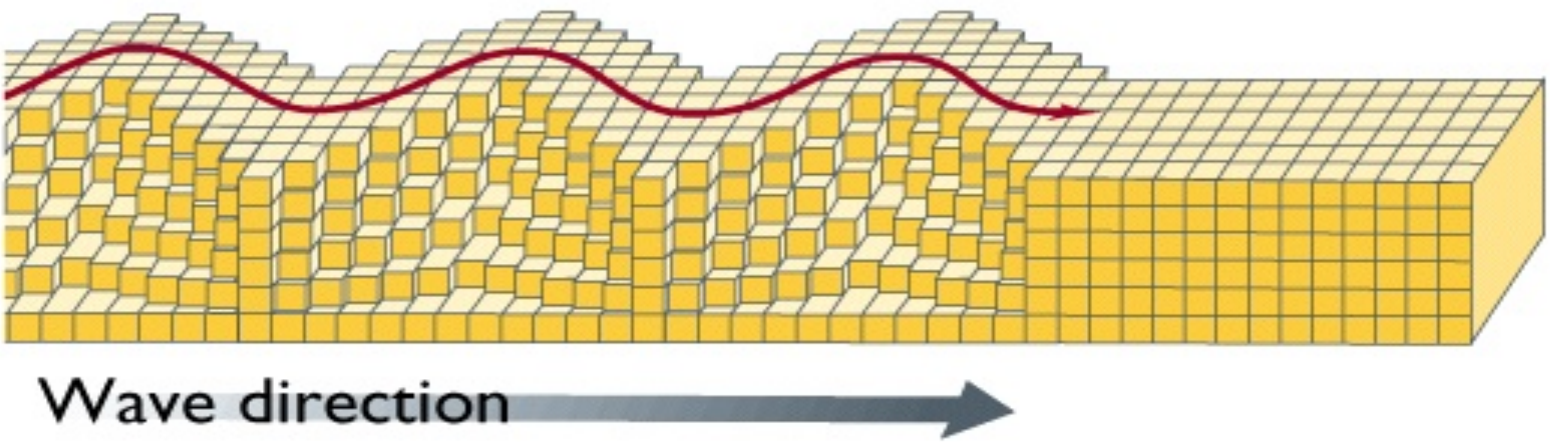
- **P-waves** – most rapid (8 km/sec)
- **S-waves** – slower (5 km/sec), cannot move through liquids
- **Surface waves** – even slower, move only on surface, most destructive



# Surface waves




(a)

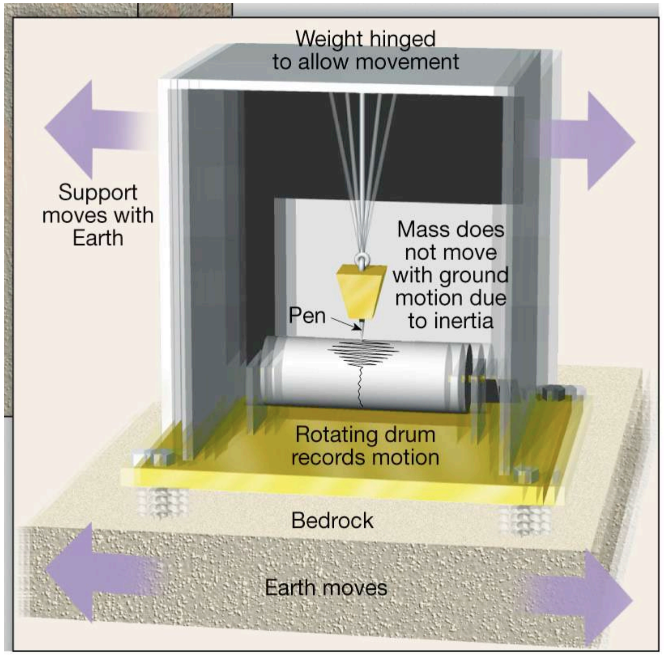



(b)

# Seismology

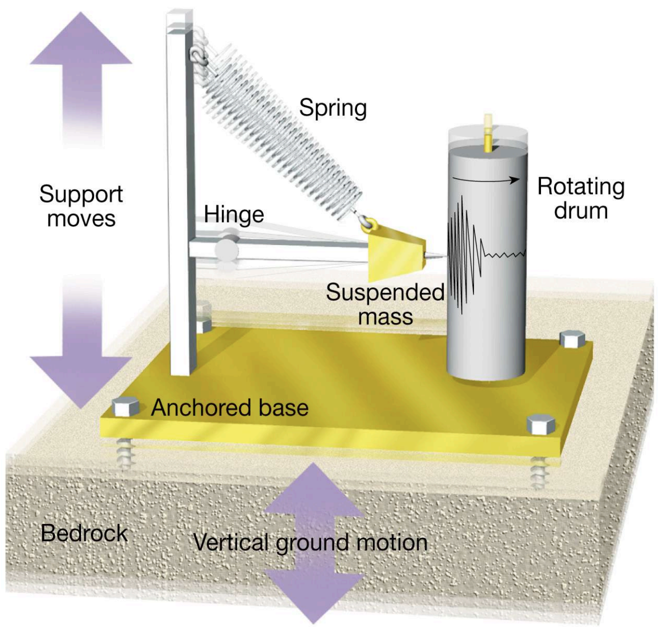
- The study of earthquake waves, seismology.
- Seismographs are instruments that record seismic waves.
  - Records the movement of Earth in relation to a stationary mass on a rotating drum or magnetic tape
  - More than one type of seismograph is needed to record both vertical and horizontal ground motion.
  - Records obtained are called seismograms.

# Detecting and measuring seismic waves




*Seismometers*:

- The paper roll moves with the ground
- The pen remains stationary, because of the spring, hinge and weight

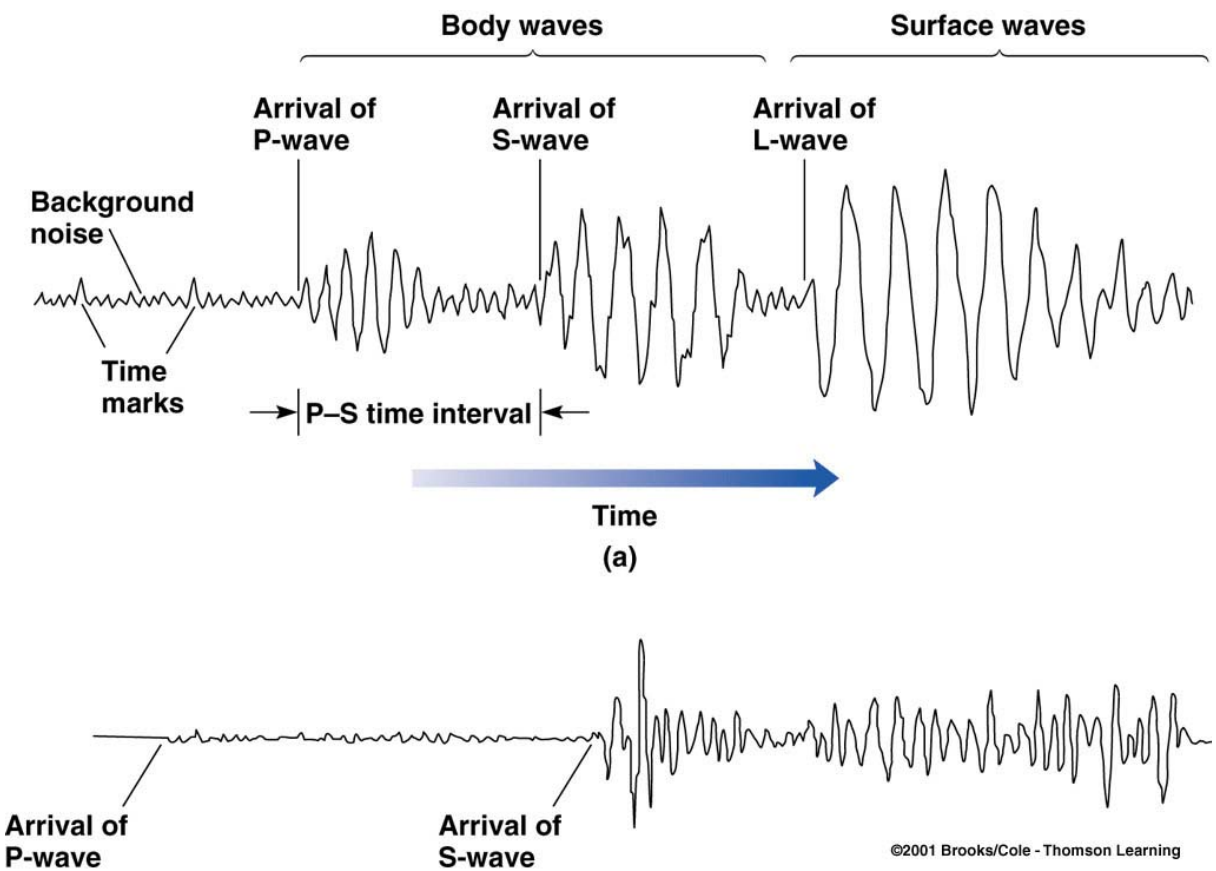




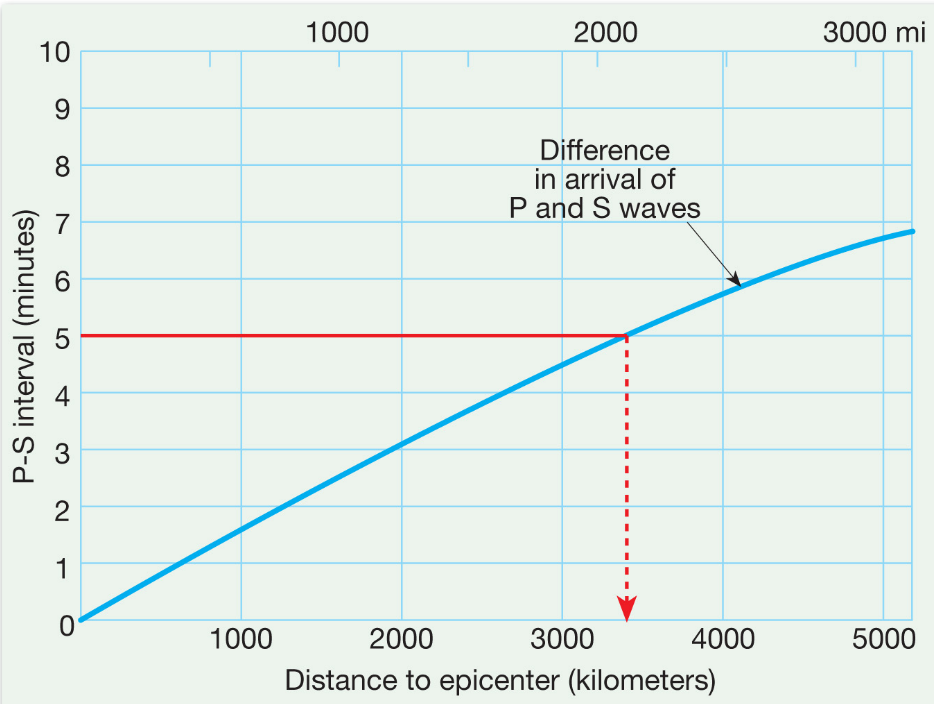

# Earthquake Seismic Waves

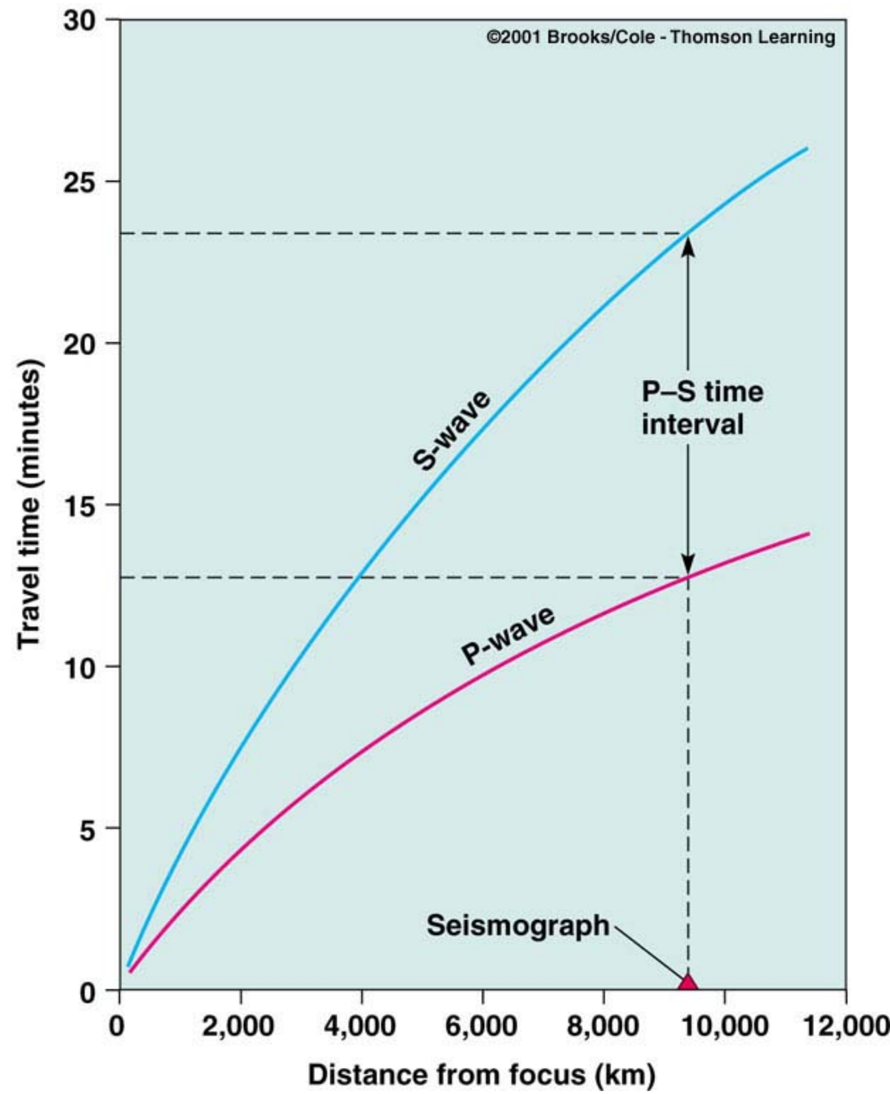
## Seismic wave behavior

- P waves arrive first, then S waves, then surface waves
- Average speeds for all these waves is known
- After an earthquake, the difference in arrival times at a seismograph station can be used to calculate the distance from the seismograph to the epicenter.

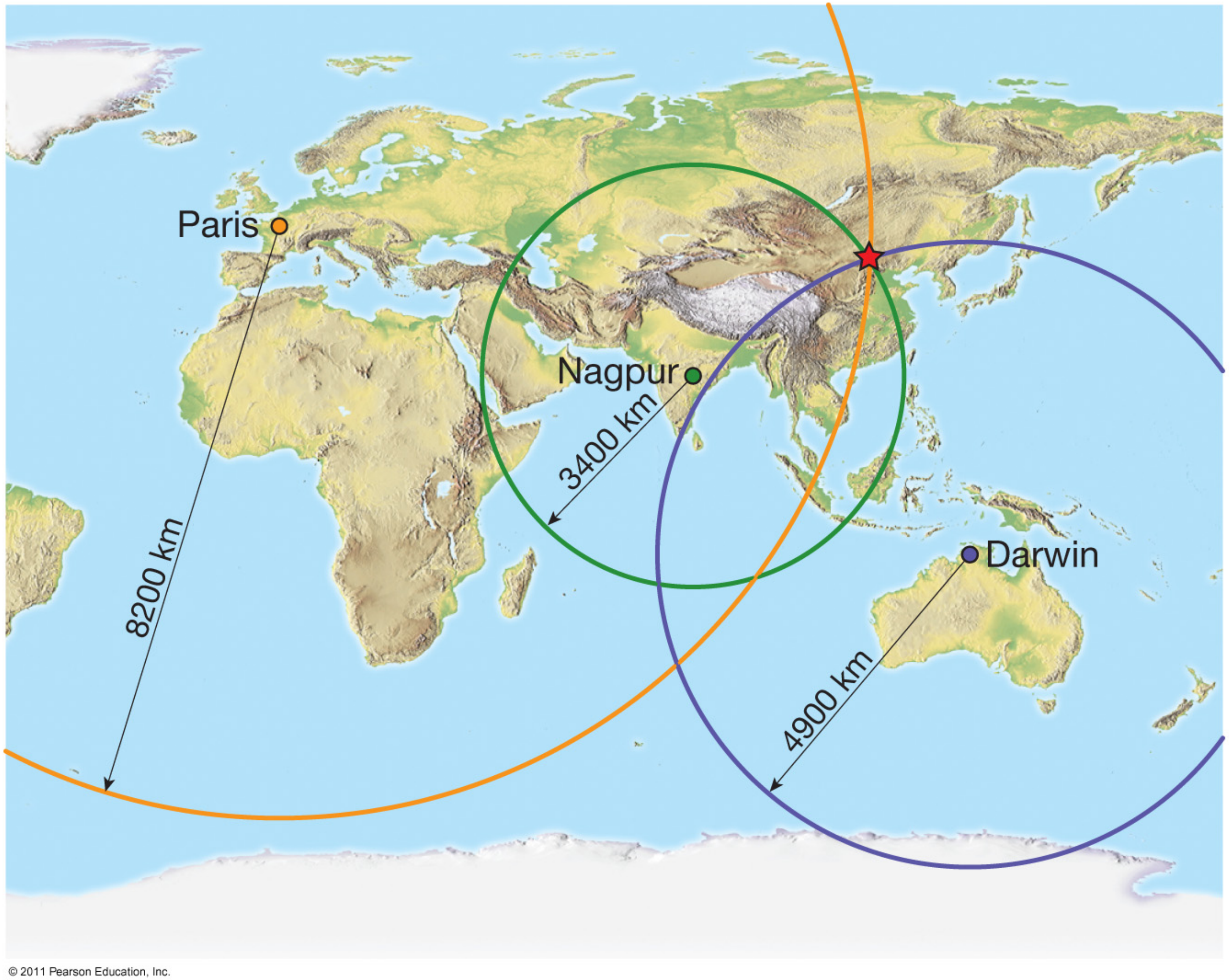


# A Travel-Time Graph



# Finding an Earthquake Epicenter



# *Locating the Source of Earthquakes*

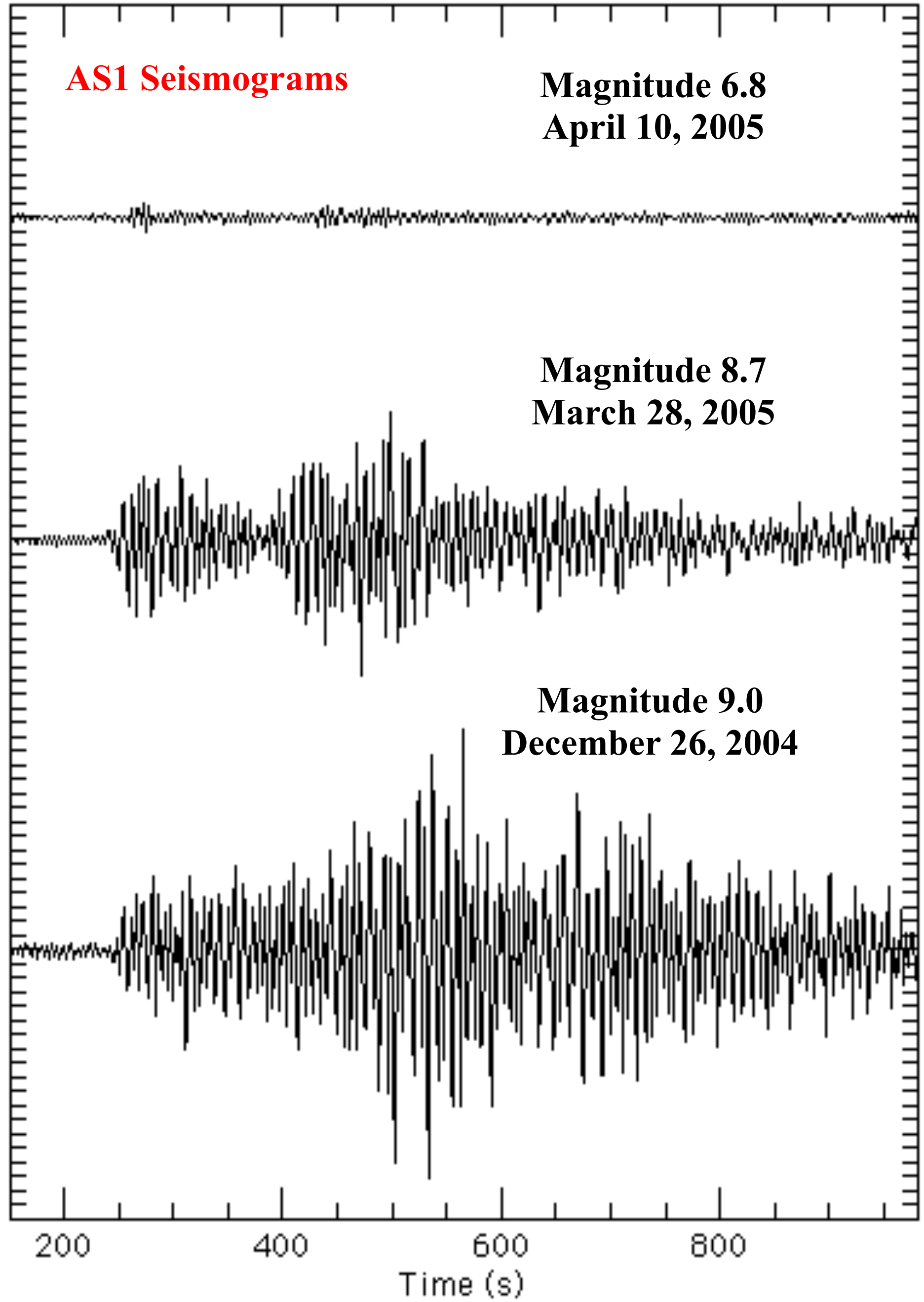
- The epicenter is located using the difference in velocities of P and S waves.
- Locating the epicenter of an earthquake
  - Three station recordings are needed to locate an epicenter.
  - Each station determines the time interval between the arrival of the first P wave and the first S wave at their location.
  - A travel-time graph is used to determine each station's distance to the epicenter.
  - A circle with a radius equal to the distance to the epicenter is drawn around each station.
  - The point where all three circles intersect is the earthquake epicenter.

Example:

**Same Distance, Different Magnitudes**

**Three Sumatra Earthquakes Recorded at Weston Observatory Boston College**

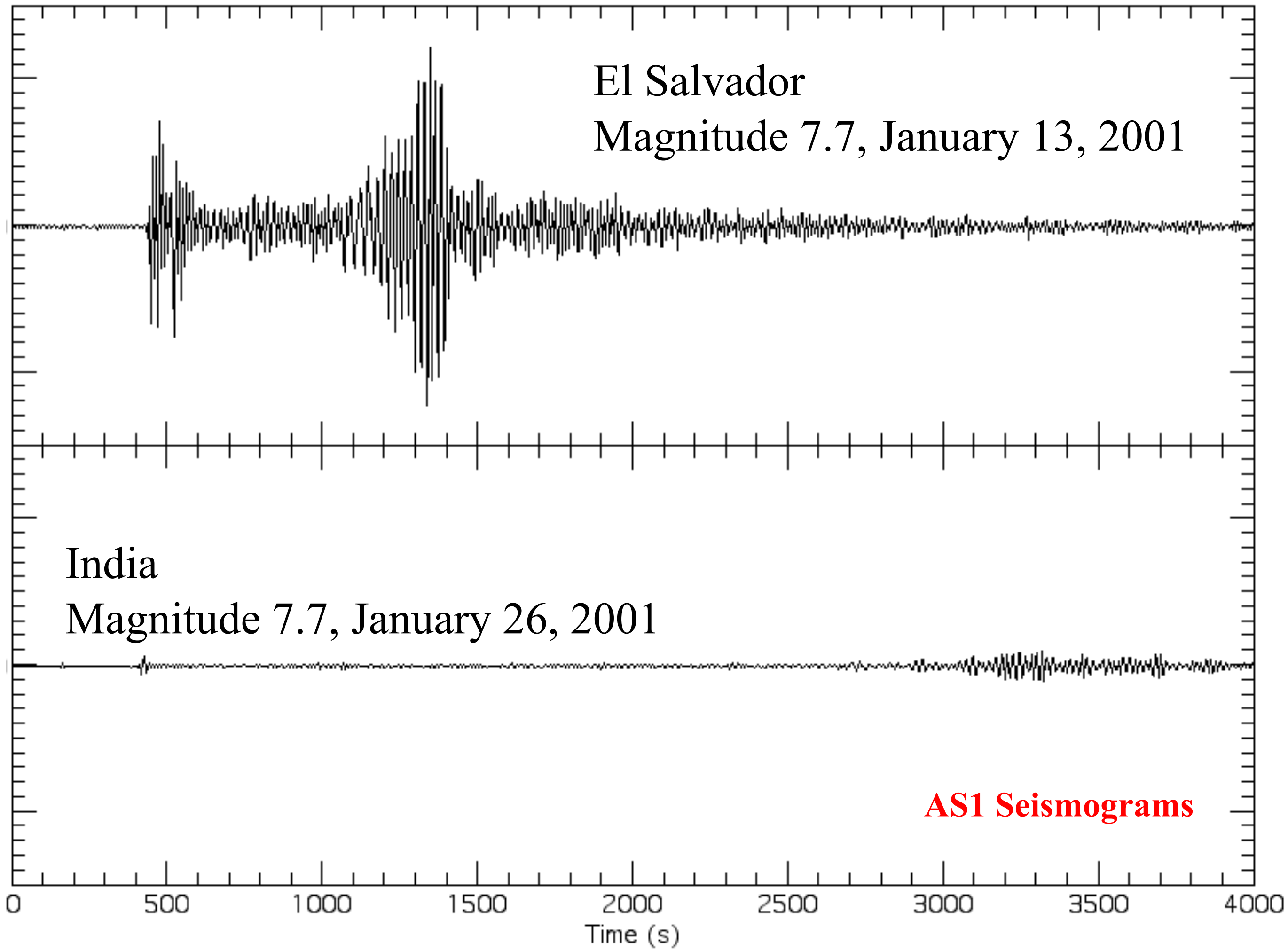
Seismograms are shown on the same scale.



Example:

# Same Earthquake, Different Distances

Seismograms are shown on the same scale.




**El Salvador and India Earthquakes**
**Recorded at Devlin Hall Boston College**

**Figure 3.4-5: Ray path effects for increasing velocity.**

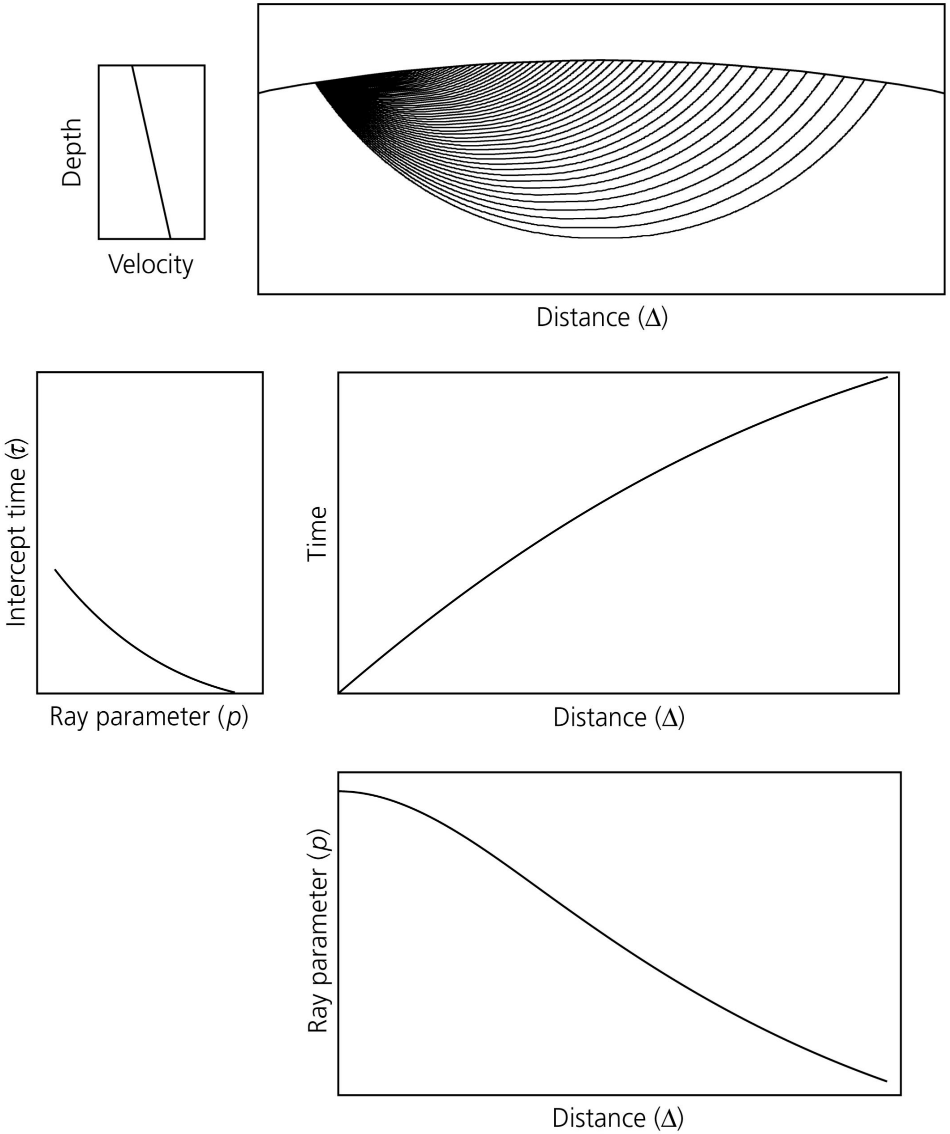



**Figure 3.4-6: Ray path triplication effects for a velocity increase.**

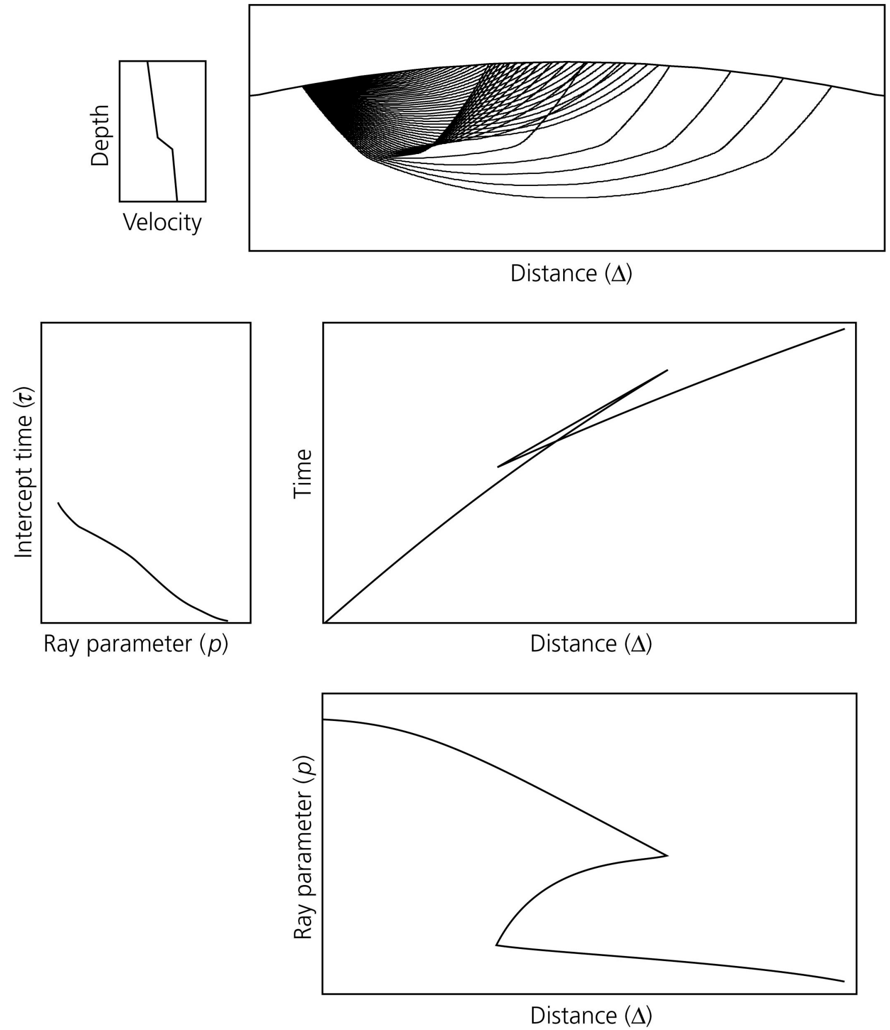


**Figure 3.4-7: Ray path shadow-zone effects for a velocity decrease.**

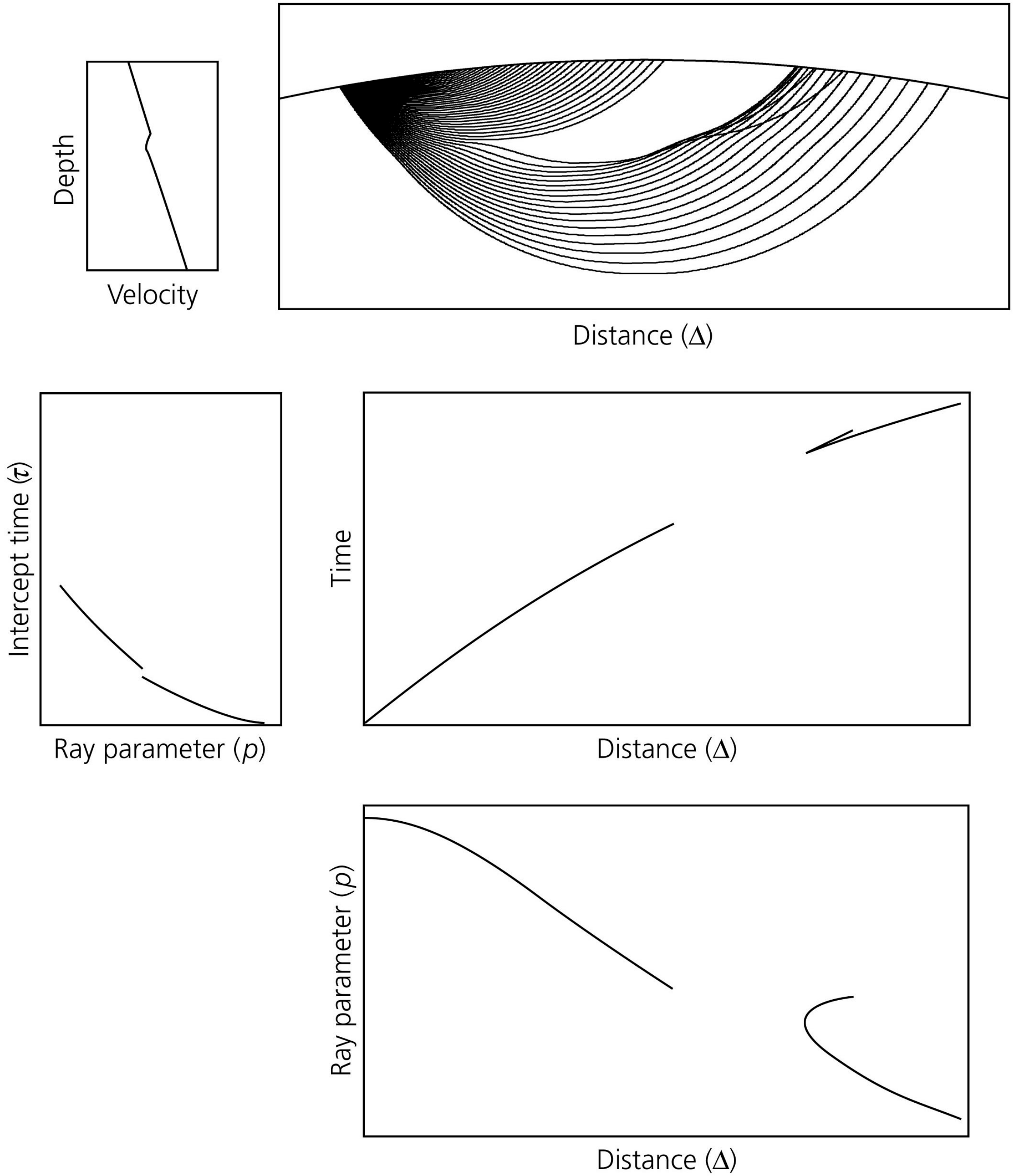


**Figure 3.5-5: Illustration of various body wave phases.**

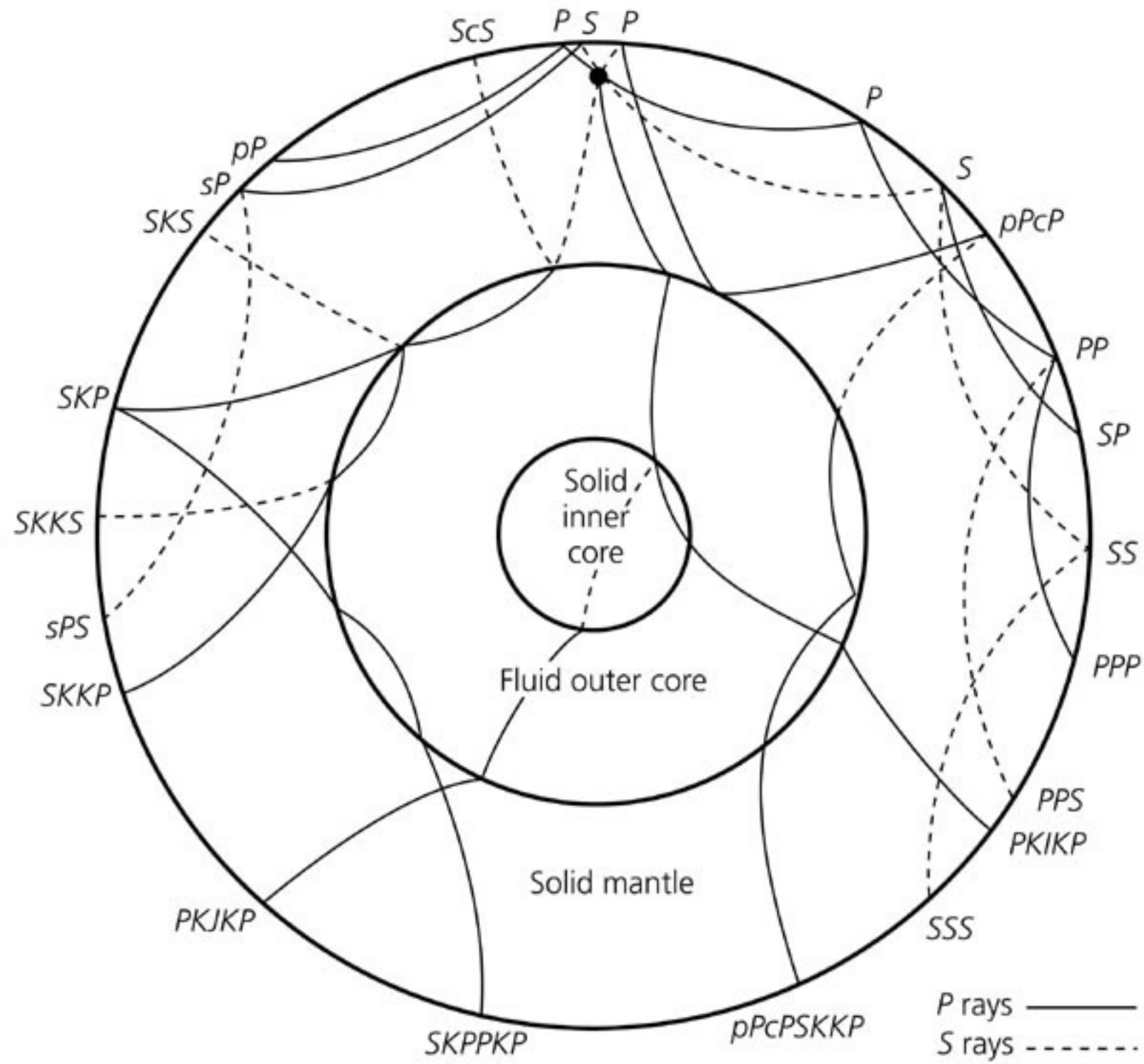


**Table 3.5-2: Body wave phase nomenclature**

| Name | Description |
|---|---|
| *P* | Compressional wave |
| *S* | Shear wave |
| *K* | *P* wave through outer core |
| *I* | *P* wave through inner core |
| *J* | *S* wave through inner core |
| *PP* | *P* wave reflected at surface |
| *PPP* | *P* wave reflected at surface twice |
| *SP* | *S* wave reflected at surface as *P* wave |
| *PS* | *P* wave reflected at surface as *S* wave |
| *pP* | *P* wave upgoing from focus, reflected at surface |
| *sP* | *S* wave upgoing from focus, converted to *P* at surface |
| *c* | Wave reflected at core-mantle boundary (e.g. *ScS*) |
| *i* | Wave reflected at inner core-outer core boundary (e.g. *PKiKP*) |
| P′ | Abbreviation for *PKP* |
| $P_d$ or $P_{diff}$ | *P* wave diffracted along core-mantle boundary |

**Figure 3.5-3: Travel time data and curves for the IASP91 model.**

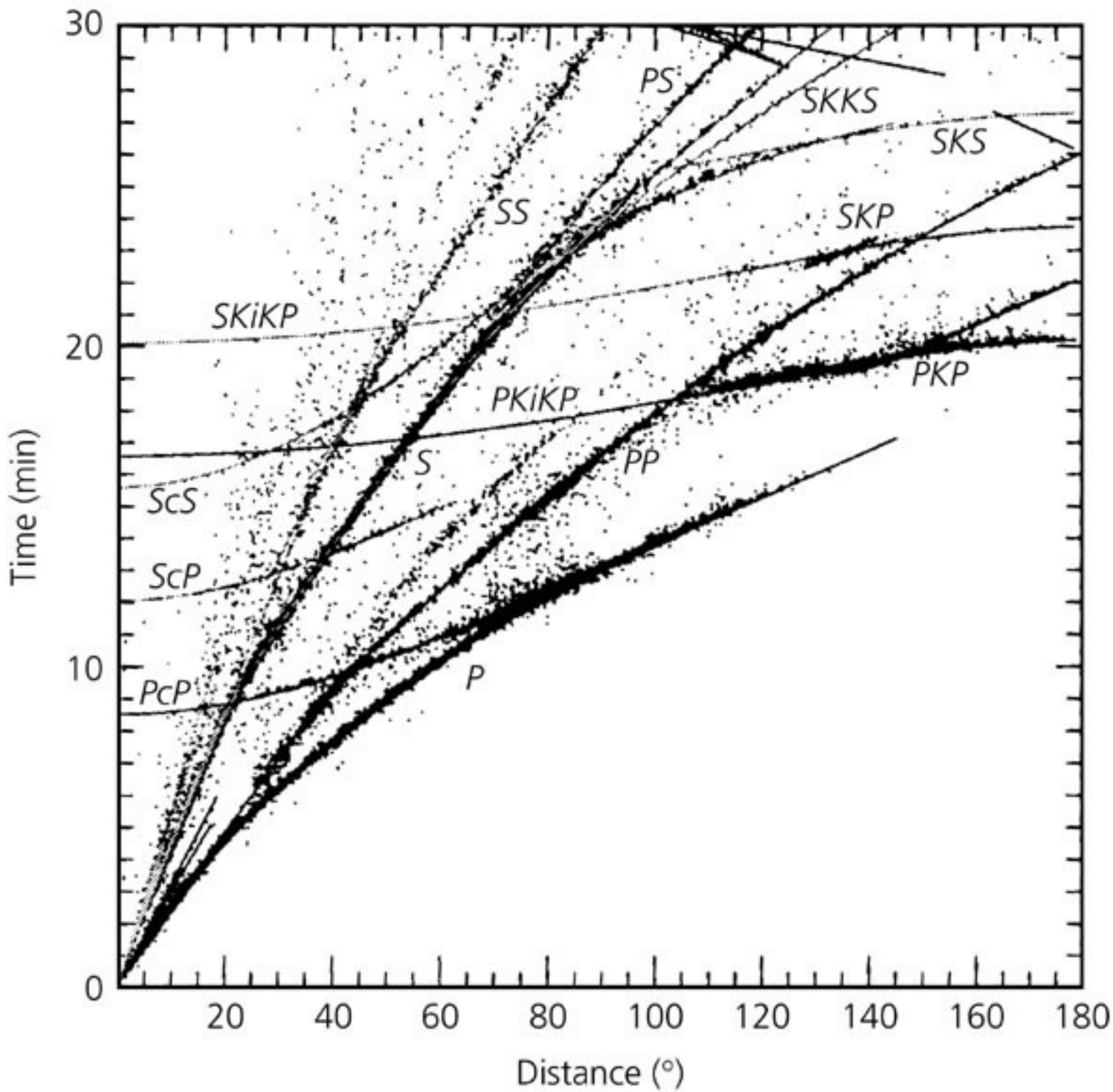


**Figure 3.5-1: Comparison of the J-B and IASP91 earth models.**

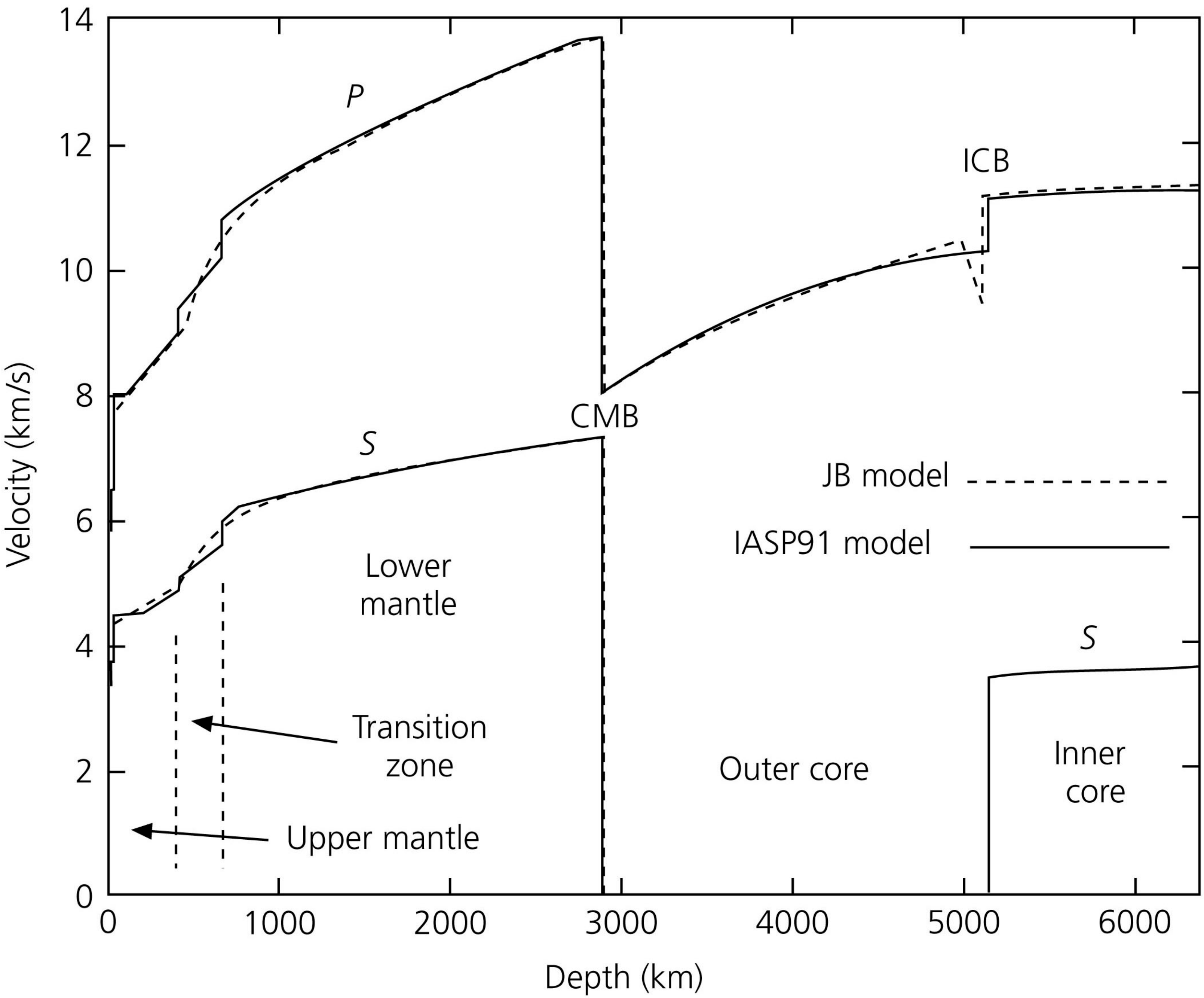


**Table 3.5-1: Regions in Jeffreys-Bullen earth model**

| Region | Depth (km) | Features of region |
|---|---|---|
| A | | Crustal layers |
| | 33 | |
| B | | Upper mantle: steady positive *P* and *S* velocity gradients |
| | 413 | |
| C | | Mantle transition region |
| | 984 | |
| D | | Lower mantle: steady positive *P* and *S* velocity gradients |
| | 2898 | |
| E | | Outer core: steady positive *P* velocity gradient |
| | 4982 | |
| F | | Core transition: negative *P* velocity gradient |
| | 5121 | |
| G | | Inner core: small positive *P* velocity gradient |
| | 6371 | |

After *Bullen and Bolt* [1985]

**Figure 7.3.9: Example of whole-mantle tomography using an inversion of waveforms and travel times.**

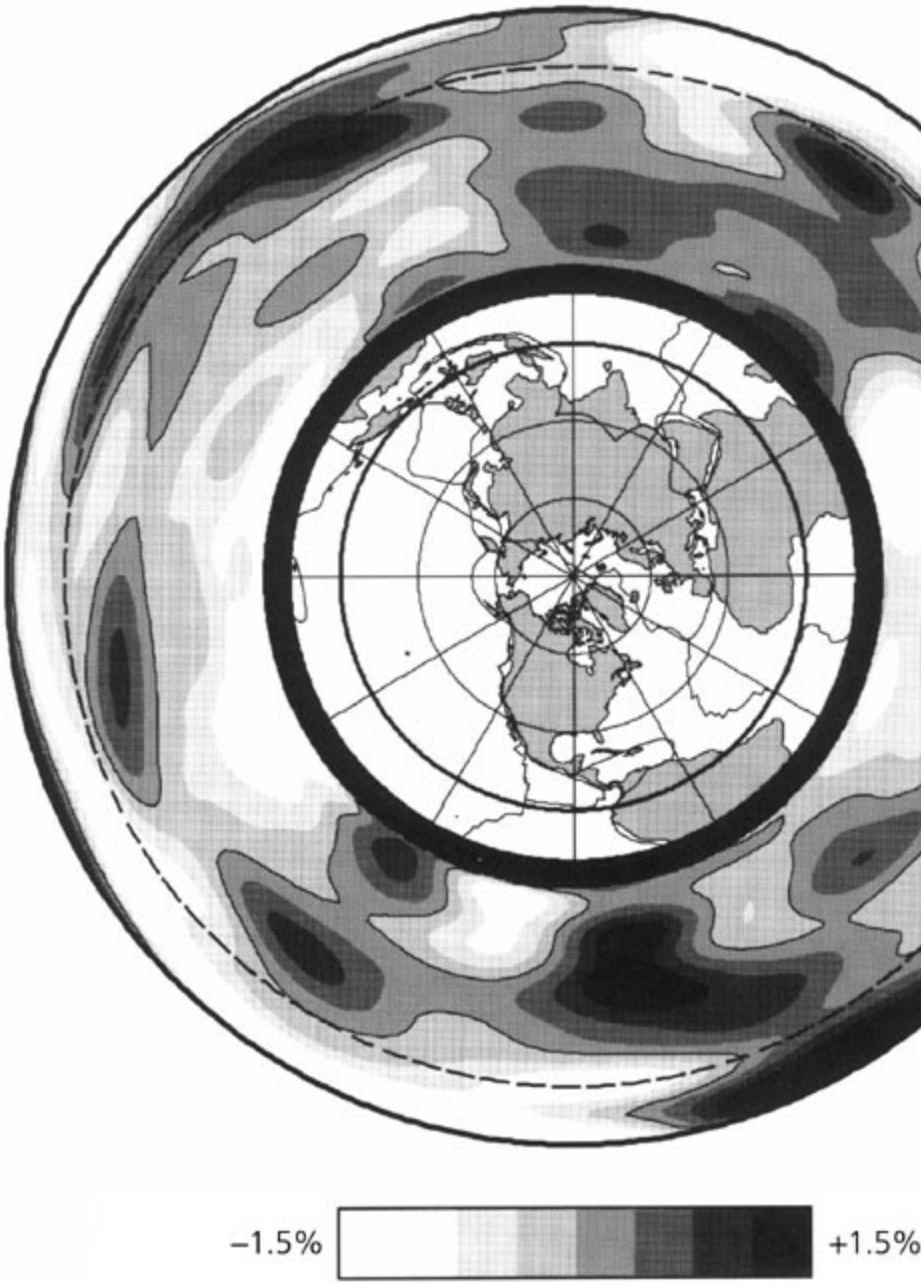


**Figure 2.7-1: Seismograms recorded at a distance of 110°, showing surface waves.**

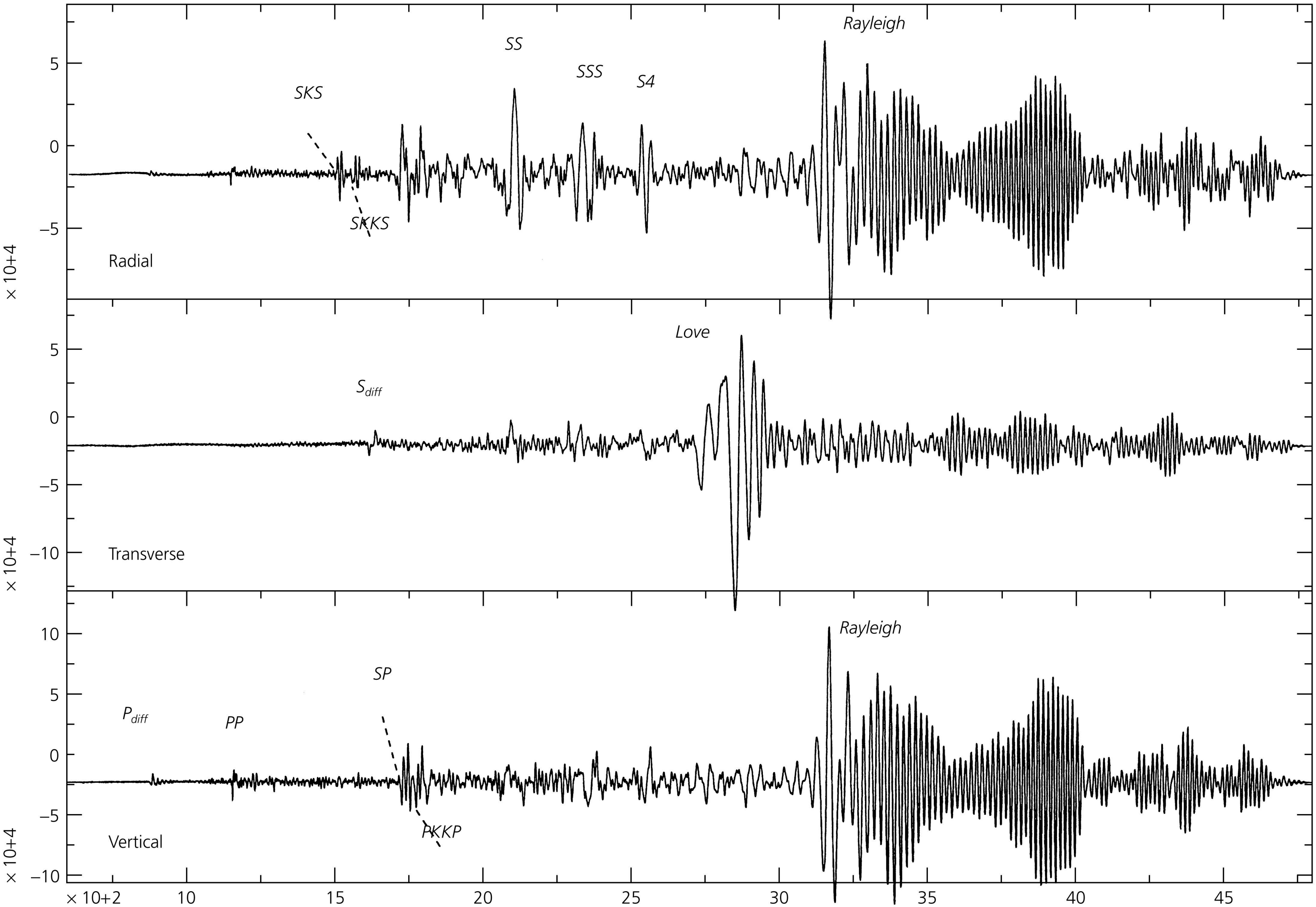


**Figure 2.7-2: Geometry for Love and Rayleigh wave motions.**

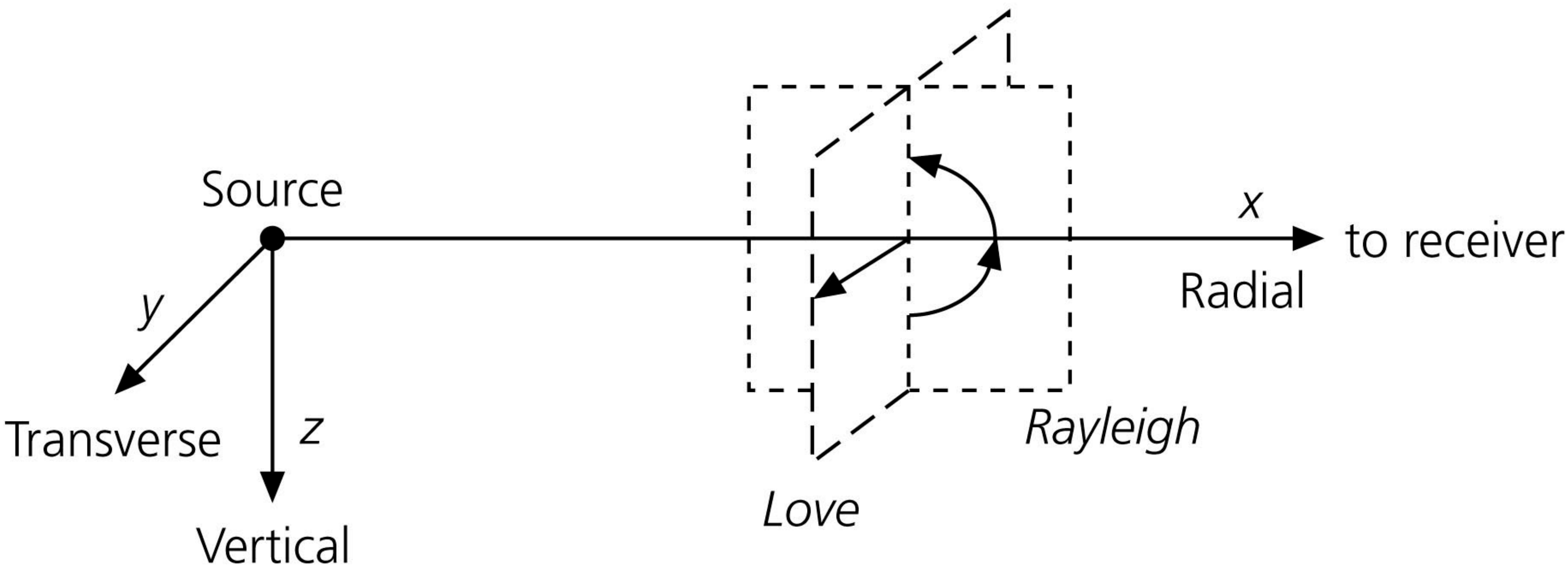


Figure 2.7-3: Multiple surface waves circle the earth.

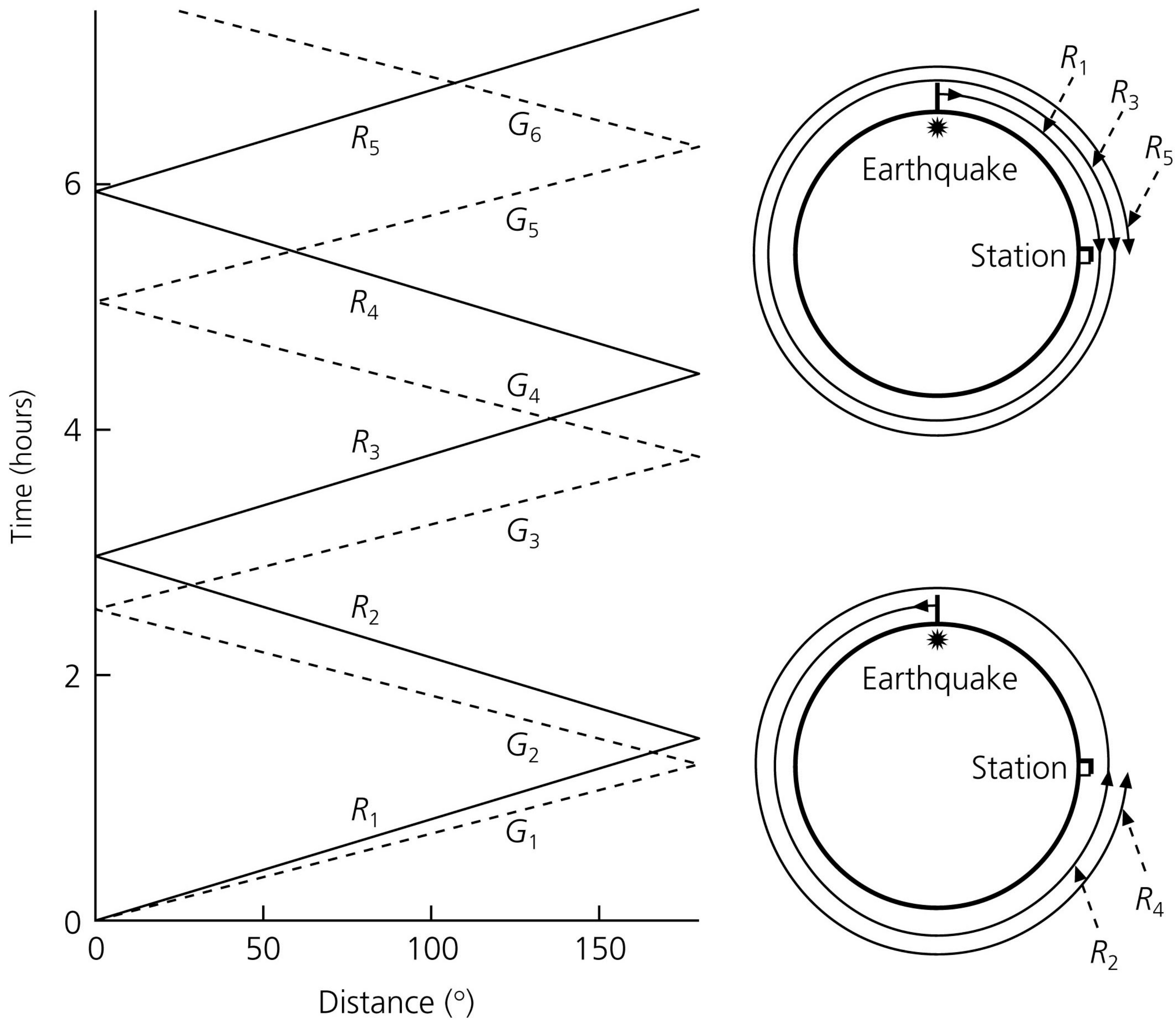


**Figure 2.7-4: Six-hour stacked IDA record section.**

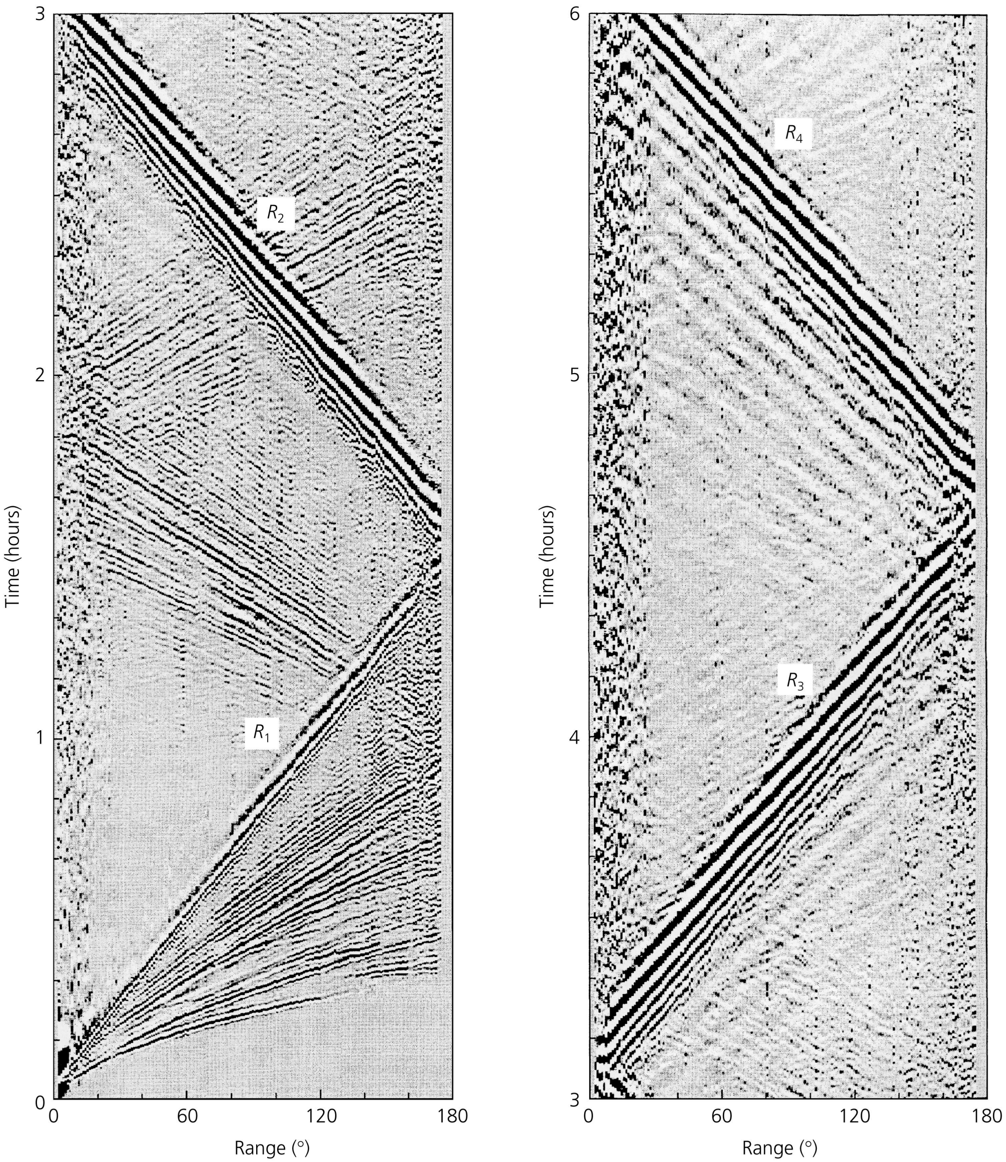



**Figure 2.7-10: Displacements of for Love waves in a layer over a halfspace.**

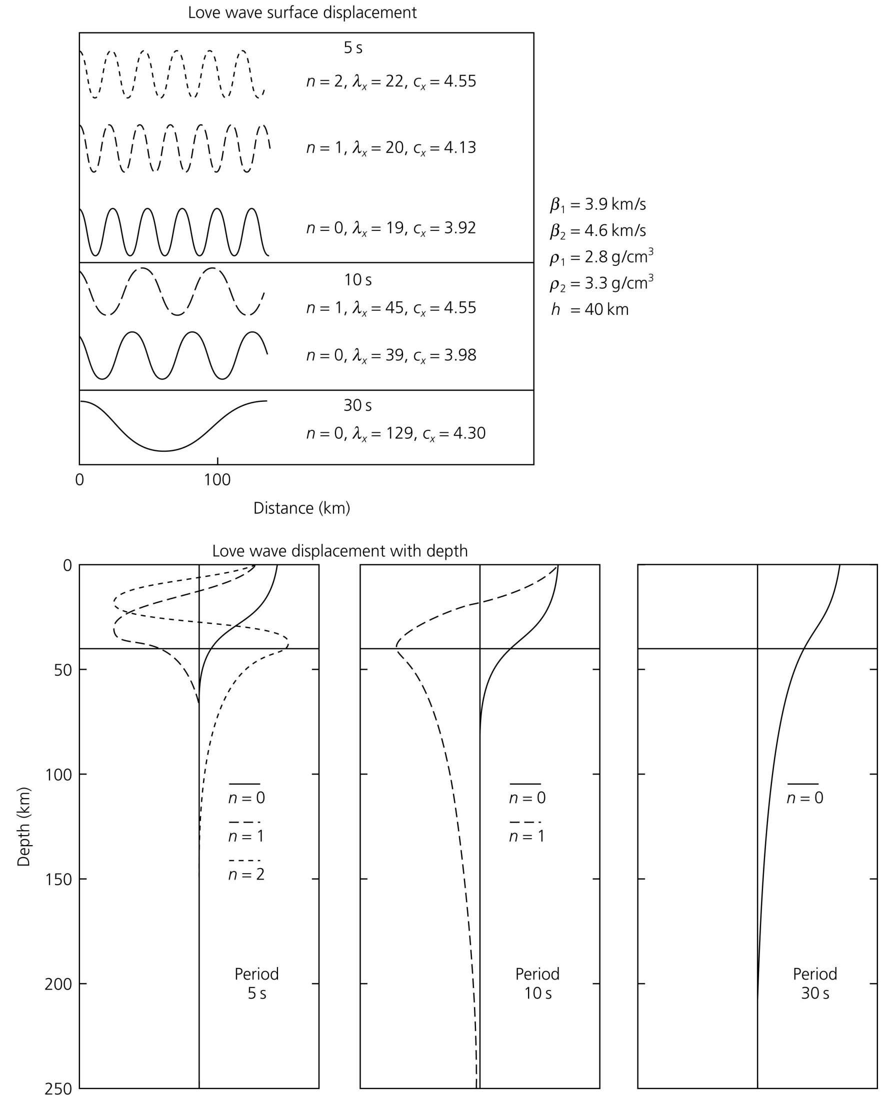


**Figure 2.8-1: Demonstration of group and phase velocities for the sum of two sine waves.**

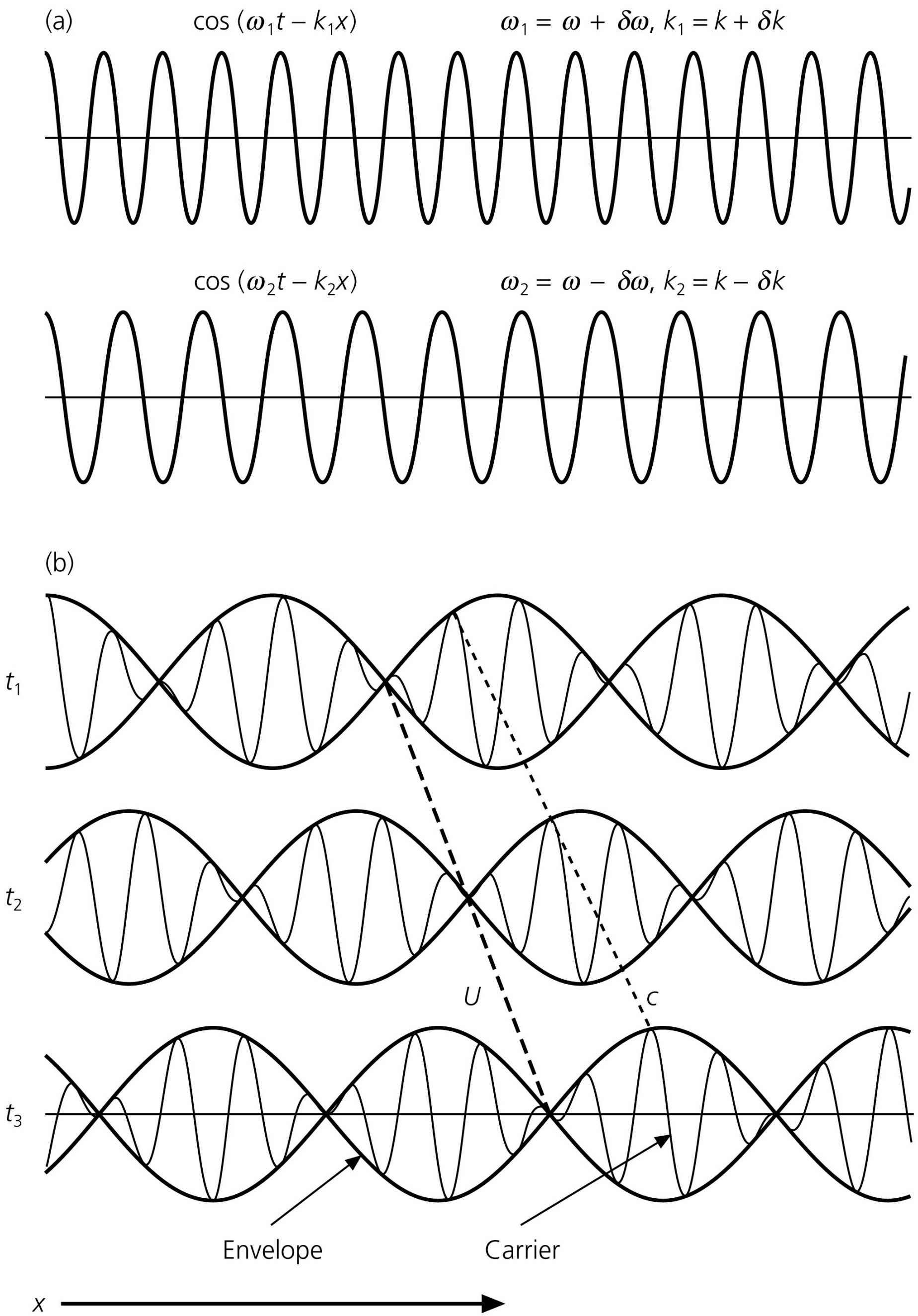
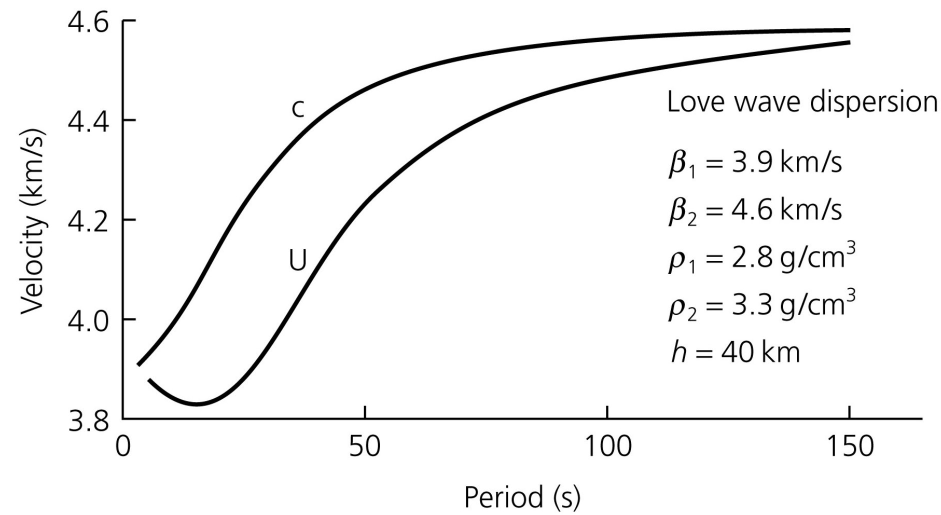



**Figure 2.8-2: Fundamental mode Love wave group and phase velocities.**




$$U = \frac{d\omega}{dk} = \frac{d(ck)}{dk} = c + k\frac{dc}{dk} = c - \lambda\frac{dc}{d\lambda}$$

U=group velocity (envelop)
C=phase velocity (carier)

# Figure 2.8-5: Rayleigh wave group velocity study of the Walvis ridge.