Earthquakes
Chapter 16 In Textbook

What Is An Earthquake?

- **An earthquake is the vibration of Earth produced by the rapid release of energy.**
  - **The energy released radiates out in all directions from its source (i.e. focus).**
  - **The energy is in the form of seismic waves.**

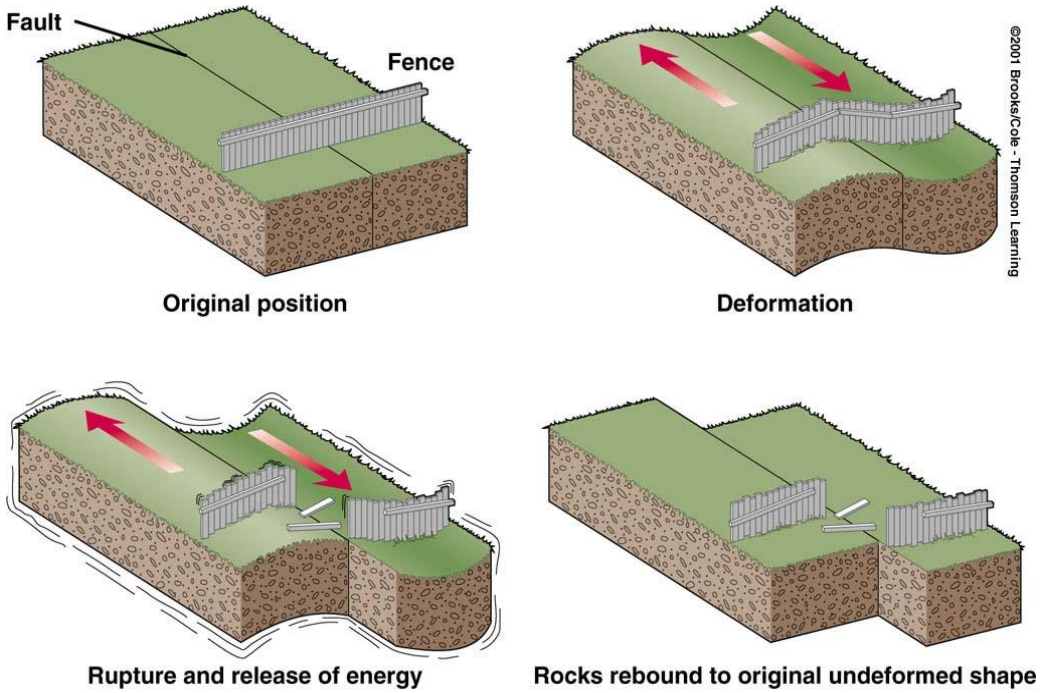
What Causes Earthquakes?

1) **Movement of magma (magma chambers) beneath Earths crust.**
2) **Faulting - rocks break under pressure and stress.**
3) **Elastic rebound – rocks release from being stressed.**

- **Elastic Rebound**
  - **First explained by H.F. Reid.**
  - **Rocks on both sides of an existing fault are deformed by tectonic forces.**
  - **Rocks bend and store elastic energy.**
  - **Frictional resistance holding the rocks together is overcome. The rocks rebound to their unstressed state releasing energy as it occurs.**

What Is The Elastic Rebound Theory?

- The theory explains how energy is stored in rocks.
  - Rocks bend until the strength of the rocks is exceeded.
  - Rupture occurs and the rocks quickly rebound to an undeformed shape.
  - Energy is released in the form of waves that radiate outward from the fault in all directions.



Offset produced by the 1906 San Francisco Earthquake

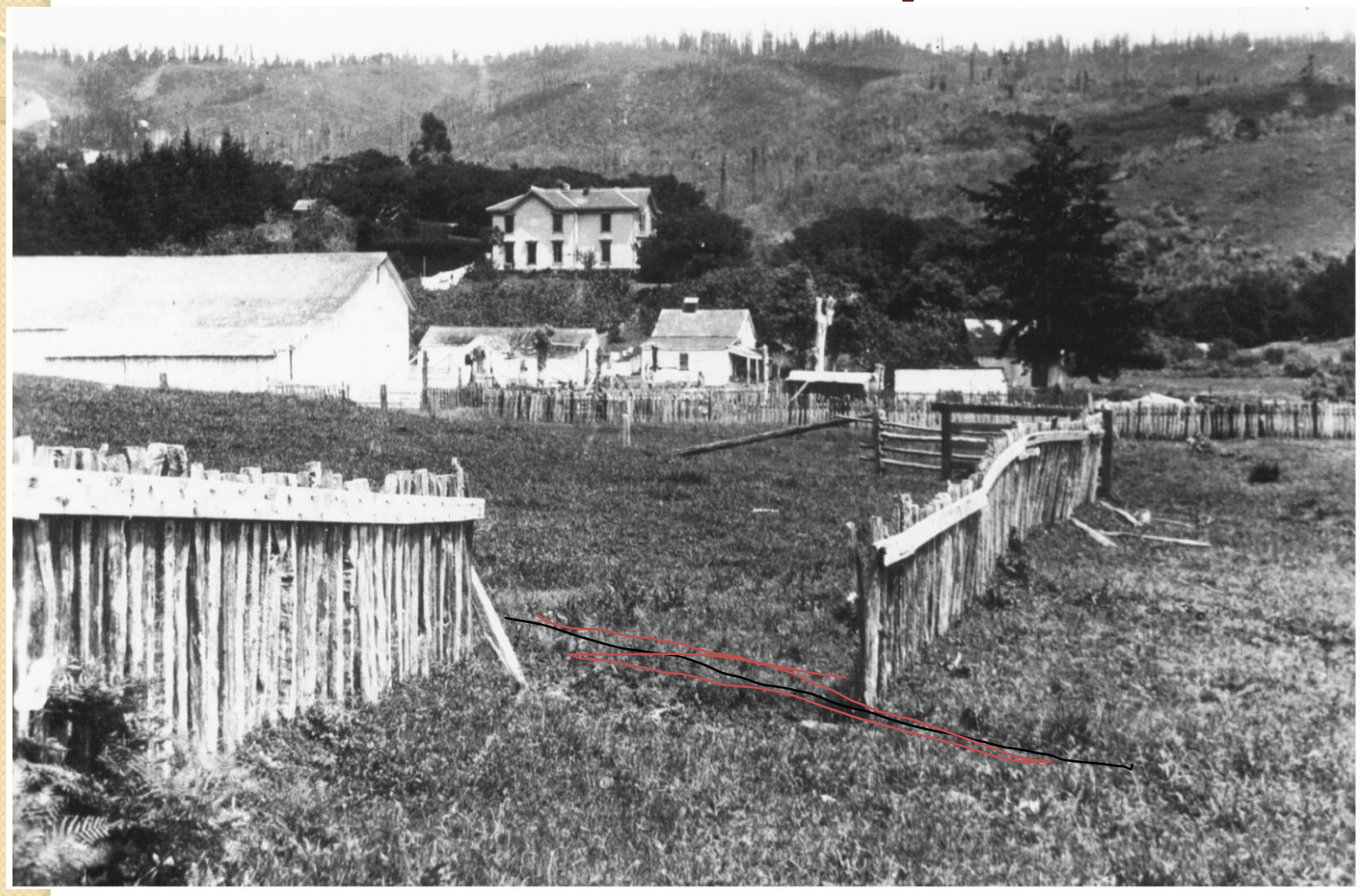
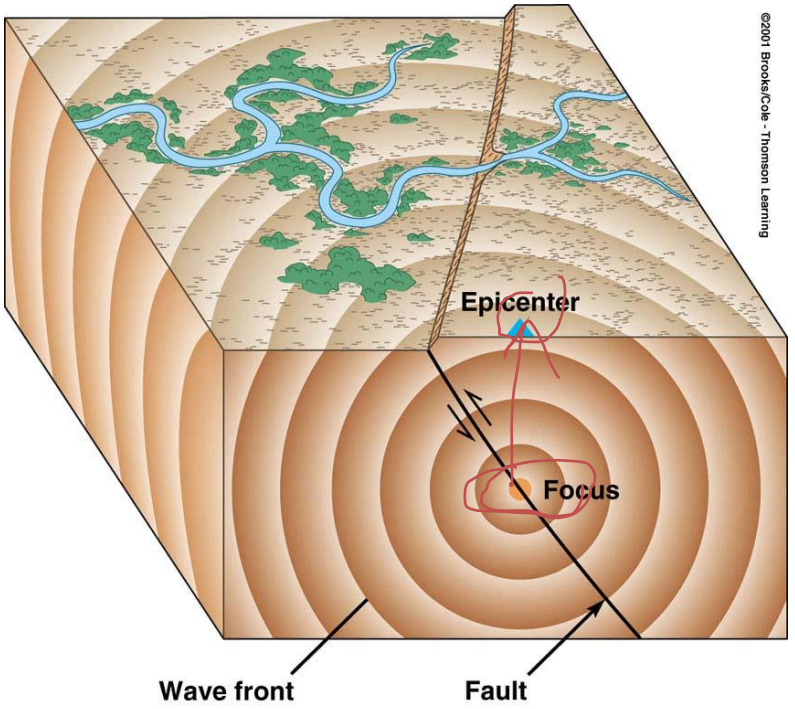


Figure 11.4

The Focus and Epicenter of an Earthquake.

- The point within (or down inside) Earth where energy is released is the **focus**.
- The point directly above the focus on Earth's surface is the **epicenter**.



Earthquake Focus and Epicenter

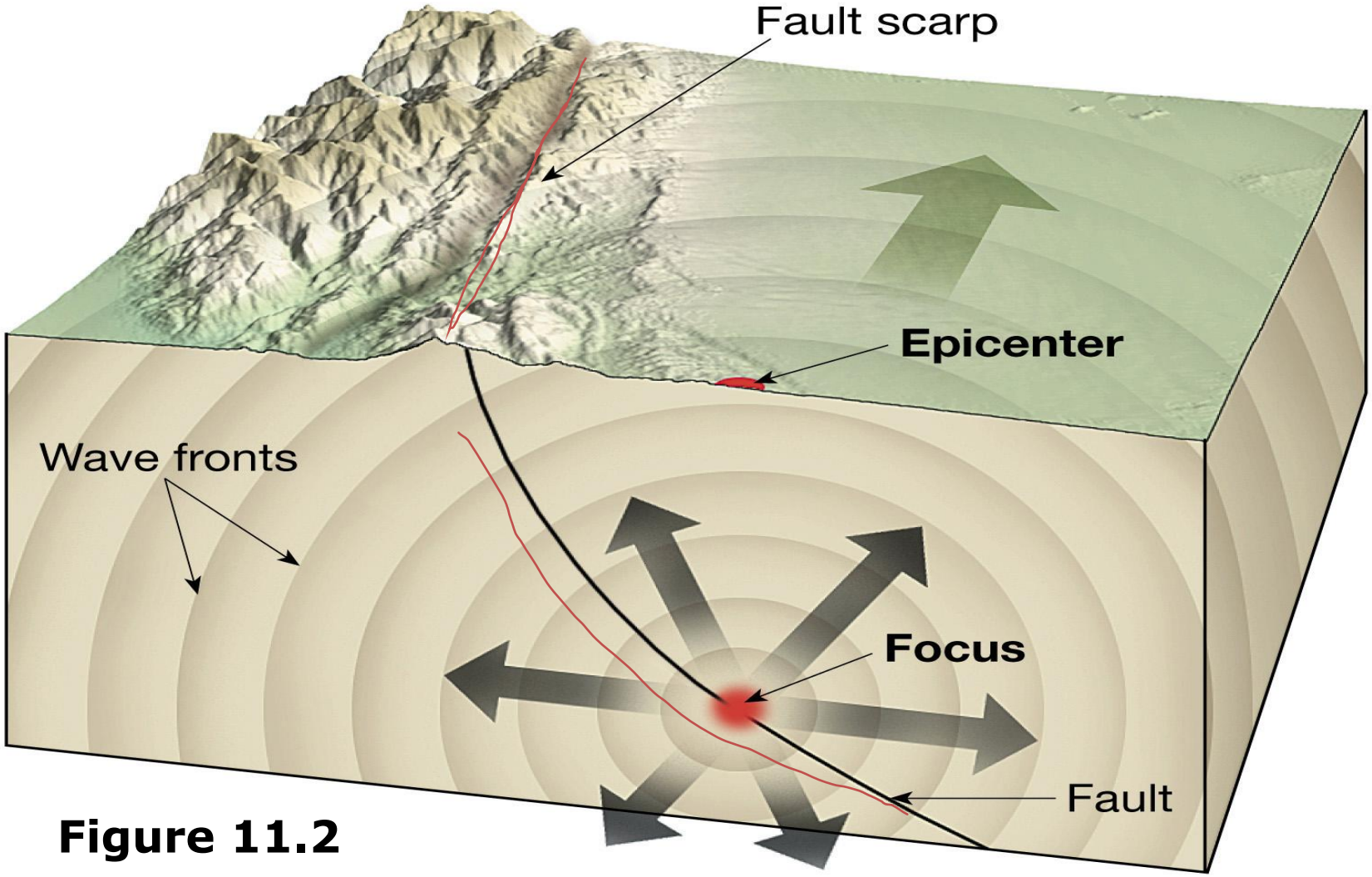
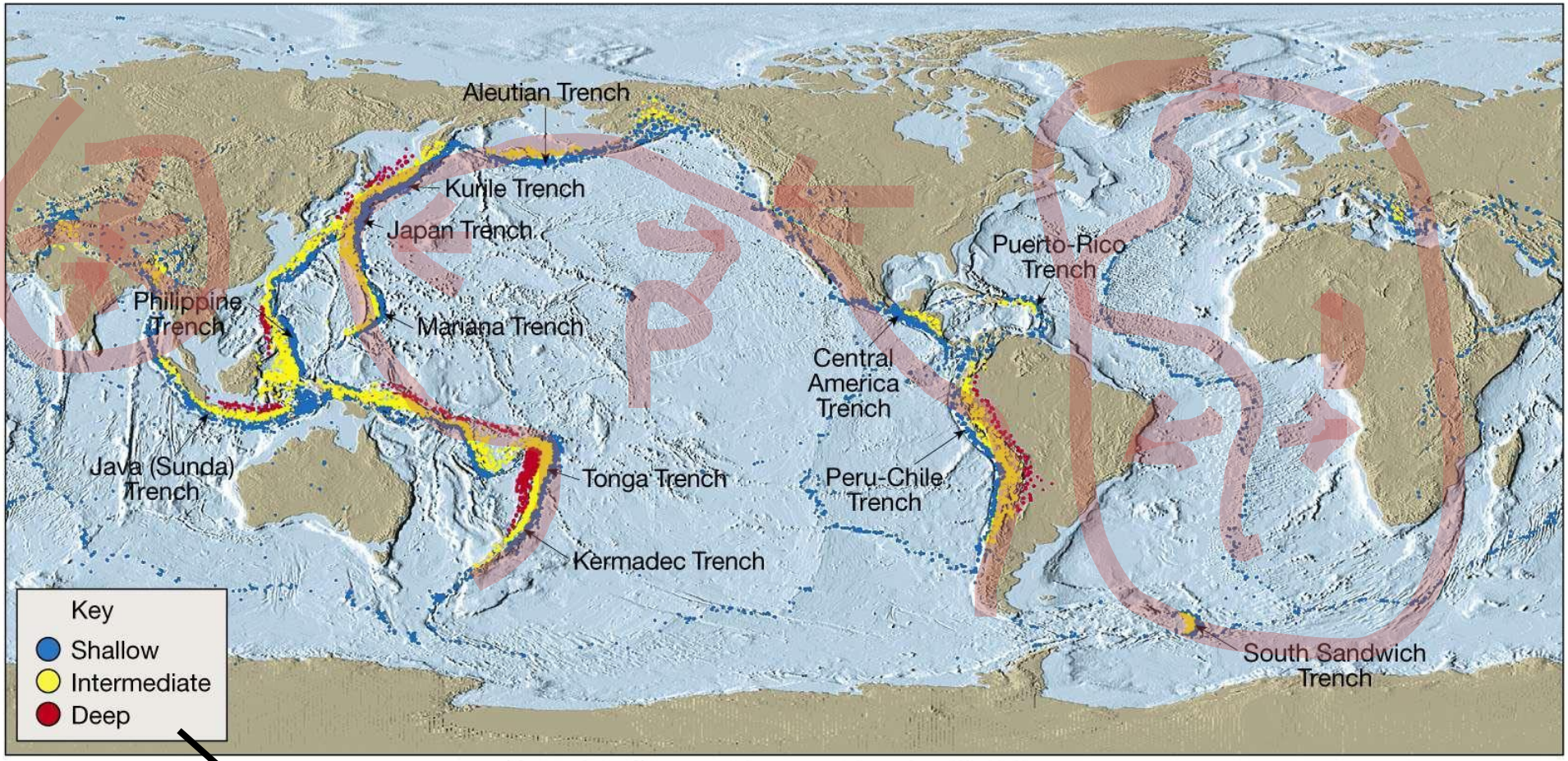


Figure 11.2

- Adjustments that follow a major earthquake often generate smaller earthquakes called aftershocks.

- Smaller earthquakes, called foreshocks, often precede a major earthquake.

Global Distribution of Earthquakes



Remember The Hugo Benioff Zone?

- **Earthquake Depths**

Earthquakes originate at depths ranging from 5 to nearly 700 kilometers.

Shallow-focus Earthquakes (surface to 70 kilometers)

Intermediate-focus Earthquakes (between 70 and 300 kilometers)

Deep-focus Earthquakes (over 300 kilometers)

Earthquakes and Plate Boundaries

- Divergent Boundaries – **Shallow Earthquakes** at **ridges**.

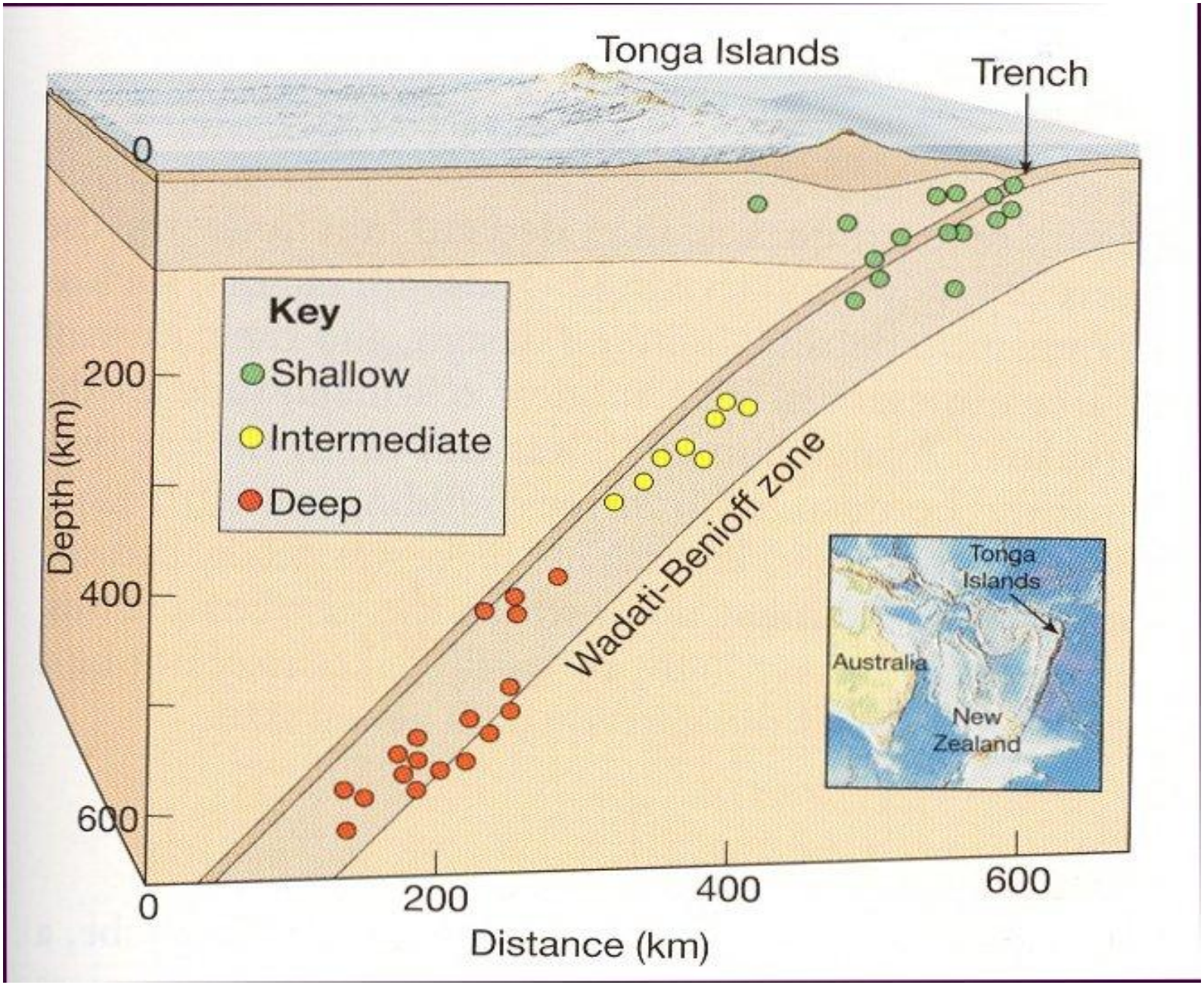
  DUE TO NORMAL FAULTING AND MOVING MOLTEN.

- Transform Boundaries – **Shallow Earthquakes** along **transform faults**.

  DUE TO ELASTIC REBOUND.

- Convergent Boundaries – **Shallow, Intermediate, and Deep Earthquakes** at **trenches** and therefore, **subduction zones**.

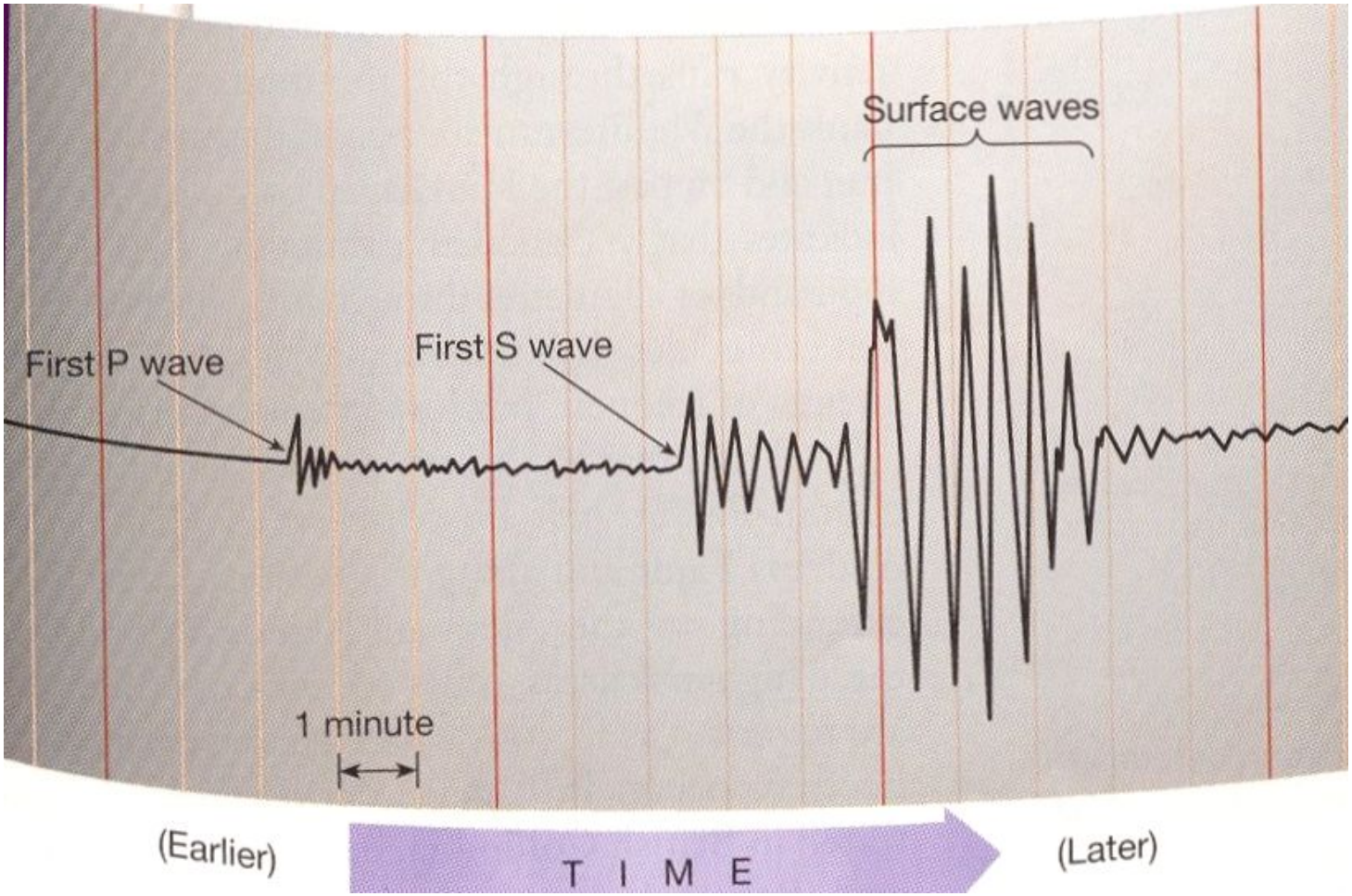
  DUE TO MOVING MOLTEN AS WELL AS REVERSE AND THRUST FAULTS.


Tonga Islands
Trench
0
Key
Shallow
Intermediate
Deep
200
400
600
Depth (km)
Wadati-Benioff zone
Tonga Islands
Australia
New Zealand
0
200
400
600
Distance (km)

- **The study of earthquake waves is called seismology. The scientists who work in this field are called seismologists.**

- **Seismographs are instruments that record seismic waves. Seismographs can be vertical and horizontal.**

- **Seismograms are paper printouts that are created by seismographs.**



A seismogram (printout). Note the arrivals of p-waves, s-waves, and surface waves.

A Vertical Ground Motion Seismograph

The mass will not move due to the Principle of Inertia! So the pen does not move either!

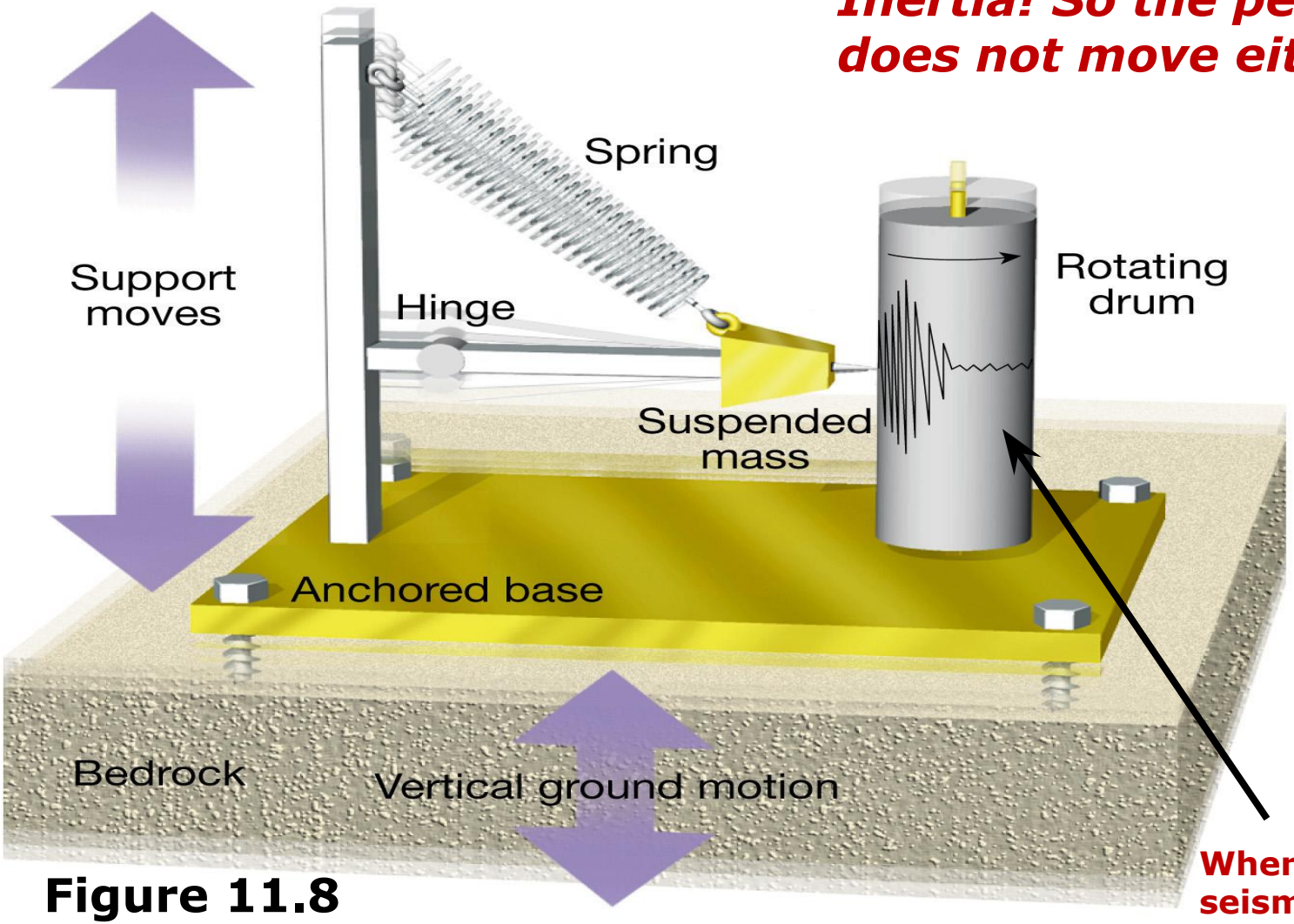


Figure 11.8

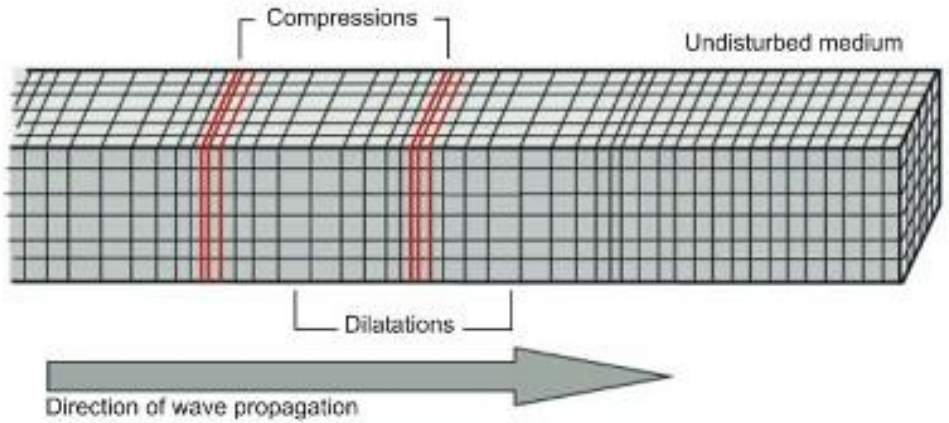
Types of Seismic Waves

1) **Primary Waves (P-waves)**

Fastest moving waves. First waves to arrive at seismic stations.

	Other Names	Movement Through States of Matter	Speed	Particle Motion
Primary Wave (P wave)	push-pull wave	Solid Liquid Gas	6 km/s	compressional (expansion & contraction)

P-wave

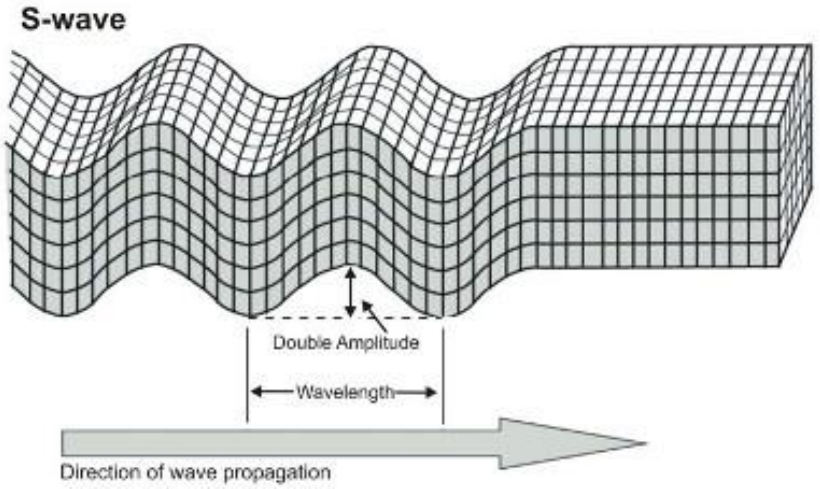


Types of Seismic Waves

2) Secondary Waves (S-waves)

Second fastest waves. Second to arrive at seismic stations.

	Other Names	Movement Through States of Matter	Speed	Particle Motion
Secondary Wave (S wave)	shear wave	Solid	3.6 km/s	shearing motion (horizontal only or vertical only)



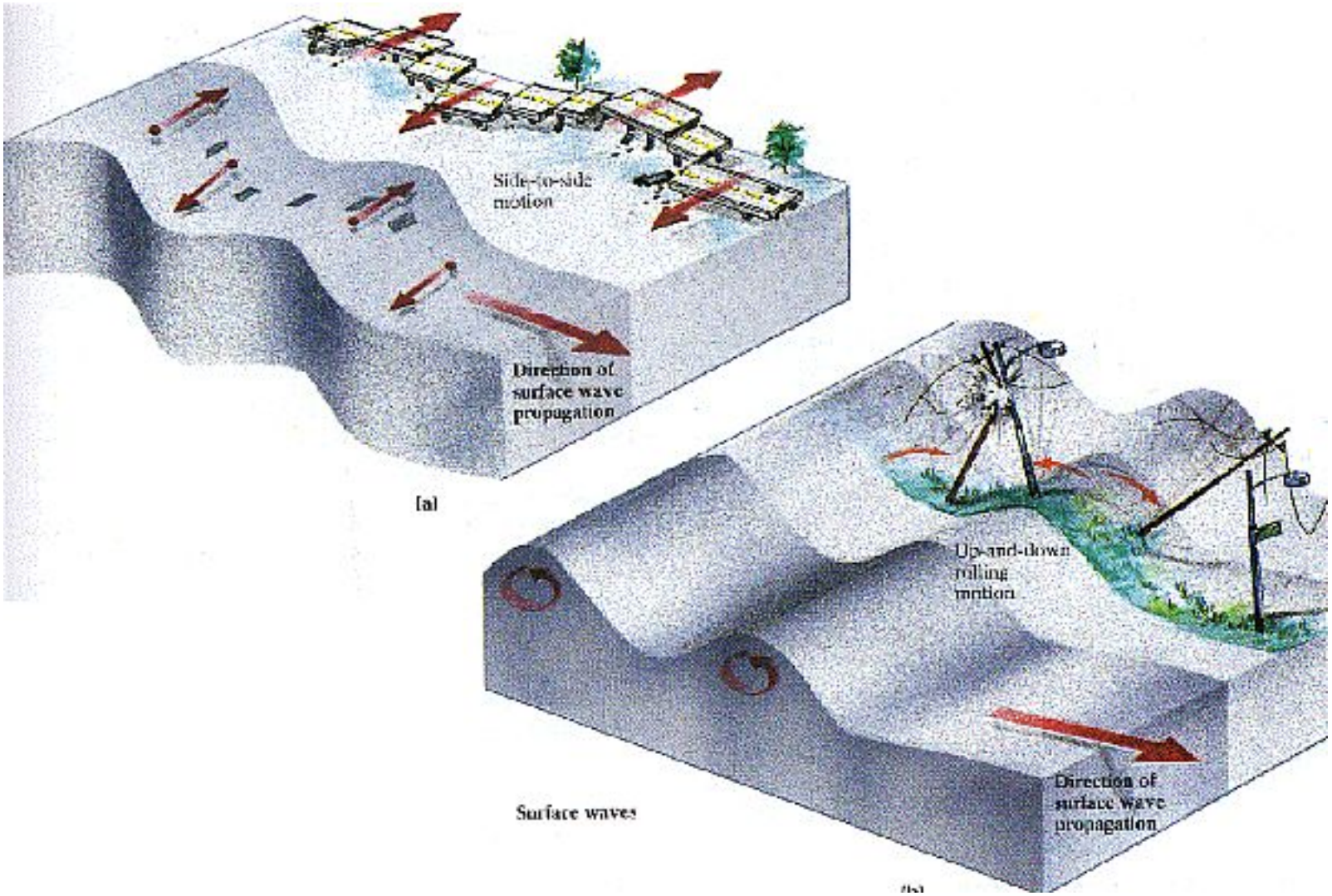
Types of Seismic Waves

3) Surface Waves (L-waves)

Slowest moving waves. Last to arrive at seismic stations. Travel along Earth's surface.

	Other Names	Movement Through States of Matter	Speed	Particle Motion
Surface Wave (L wave)	long wave	Solid	slowest (10% slower than S wave)	shearing motion (horizontal only)

Most destructive waves since people and property exist on Earth's surface.


Side-to-side motion
Direction of surface wave propagation
(a)
Up-and-down rolling motion
Direction of surface wave propagation
Surface waves
(b)

Seismic Waves (Summary):

Surface Waves (L-waves)

- Complex motion (i.e. shearing).
- Causes the greatest destruction.
- Exhibits the greatest amplitude and slowest velocity.

Body Waves - Travel through Earth's interior.

- Two types:

1) Primary (P-waves)

- Push-pull (compress and expand) motion.
- Travels through solids, liquids, and gases.

2) Secondary (S-waves)

- "Shake" motion at right angles to their direction of travel (i.e. shearing).
- Travels only through solids.

This is how we know that the outer core is a liquid!

Measuring the Size of Earthquakes

- **Terms:**
  - **Intensity – A measure of the degree of shaking at a given locale based on the amount of damage perceived.**
  - **Magnitude – the amount of energy released at the source of the earthquake (i.e. the focus).**

Measuring the Size of Earthquakes

- **Two Scales:**

Richter	magnitude (energy released)	uses instruments (seismographs)	uses Arabic values **Numbers**	open-ended scale
Modified Mercalli	intensity (amount of destruction)	uses human observations	uses Roman numerals	closed scale

TABLE 11.3 Earthquake Magnitude and Energy Equivalence

Earthquake Magnitude	Energy Released* (Millions of Ergs)	Approximate Energy Equivalence
0	630,000	1 pound of explosives
1	20,000,000	
2	630,000,000	Energy of lightning bolt
3	20,000,000,000	
4	630,000,000,000	1000 pounds of explosives
5	20,000,000,000,000	
6	630,000,000,000,000	1946 Bikini atomic bomb test
		1994 Northridge Earthquake
7	20,000,000,000,000,000	1989 Loma Prieta Earthquake
8	630,000,000,000,000,000	1906 San Francisco Earthquake
		1980 Eruption of Mount St. Helens
9	20,000,000,000,000,000,000	1964 Alaskan Earthquake
		1960 Chilean Earthquake
10	630,000,000,000,000,000,000	Annual U.S. energy consumption

*For each unit increase in magnitude, the energy released increases about 31.6 times.
SOURCE: U.S. Geological Survey.

Modified Mercalli Intensity Scale

I	Not felt
II	Felt only by persons at rest
III–IV	Felt by persons indoors only
V–VI	Felt by all; some damage to plaster, chimneys
VII	People run outdoors, damage to poorly built structures
VIII	Well-built structures slightly damaged; poorly built structures suffer major damage
IX	Buildings shifted off foundations
X	Some well-built structures destroyed
XI	Few masonry structures remain standing; bridges destroyed
XII	Damage total; waves seen on ground; objects thrown into air

Richter Scale - Introduced by Charles Richter in 1935.

Magnitude (Energy) Scale:

- **Based on the amplitude of the largest seismic wave recorded.**
- **Scale increases in amplitude by a factor of 10 for every increment of one.**

- E.g. Difference between Earthquake A (5.0) and Earthquake B (6.0) is 10 times the amplitude.
- E.g. Difference between Earthquake A (5.0) and Earthquake C (7.0) is 100 times the amplitude.

- **Scale increases in magnitude (or energy released) by a factor of 30 for every increment of one.**

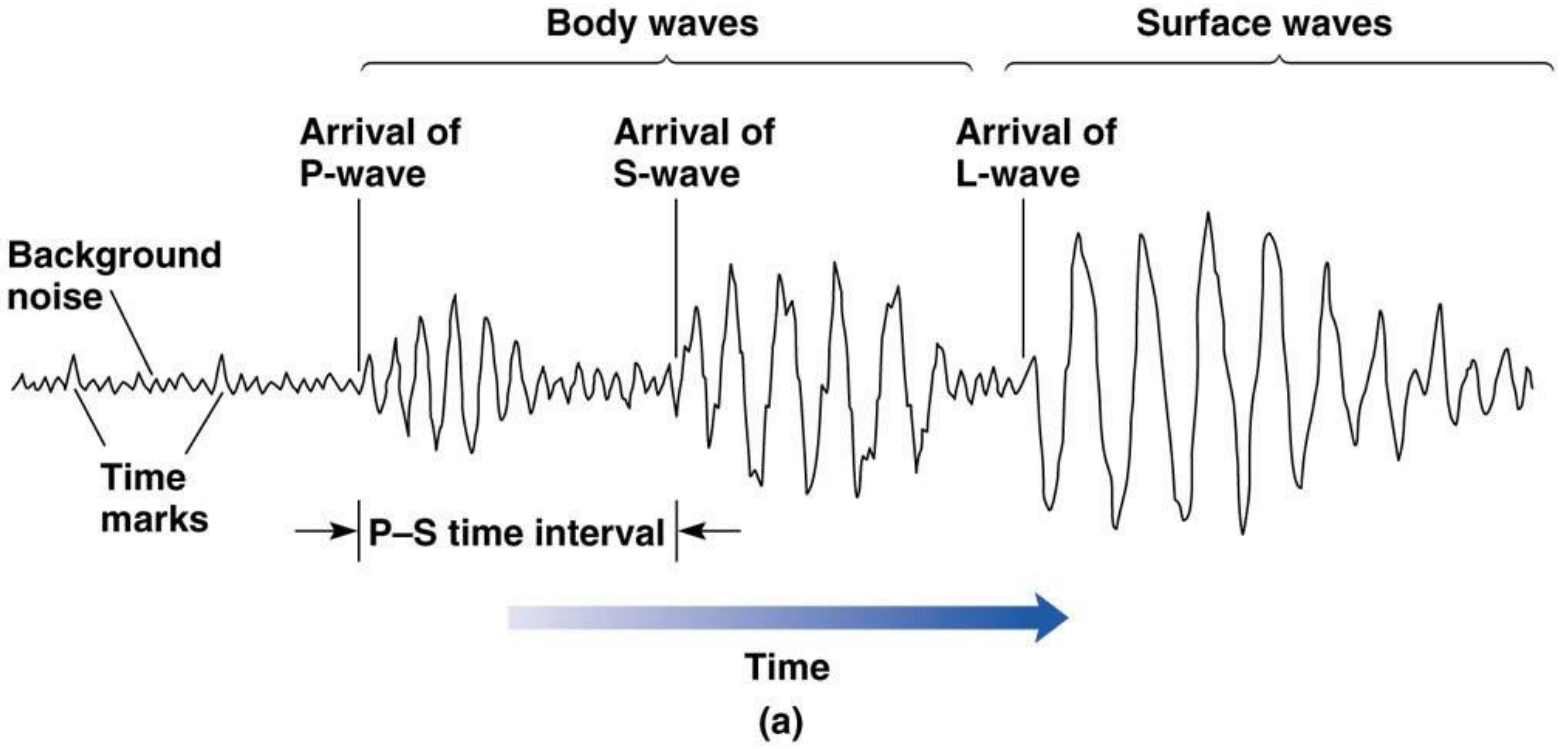
- E.g. Difference between Earthquake X (4.0) and Earthquake P (5.0) is 30 times the energy released.
- E.g. Difference between Earthquake X (4.0) and Earthquake Y (6.0) is 900 times the energy released.

Locating the Source of Earthquakes

- **How to locate 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 and the time interval is used to determine each station's distance to the epicenter.**

How is an Earthquake's Epicenter Located?

- **Seismic Wave Behavior**
  - **P-waves arrive first, then S-waves, then L-waves.**
  - **Average speeds for all of 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 station to the epicenter. (Travel-time graph).**

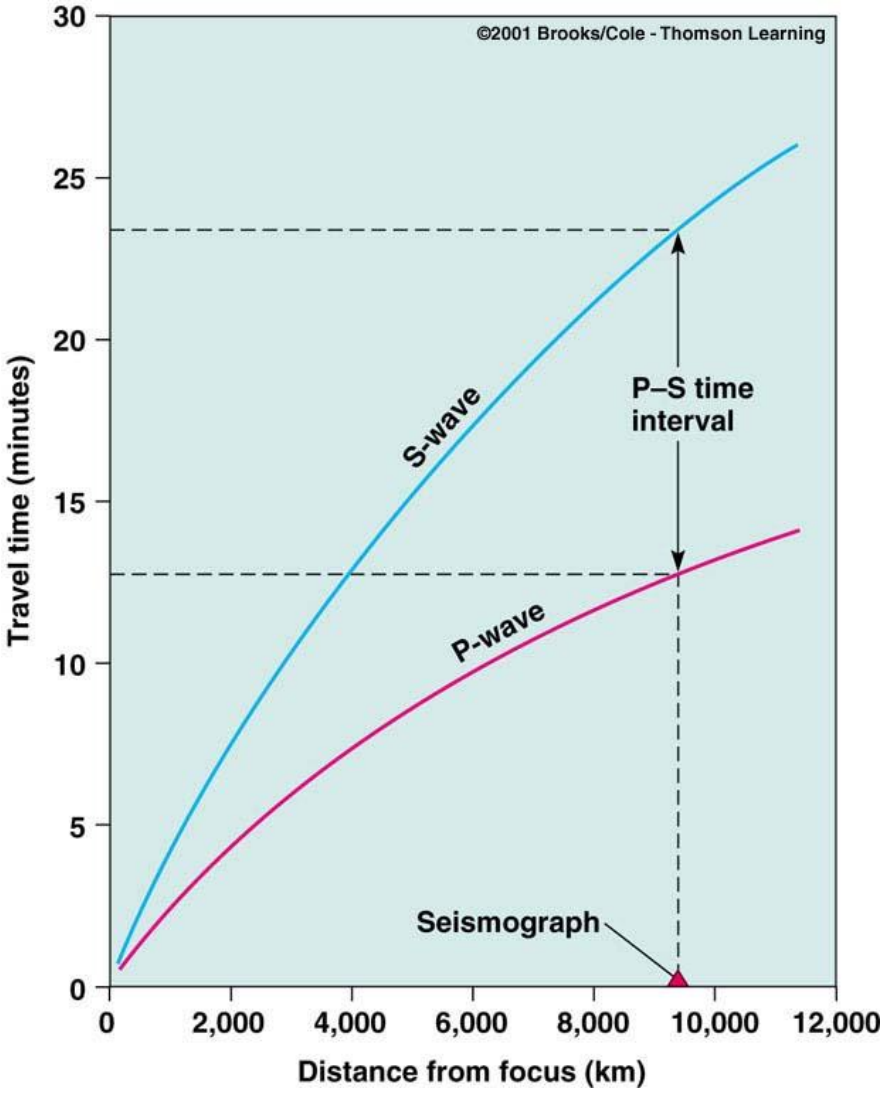


How is an Earthquake's Epicenter Located?

Travel-time Graph

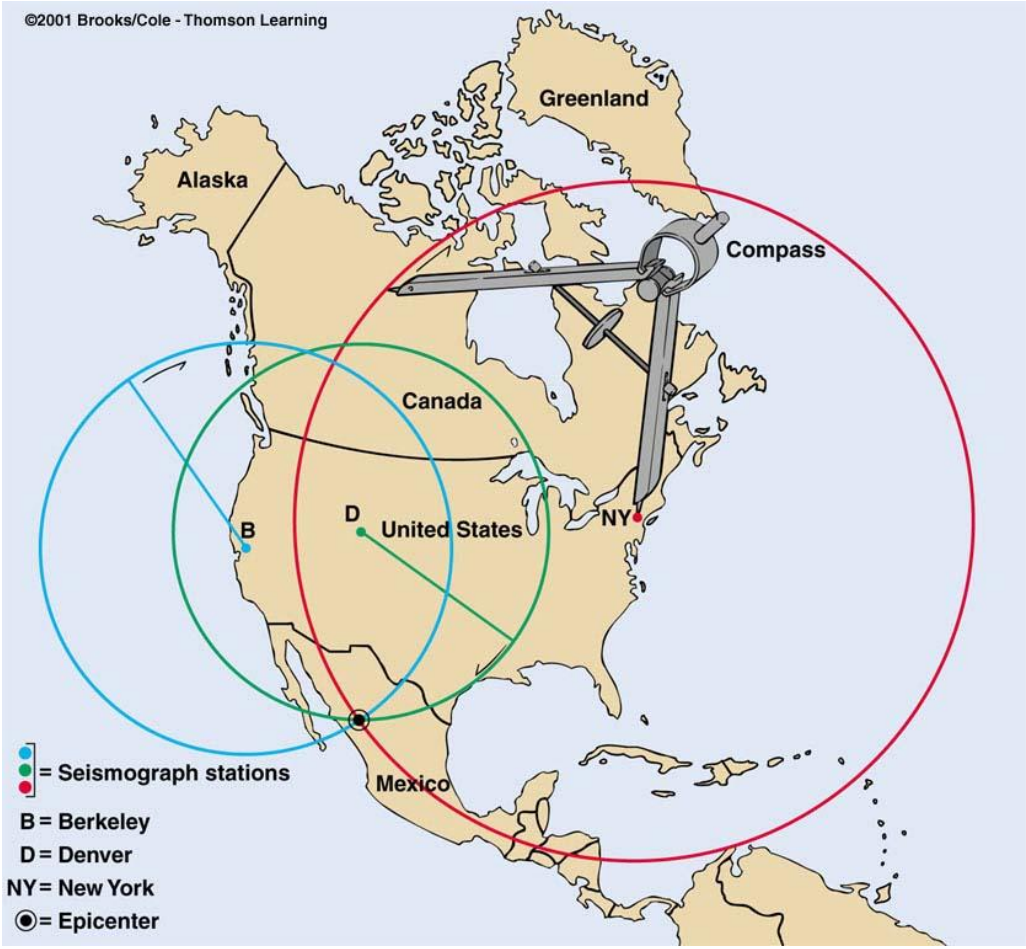
The graph shows the travel times for P- and S-waves.

The farther away a seismograph station is from the focus of an earthquake, the greater the interval will be between the arrivals of the P- and S-waves.



How is an Earthquake's Epicenter Located? Why are three station needed?

- **Three seismograph stations are needed to locate the epicenter of an earthquake.**
- **A circle, where the radius equals the distance to the epicenter from the station, is drawn. Direction is unknown!**
- **The intersection of the three circles locates the epicenter. Go directly below the epicenter and you will find the focus.**



Do Core Laboratory 5!

Damage Caused by the 1964 Anchorage, Alaska Earthquake

Figure 11.17

Damage caused by **liquefaction** in the Marina District of San Francisco from the 1989 Loma Prieta Earthquake.

Earthquake Destruction

- **Tsunamis, or seismic sea waves.**
- **Landslides and ground subsidence.**
- **Fire.**

Can Earthquakes be Predicted?

- **Short-range Predictions:**
  - **Currently, no reliable method exists for making short-range predictions of earthquakes.**
- **Long-range Predictions/Forecasts:**
  - **Gives the probability of a certain magnitude earthquake occurring on a time scale of 30 to 100 years (or more).**

Most occur at plate boundaries and hotspots! The exception would be places where faulting occurs!