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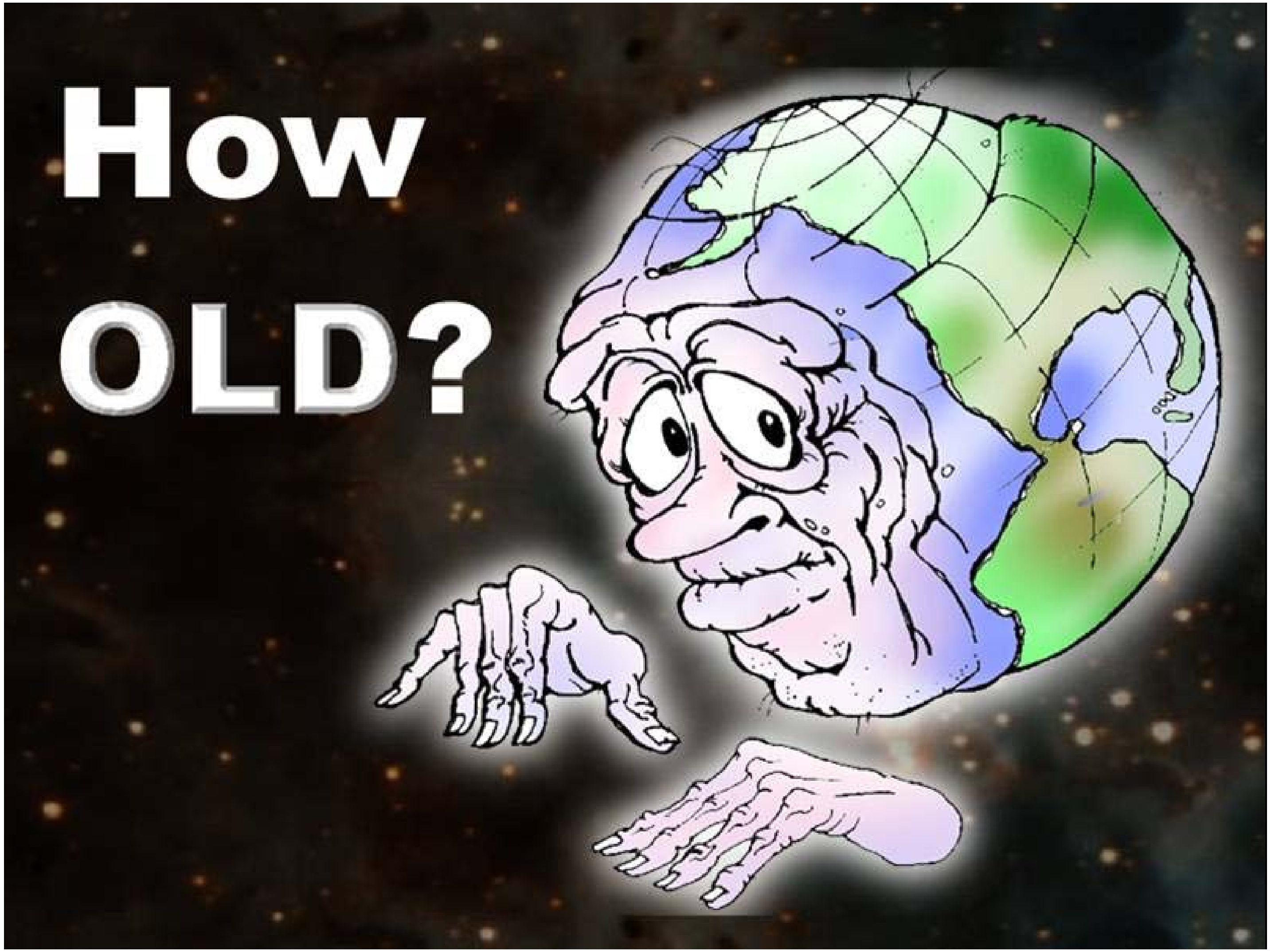
GPH 201

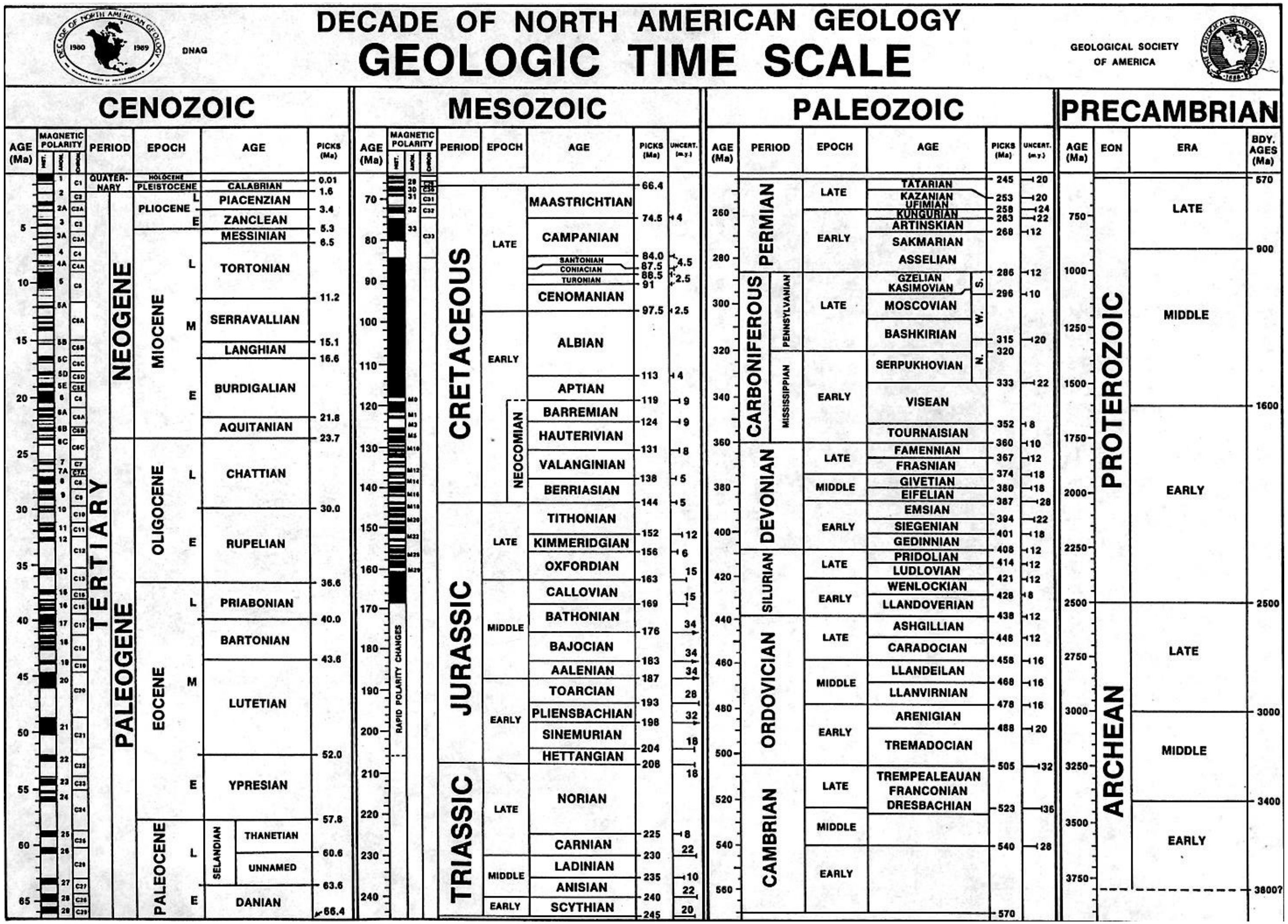
Principles of Geophysics

Dr. Sattam Abdulkareem Almadani

Q. How old is Earth?

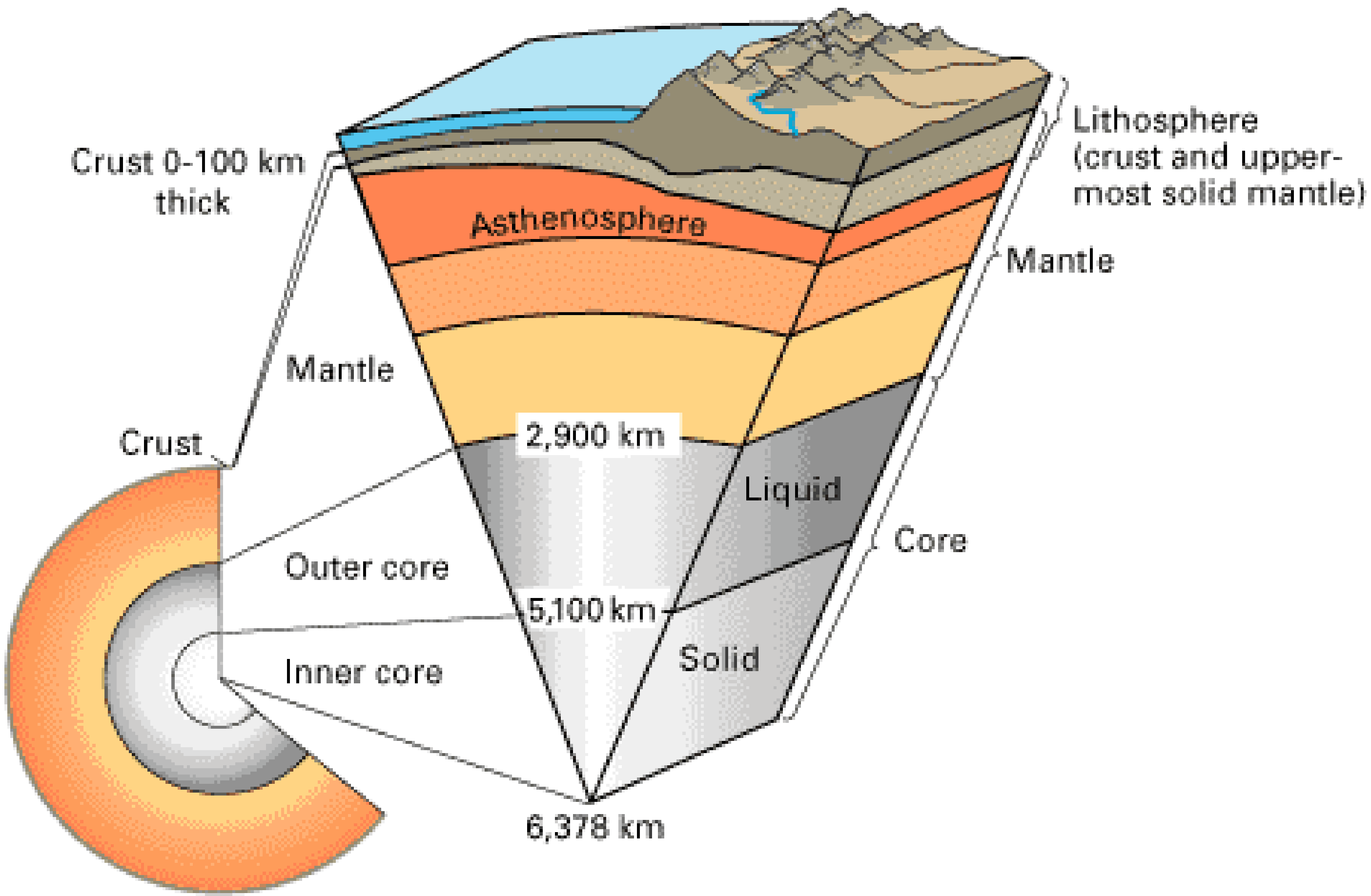


Based on the radiometric age dating, Earth is 4.6 billion years old.



How much is Earth's radius?

Earth radius is the distance from Earth's center to its surface which is about <u>6378 km</u> (3959 mi).



Earth's Internal Structure:

Earth's inner structure can be subdivided according to:

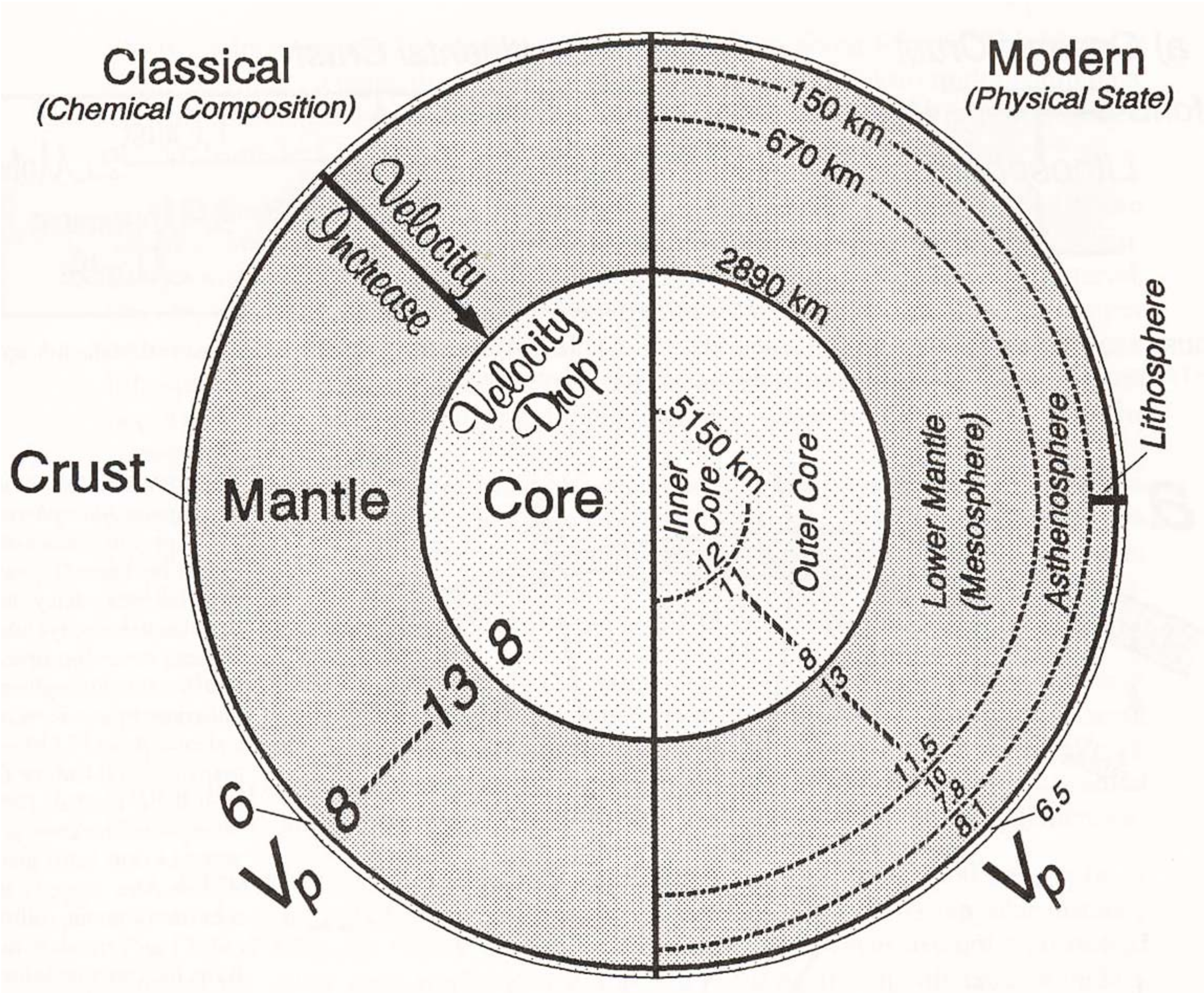
1. Chemical composition: the chemical composition of Earth materials.
2. Physical properties: how the rocks respond to increased temperature and pressure at depth.

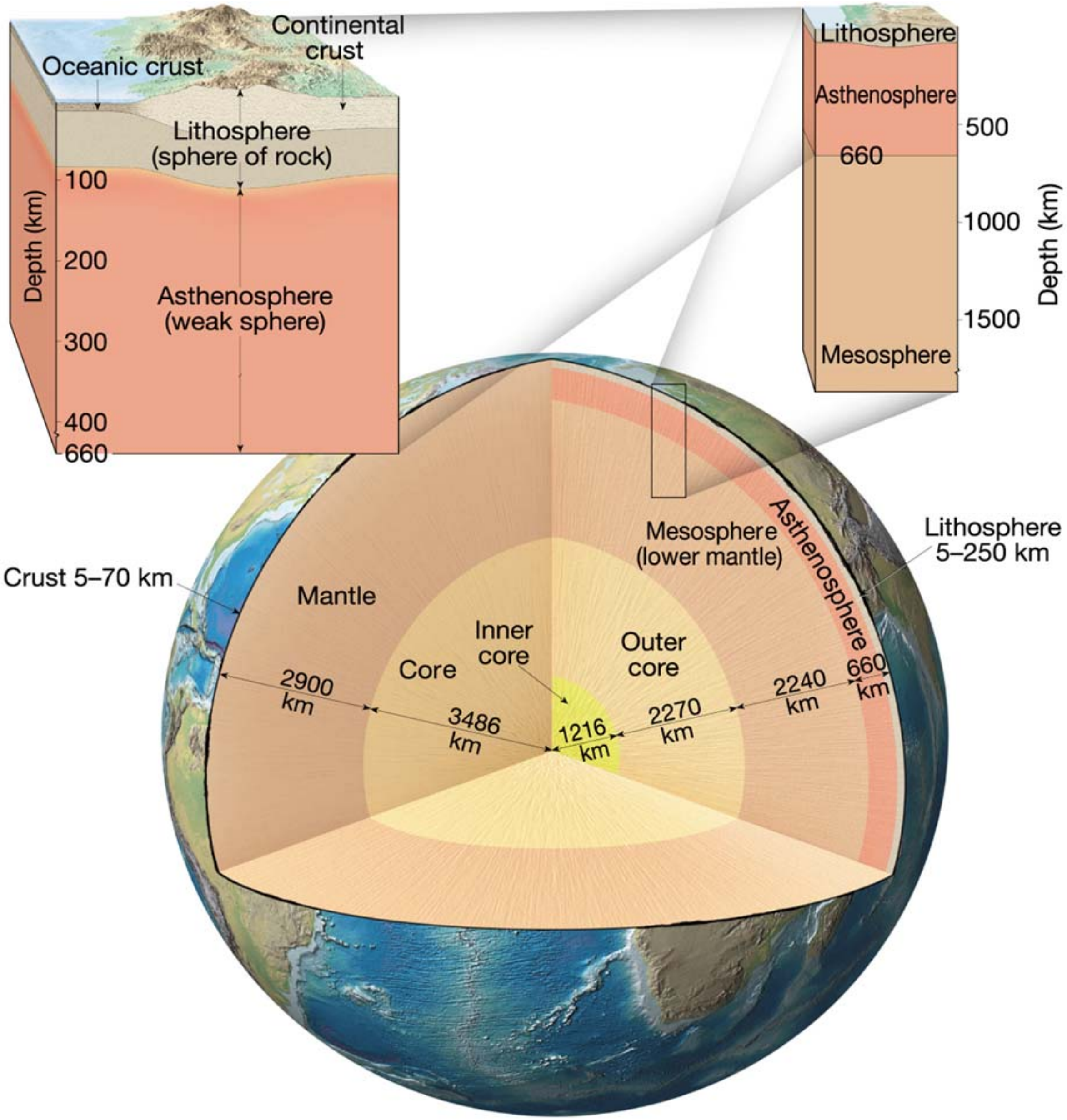
Layers defined by chemical composition:

1. Crust
2. Mantle
3. Core

Layers defined by physical properties:

1. Lithosphere
2. Asthenosphere
3. Mesosphere
4. Inner and outer core.


Classical
(Chemical Composition)
Modern
(Physical State)
150 km
670 km
2890 km
5150 km
Velocity Increase
Velocity Drop
Crust
Mantle
Core
Inner Core
Outer Core
Lower Mantle
(Mesosphere)
Asthenosphere
Lithosphere
6
8
13
8
12
11
8
13
11.5
10
7.8
8.1
6.5
Vp
Vp


Continental crust
Oceanic crust
Lithosphere (sphere of rock)
100
200
300
400
660
Depth (km)
Asthenosphere (weak sphere)
Lithosphere
Asthenosphere
500
660
1000
1500
Depth (km)
Mesosphere
Mesosphere (lower mantle)
Asthenosphere
Lithosphere 5–250 km
Crust 5–70 km
Mantle
Inner core
Outer core
Core
2900 km
3486 km
1216 km
2270 km
2240 km
660 km

Age of the Earth?

------4.6 billion years

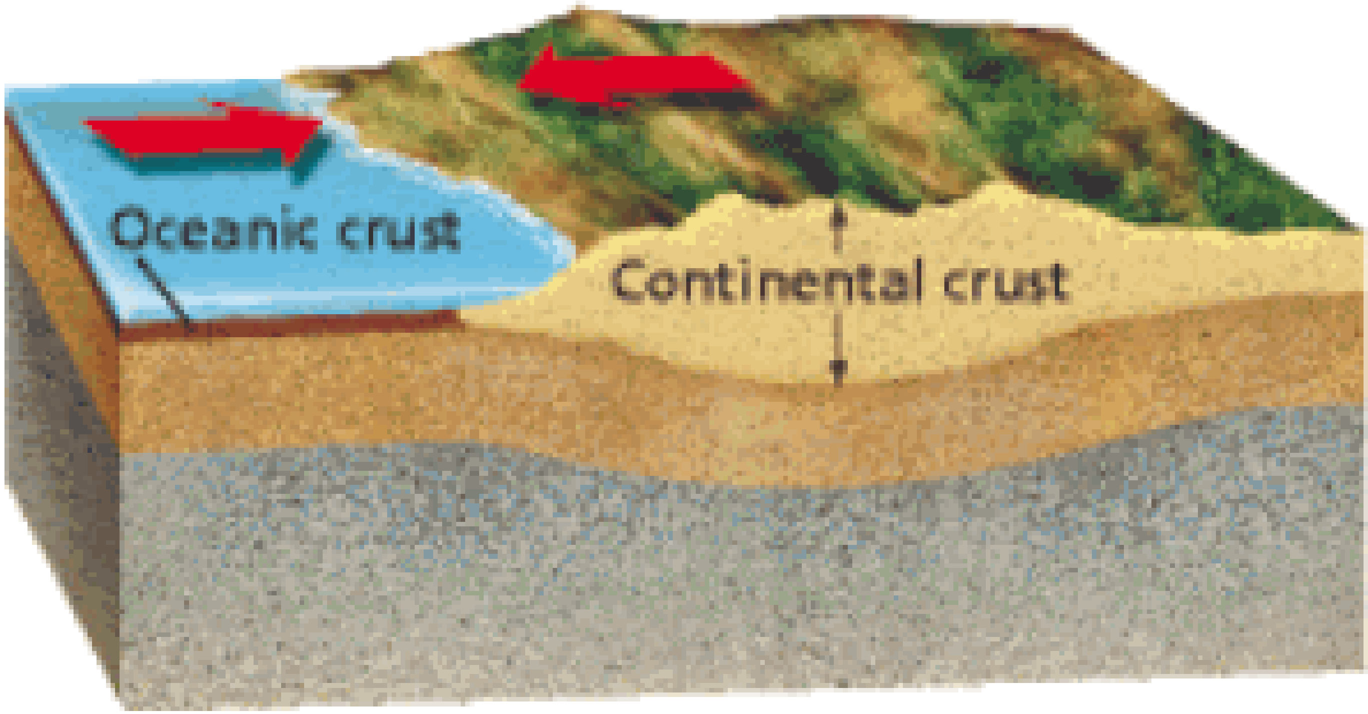
Radius of the Earth?

------6371 km

Major Layers?

------Crust, Mantle, Core

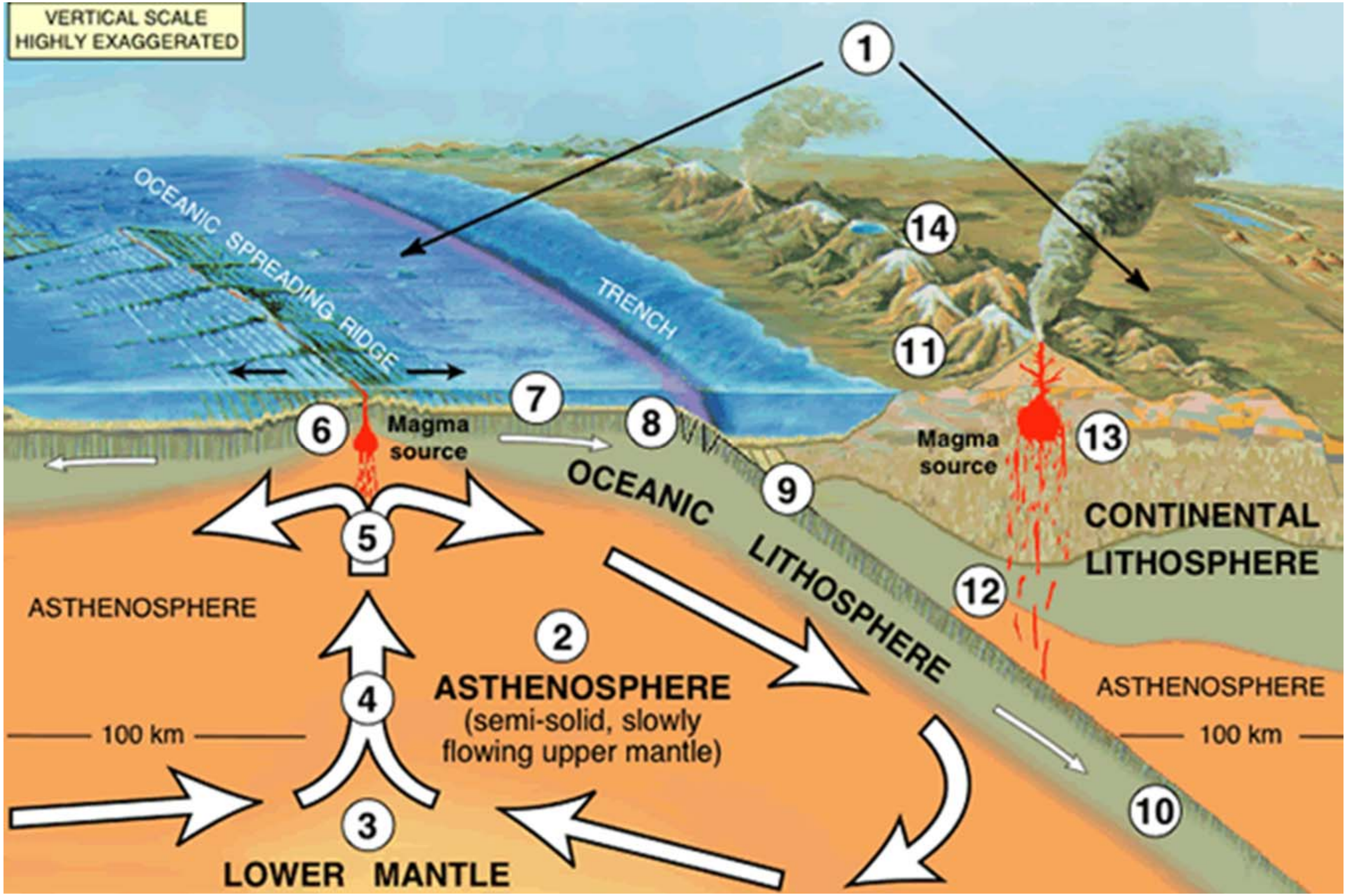
Q. What is the difference between continental crust and oceanic crust?



Continental Crust	Oceanic Crust
Thick crust (average 35-40 km)	Thin crust (roughly 7 km thick)
Less dense (2.7 g/cm^3)	More dense (3.0 g/cm^3)
Old (4 Ga years old)	Young (180 Ma years old)
Composed of granitic rocks	Composed of igneous rocks

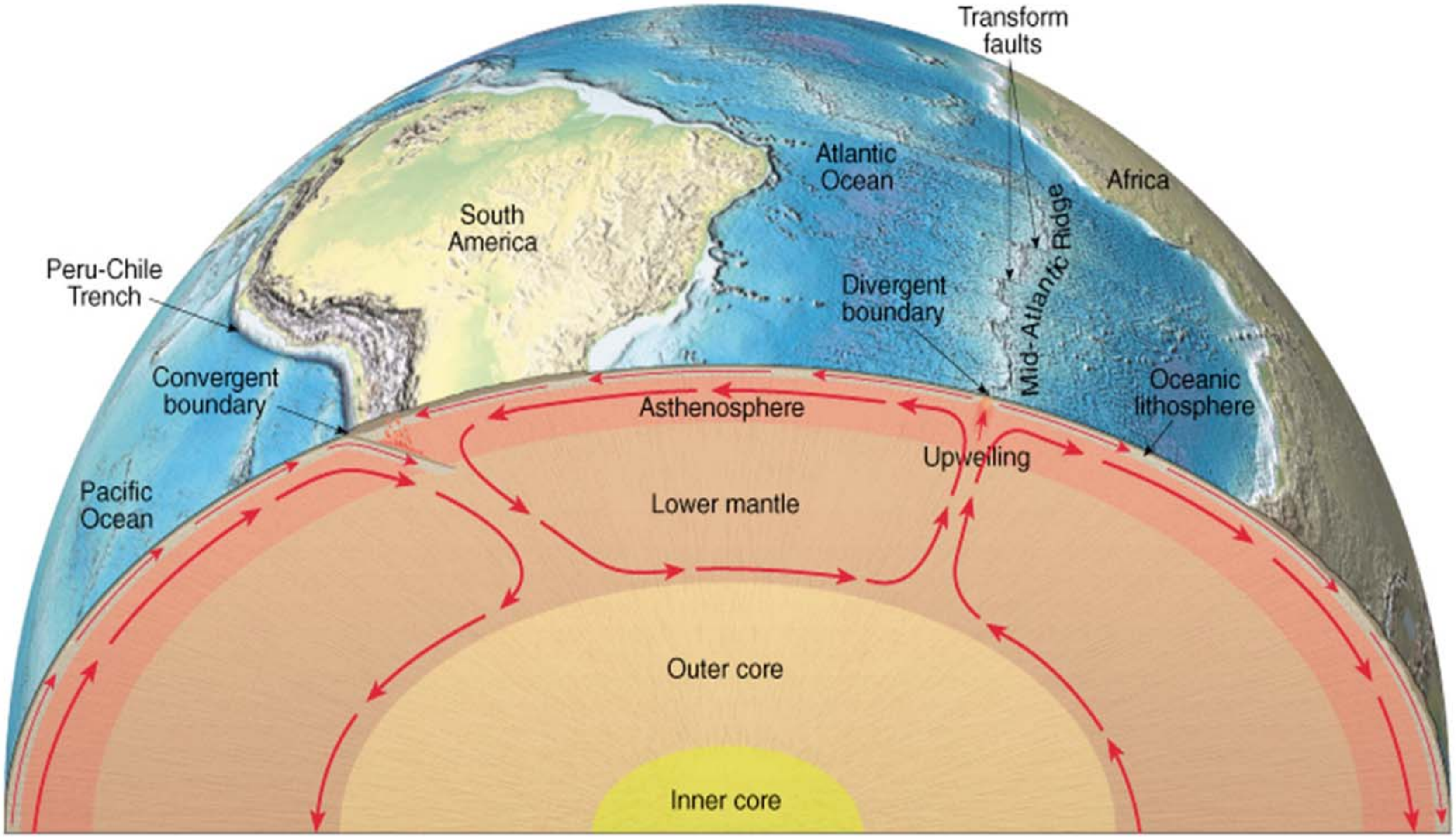
Plate Tectonics is a theory that explains the following features on Earth:

- Formation of mountain belts, volcanoes, and ocean basins.
- Location of volcanoes, faults, earthquakes, and mountain building.
- Ocean floor features.
- The continuing development of Earth's surface.
- The distribution of past and present life on Earth.



VERTICAL SCALE
HIGHLY EXAGGERATED
1
OCEANIC SPREADING RIDGE
TRENCH
14
11
7
8
6
Magma
source
Magma
source
13
OCEANIC
9
LITHOSPHERE
CONTINENTAL
LITHOSPHERE
5
12
ASTHENOSPHERE
2
ASTHENOSPHERE
(semi-solid, slowly
flowing upper mantle)
4
ASTHENOSPHERE
100 km
100 km
3
10
LOWER MANTLE

Q. What is the concept of Plate Tectonics?



Transform faults
Atlantic Ocean
Africa
South America
Mid-Atlantic Ridge
Peru-Chile Trench
Divergent boundary
Convergent boundary
Oceanic lithosphere
Asthenosphere
Upwelling
Pacific Ocean
Lower mantle
Outer core
Inner core

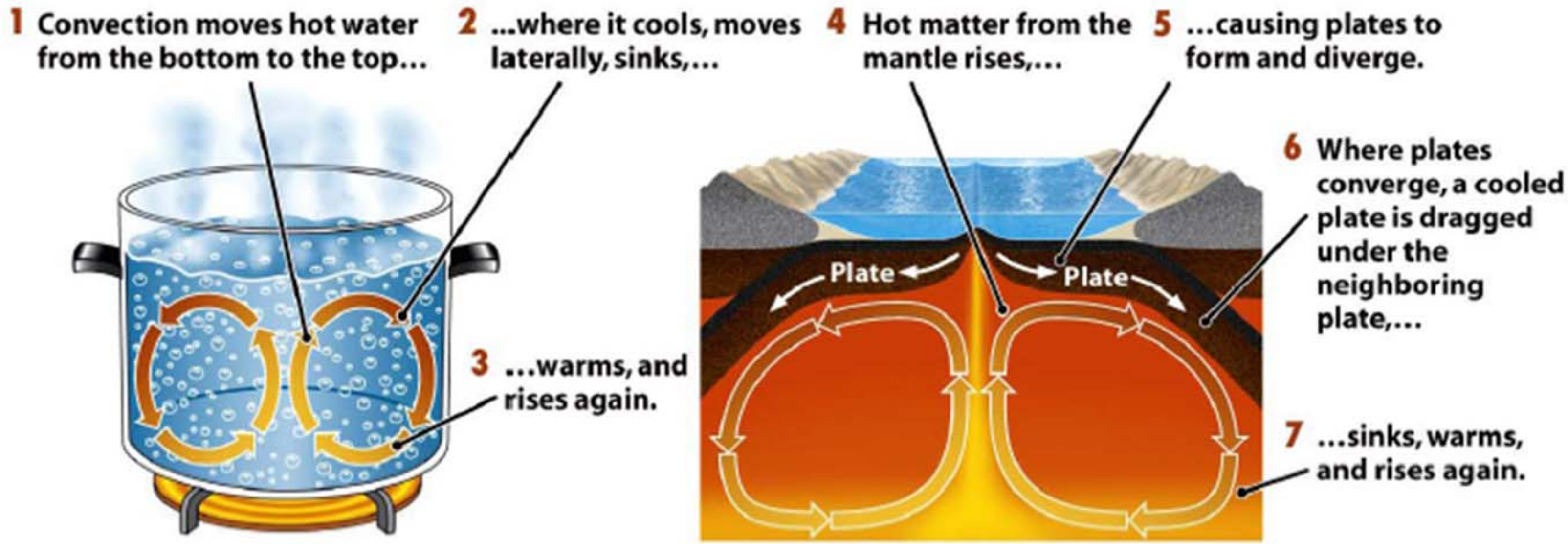
- The outer portion of the Earth is made up of about 20 distinct "plates"(~ 100 km thick), which move relative to each other.

- This motion is what causes earthquakes and makes mountain ranges.

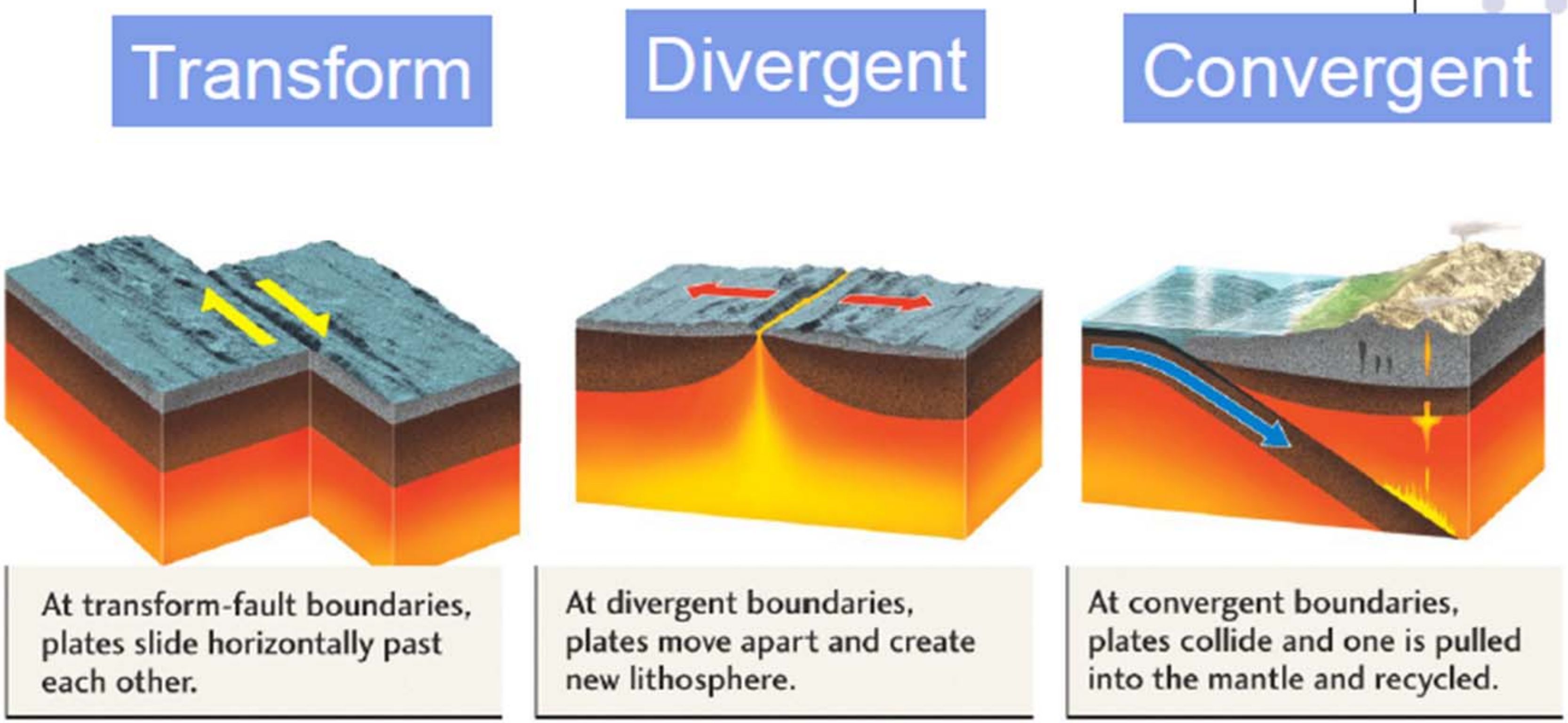
Q. What are the processes of Plate Tectonics?

Convection

On the stove *In the mantle*

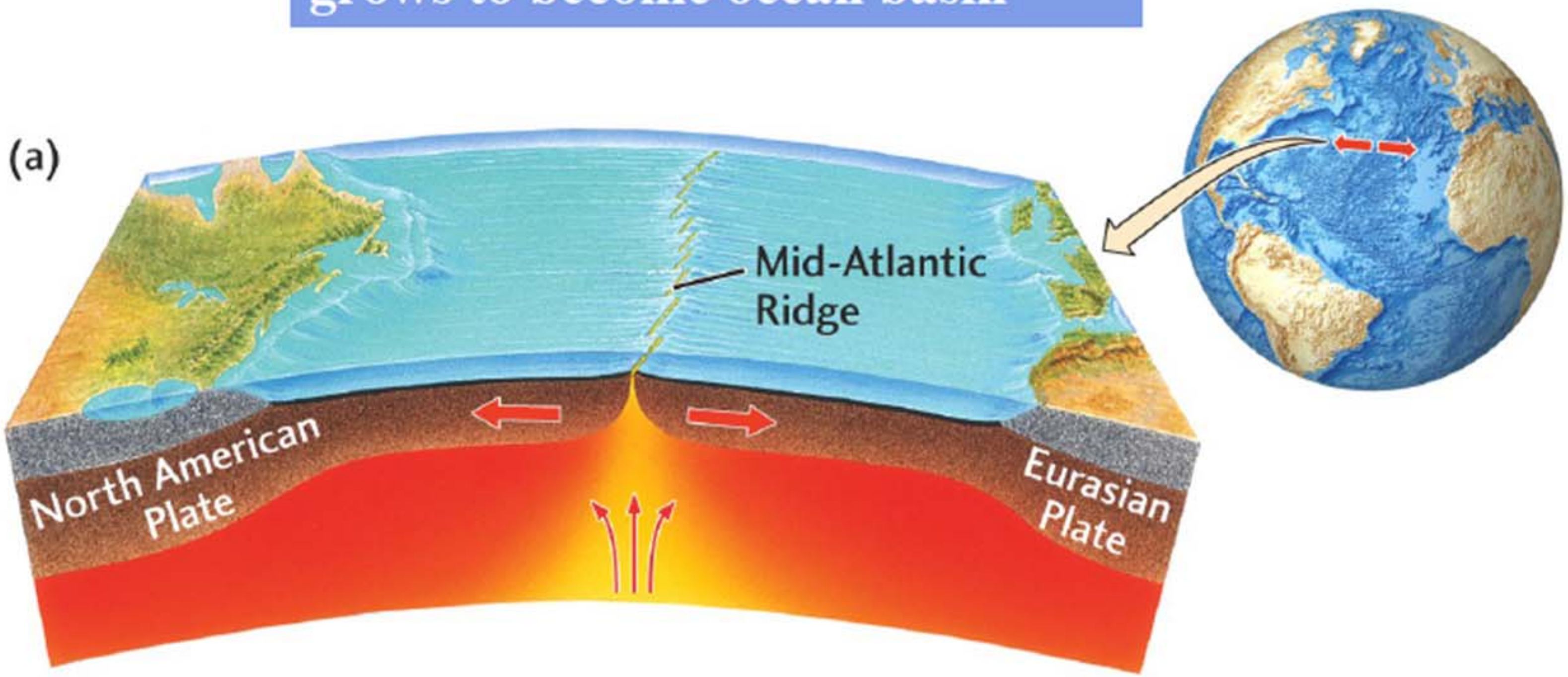


Three Types of Plate Boundaries

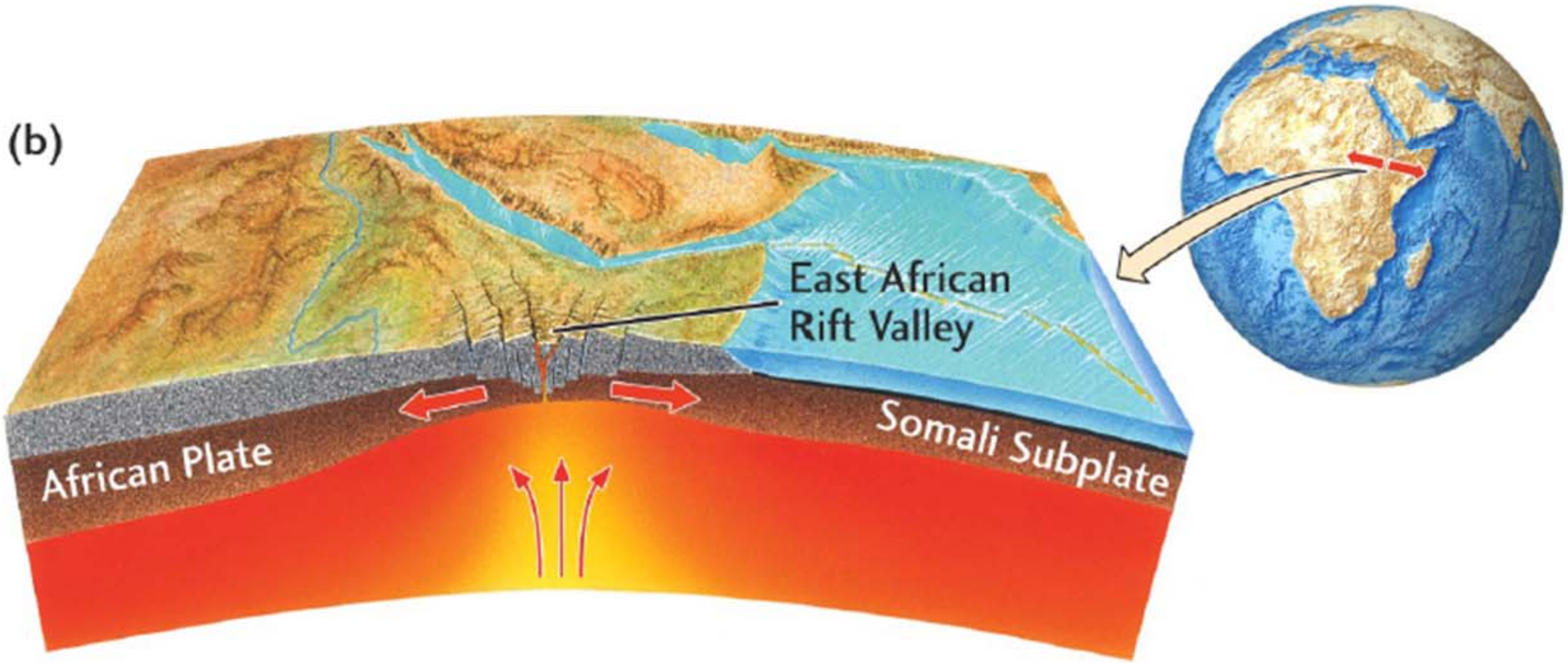


Divergent Plate Boundary

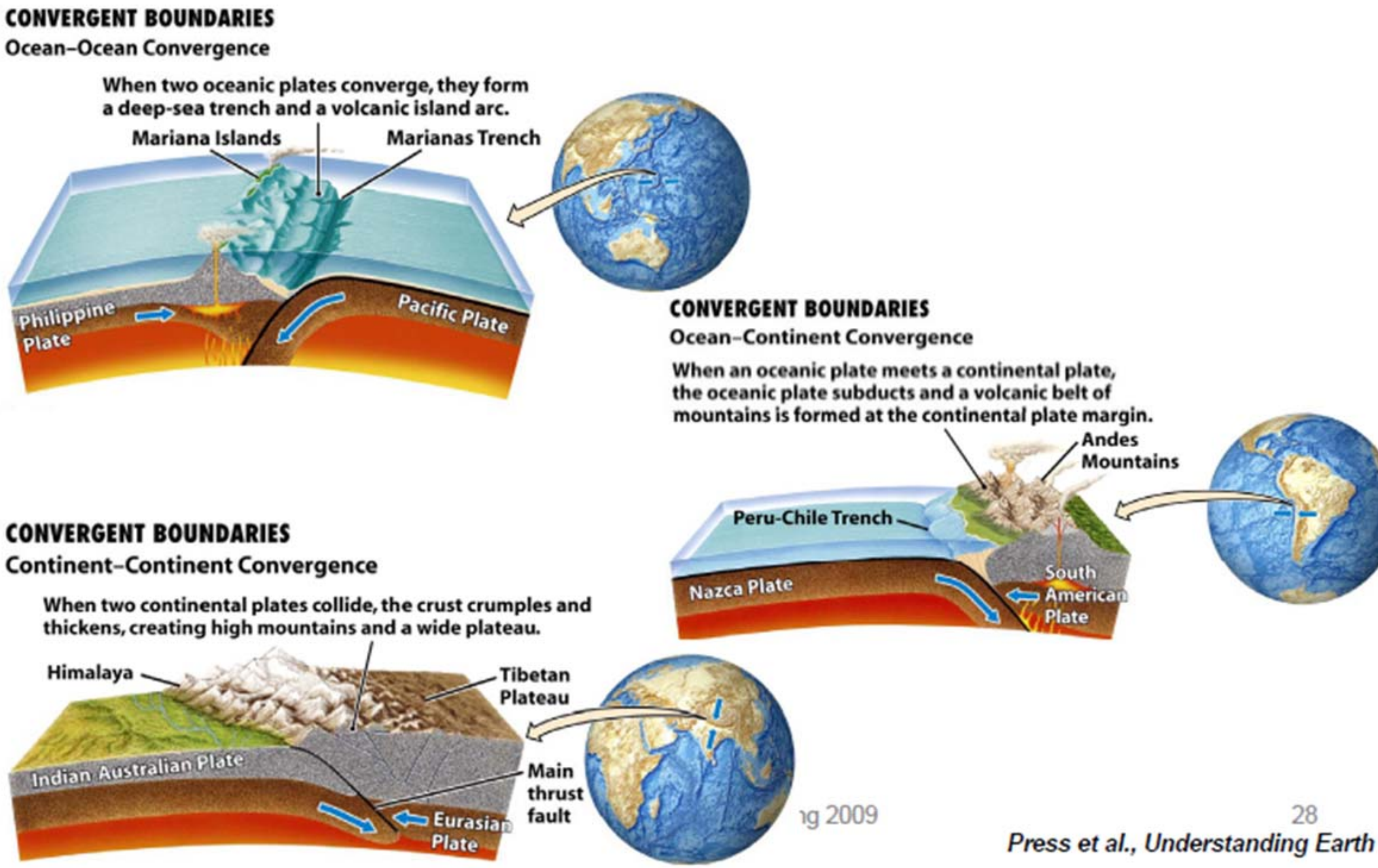
Usually start within continents—
grows to become ocean basin



Divergent Plate Boundary



Convergent plate boundary

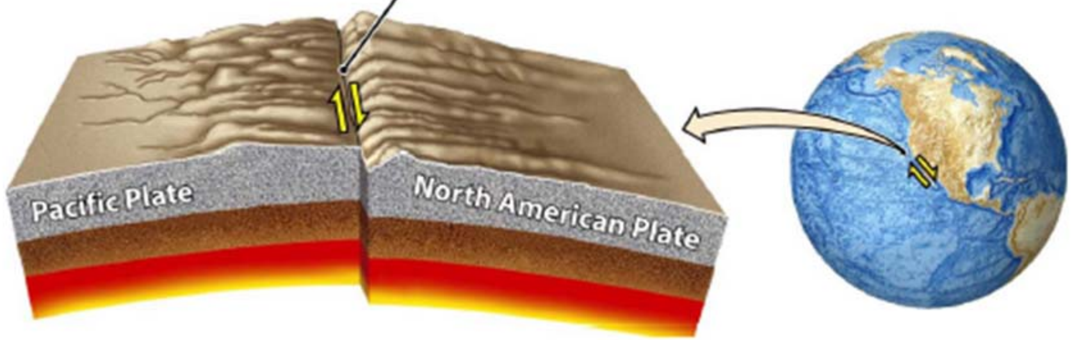


Transform Plate Boundary

TRANSFORM-FAULT BOUNDARIES

Continental Transform Fault

The San Andreas fault in California, where the Pacific Plate slides past the North American Plate, is an example of a transform fault that offsets continental crust.



1 **As the Pacific Plate and North American Plate move past each other in opposite directions…**

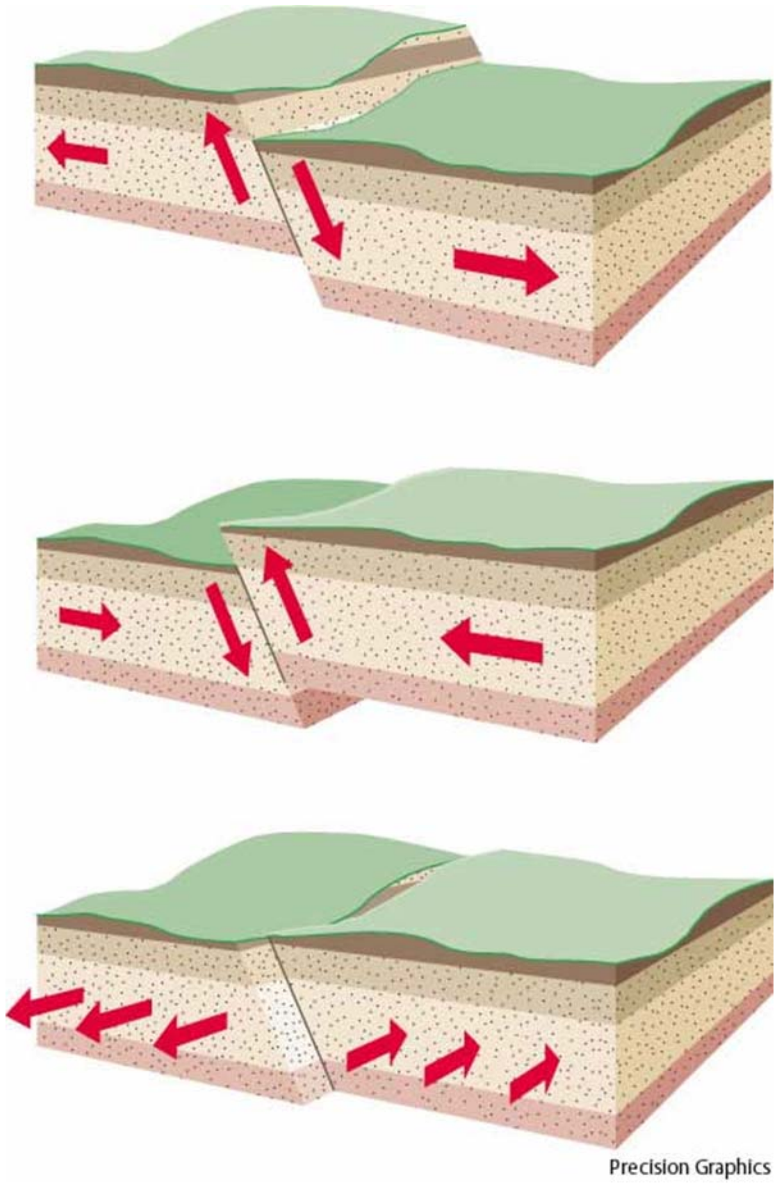
2 **…creek beds crossing the fault have been offset.**

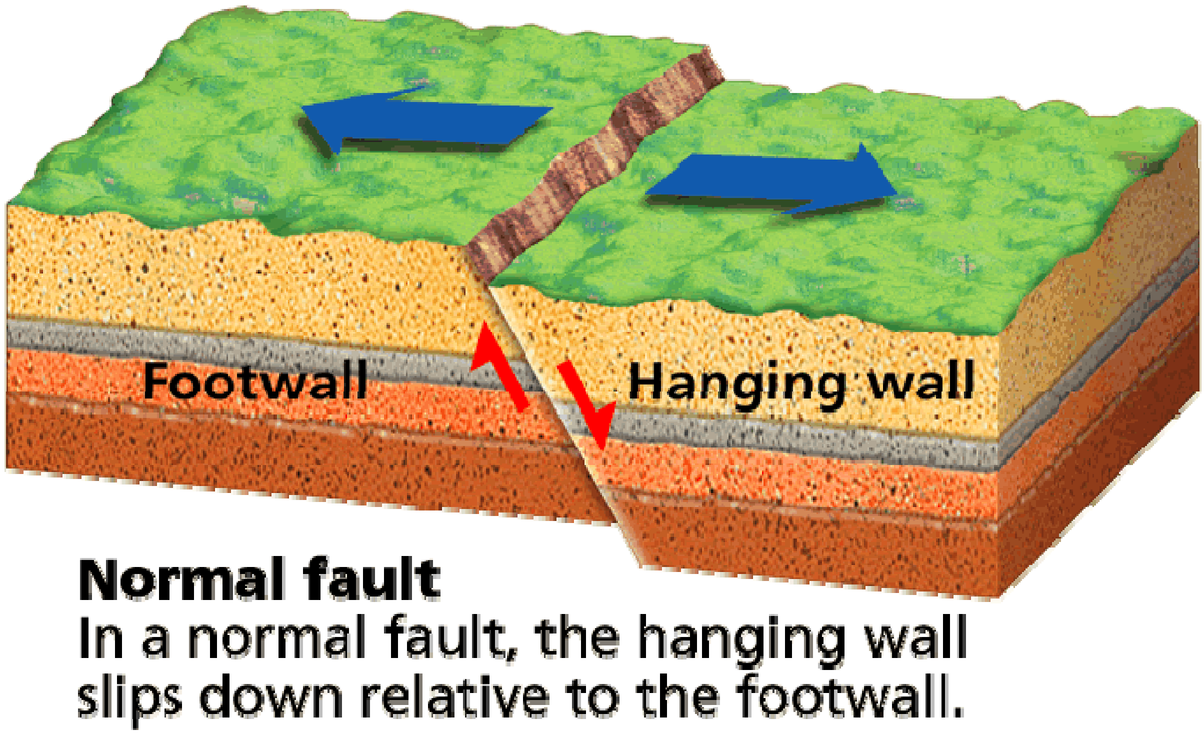
)09

Press et al., Understanding Earth

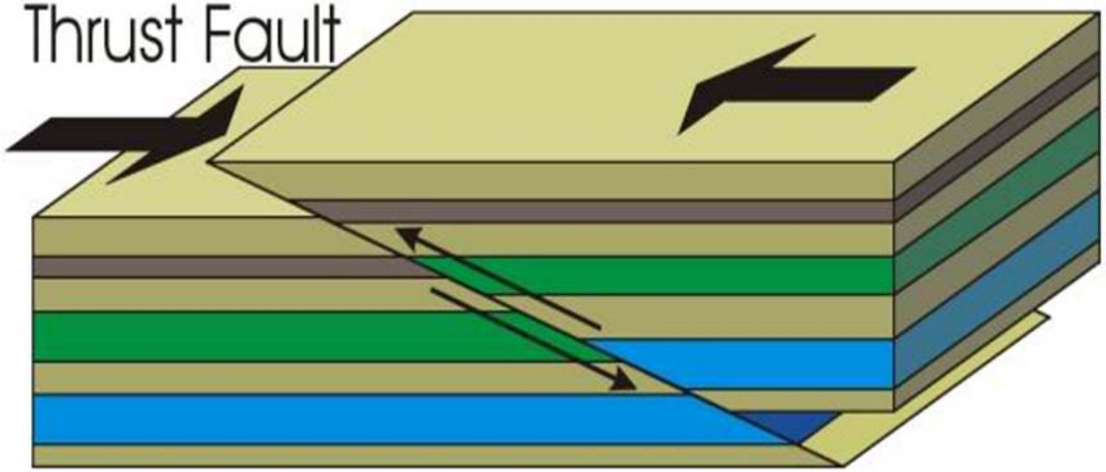
GPH 201 - Earthquake Seismology

- A fault is a fracture or zone of fractures between two blocks of rock.
- Faults allow the blocks to move relative to each other. This movement may occur rapidly, in the form of an earthquake - or may occur slowly, in the form of creep.
- Faults may range in length from a few millimeters to thousands of kilometers.
- Most faults produce repeated displacements over geologic time. During an earthquake, the rock on one side of the fault suddenly slips with respect to the other.
- The fault surface can be horizontal or vertical or some arbitrary angle in between.

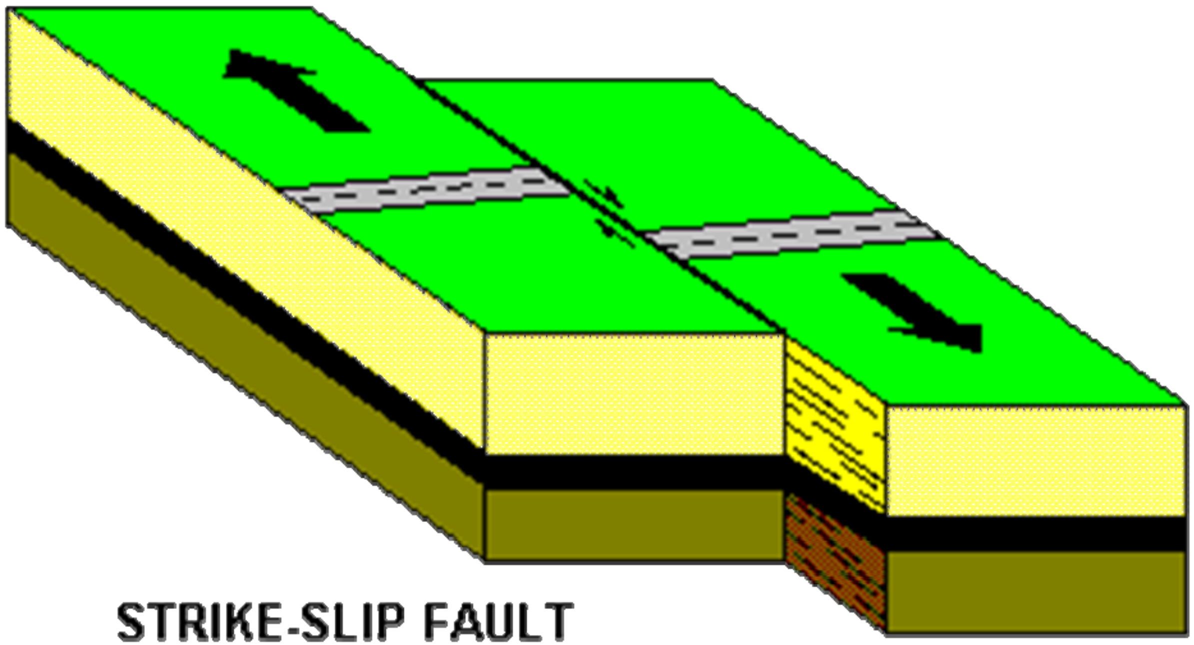

Precision Graphics



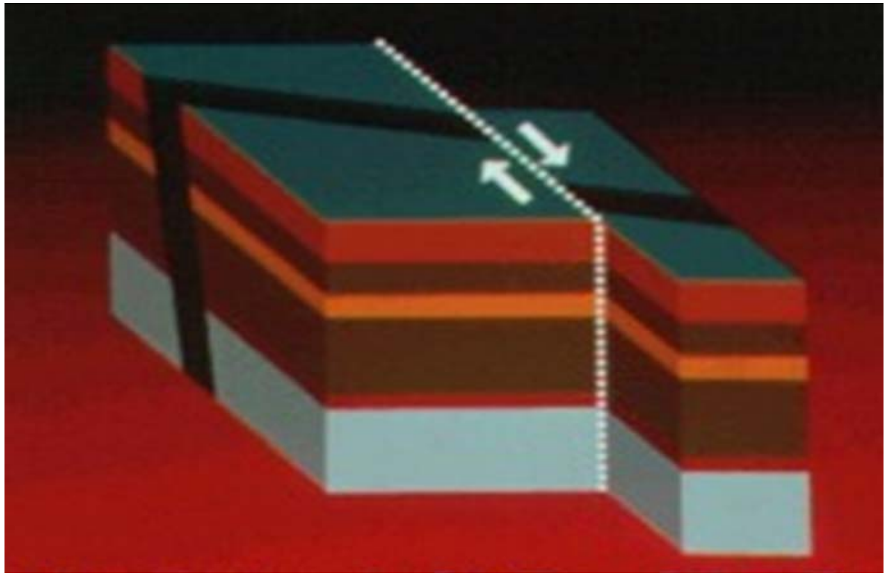
A normal fault is a dip-slip fault in which the block above the fault has moved downward relative to the block below. This type of faulting occurs in response to extension and is often observed in the Western United States Basin and Range Province and along oceanic ridge systems.

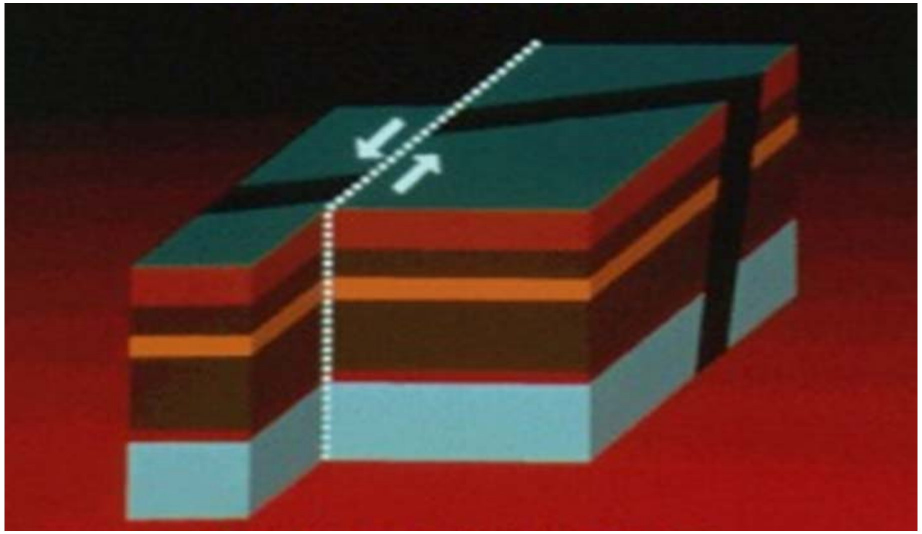


<u>A thrust fault</u> is a dip-slip fault in which the upper block, above the fault plane, moves up and over the lower block. This type of faulting is common in areas of compression, such as regions where one plate is being subducted under another as in Japan and along the Washington coast. When the dip angle is shallow, a reverse fault is often described as a thrust fault.



A strike-slip fault is a fault on which the two blocks slide past one another. These faults are identified as either right-lateral or left lateral depending on whether the displacement of the far block is to the right or the left when viewed from either side. The San Andreas Fault in California is an example of a right lateral fault.

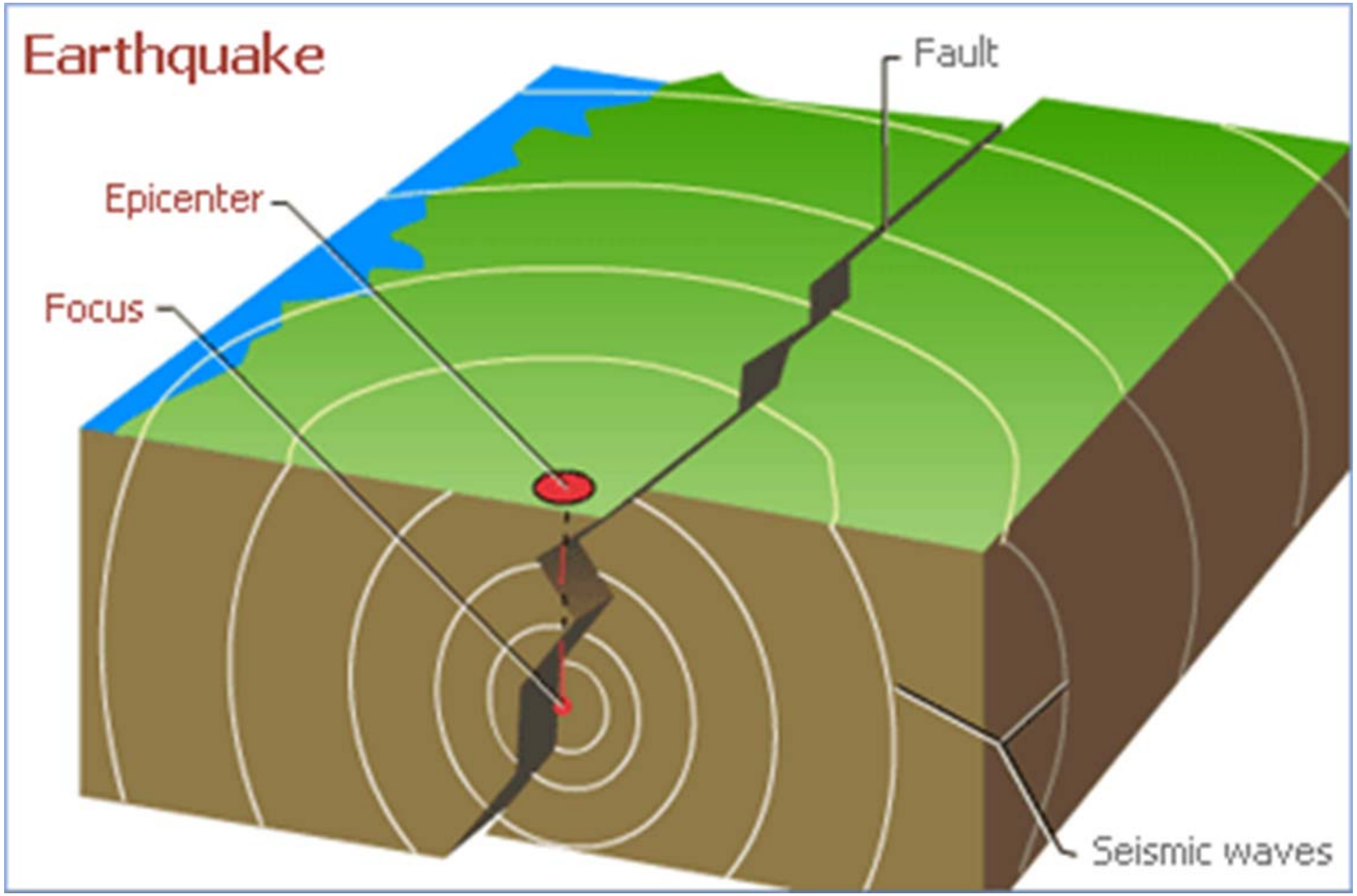




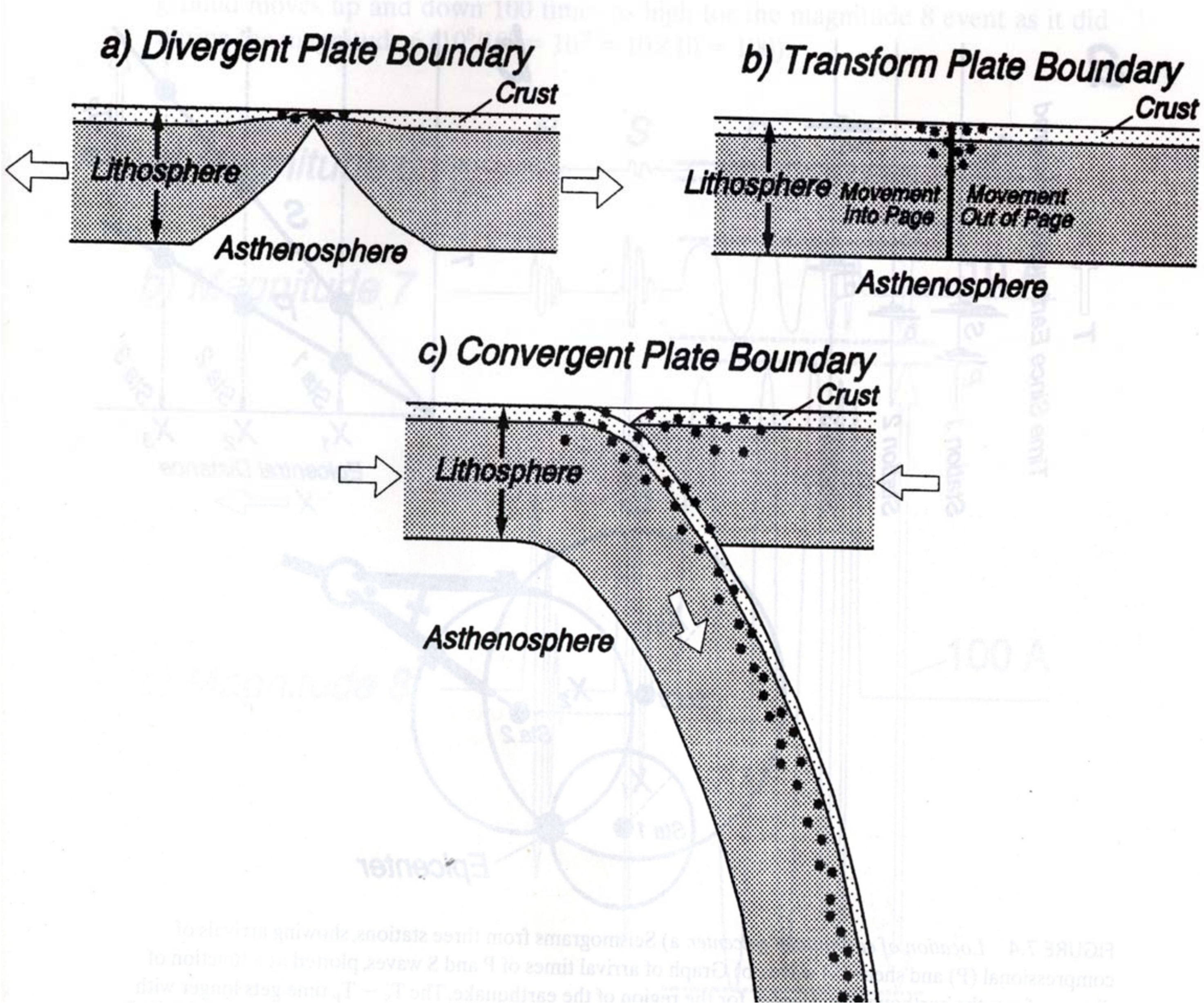
Definitions

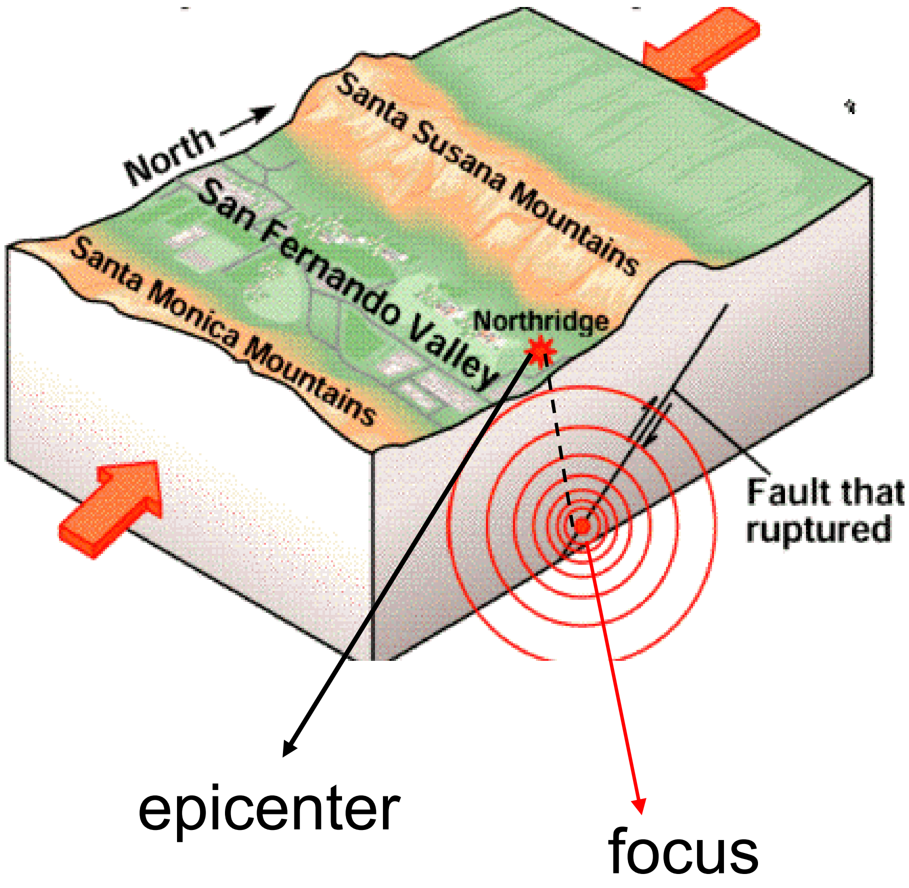
- Earthquake = Vibration of the Earth produced by the rapid release of energy
- Seismic waves = Energy moving outward from the focus of an earthquake
- Focus = location of initial slip on the fault; where the earthquake origins
- Epicenter = spot on Earth’s surface directly above the focus

Q. Why do earthquakes occur?


Earthquake
Fault
Epicenter
Focus
Seismic waves

Q. Where do earthquakes occur?


a) Divergent Plate Boundary
Crust
Lithosphere
Asthenosphere
b) Transform Plate Boundary
Crust
Lithosphere
Movement Into Page
Movement Out of Page
Asthenosphere
c) Convergent Plate Boundary
Crust
Lithosphere
Asthenosphere



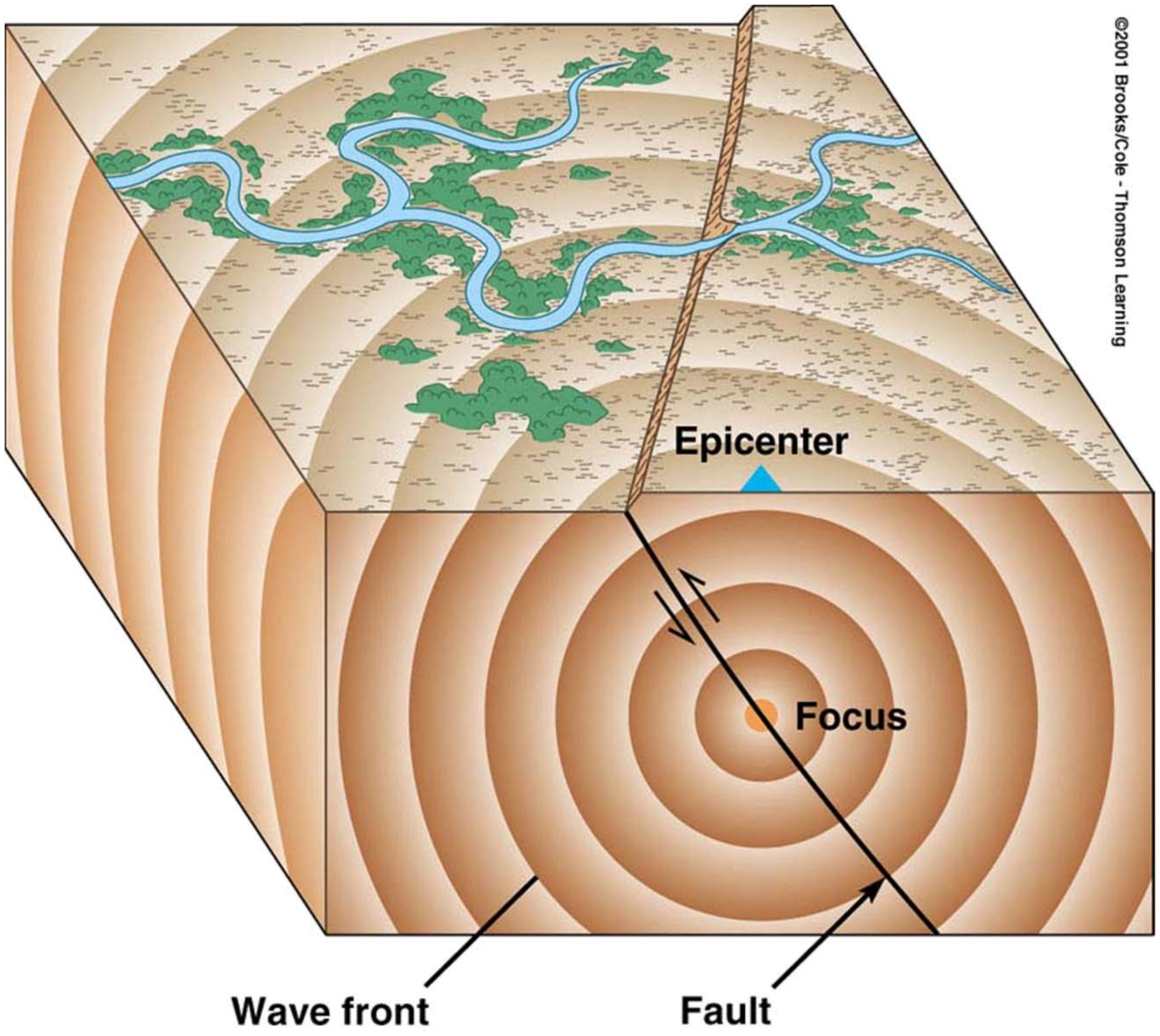
- *Fractures, faults*
- Energy released and propagates in all directions as seismic waves causing earthquakes.

Focus

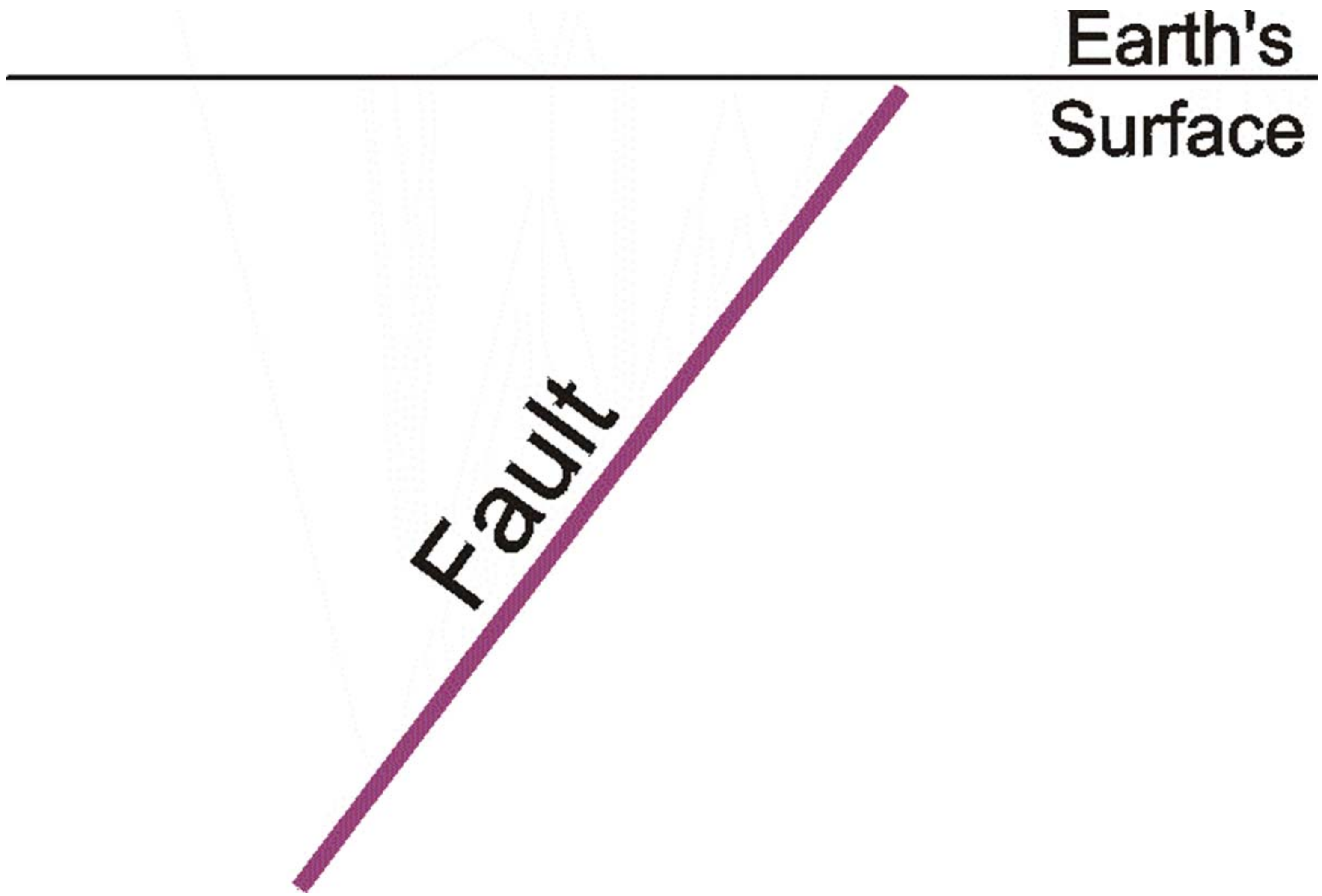
Actual point of rupture within the Earth.

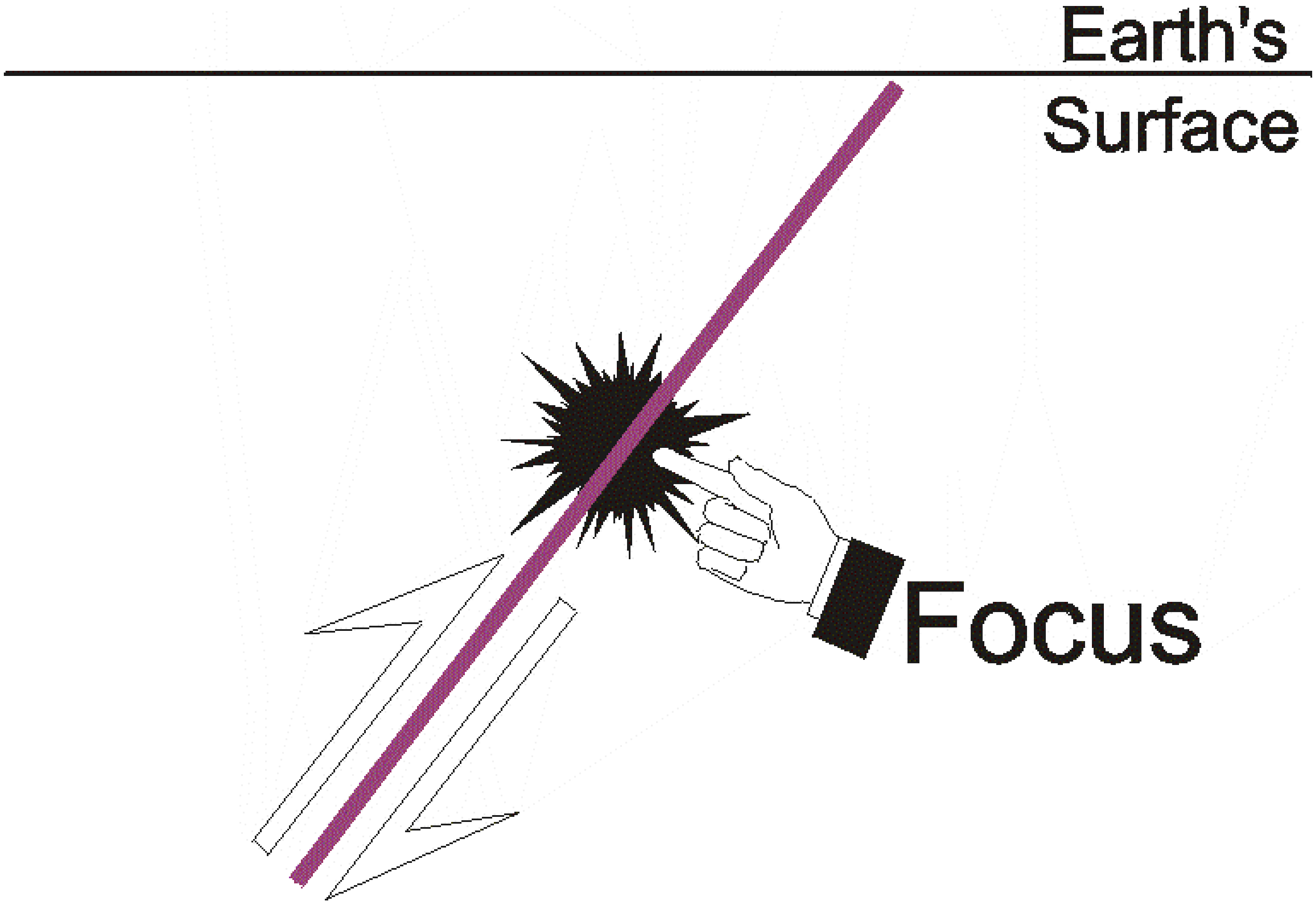
Epicenter

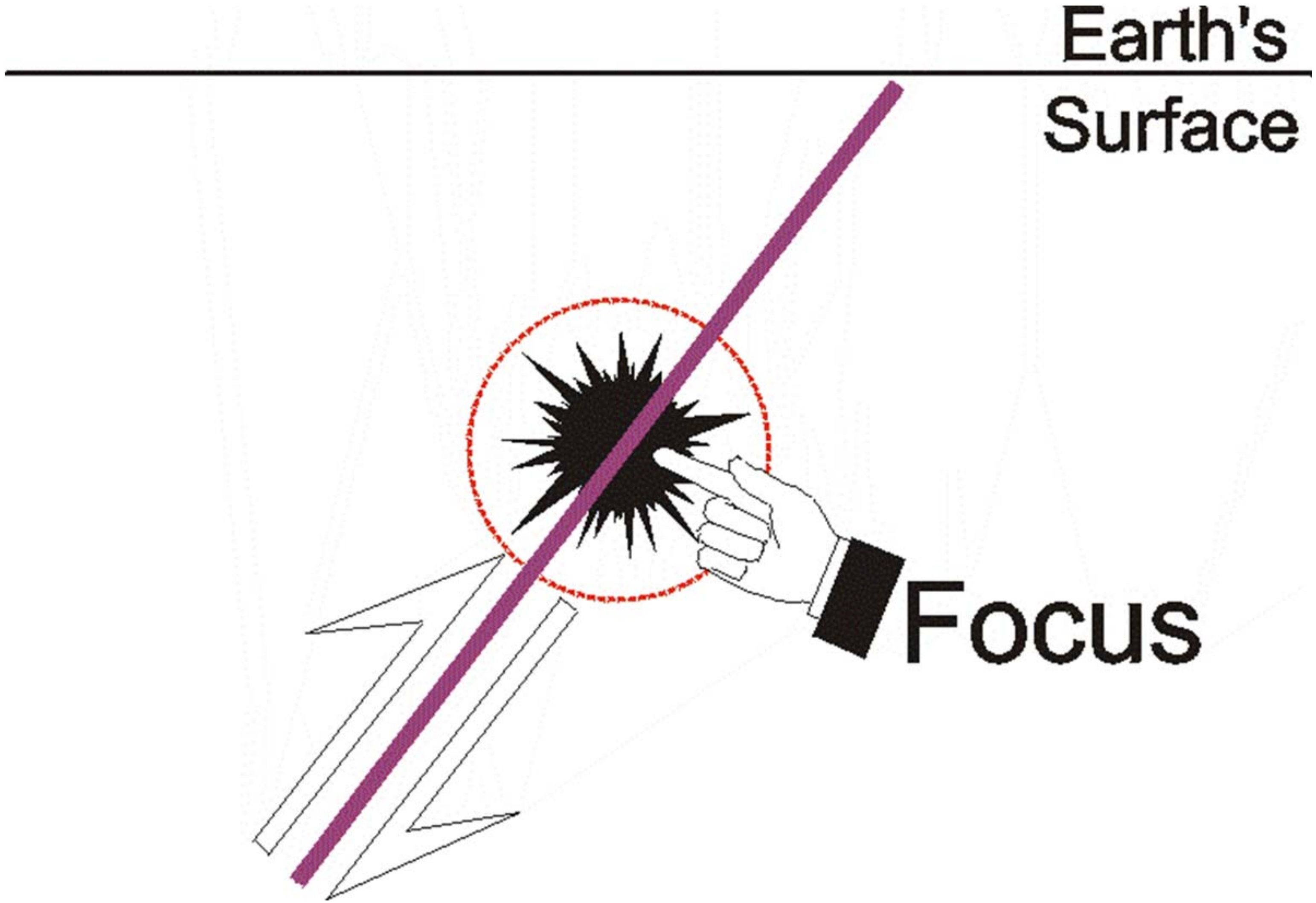
Point on Earth's surface directly above the focus.

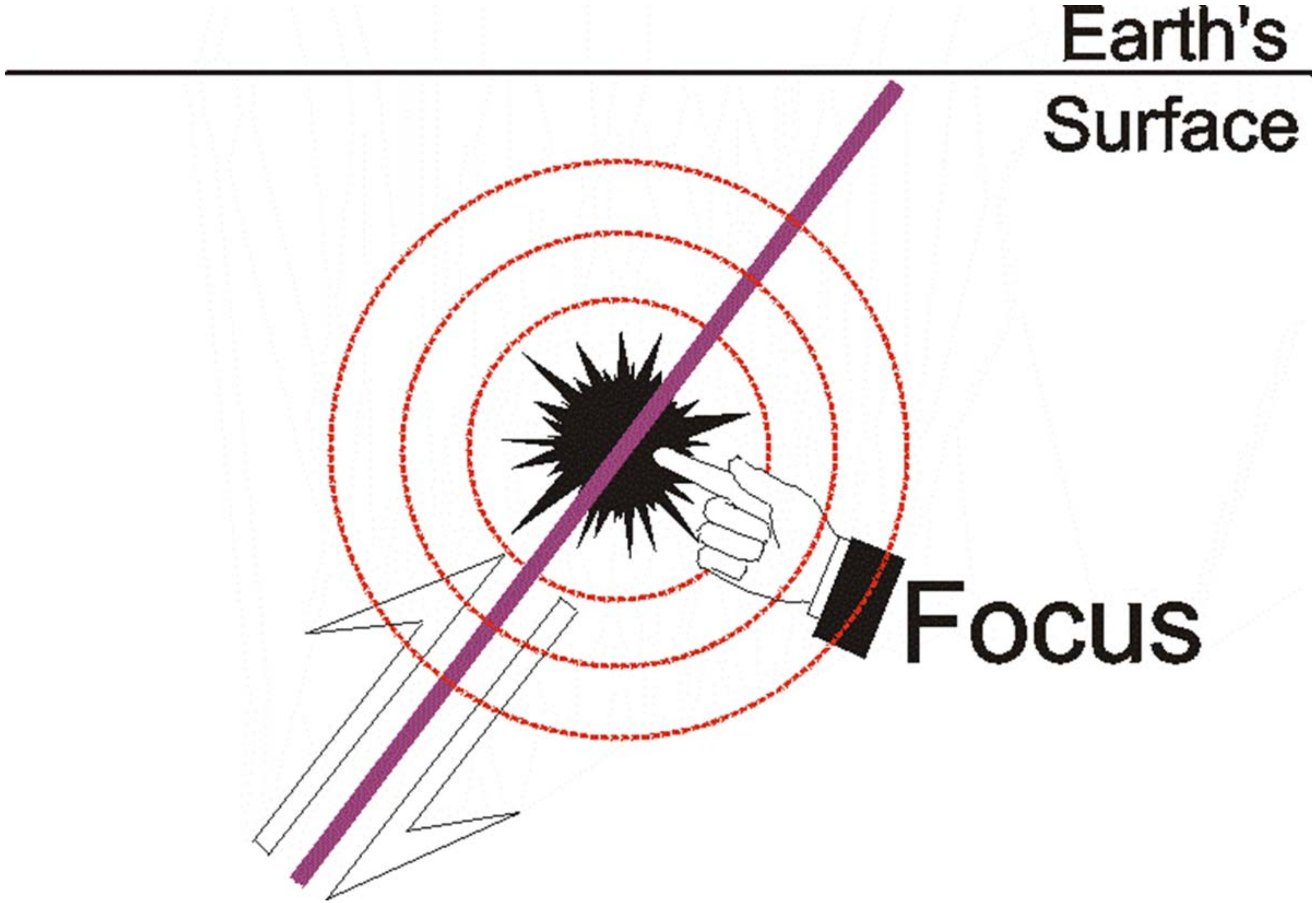


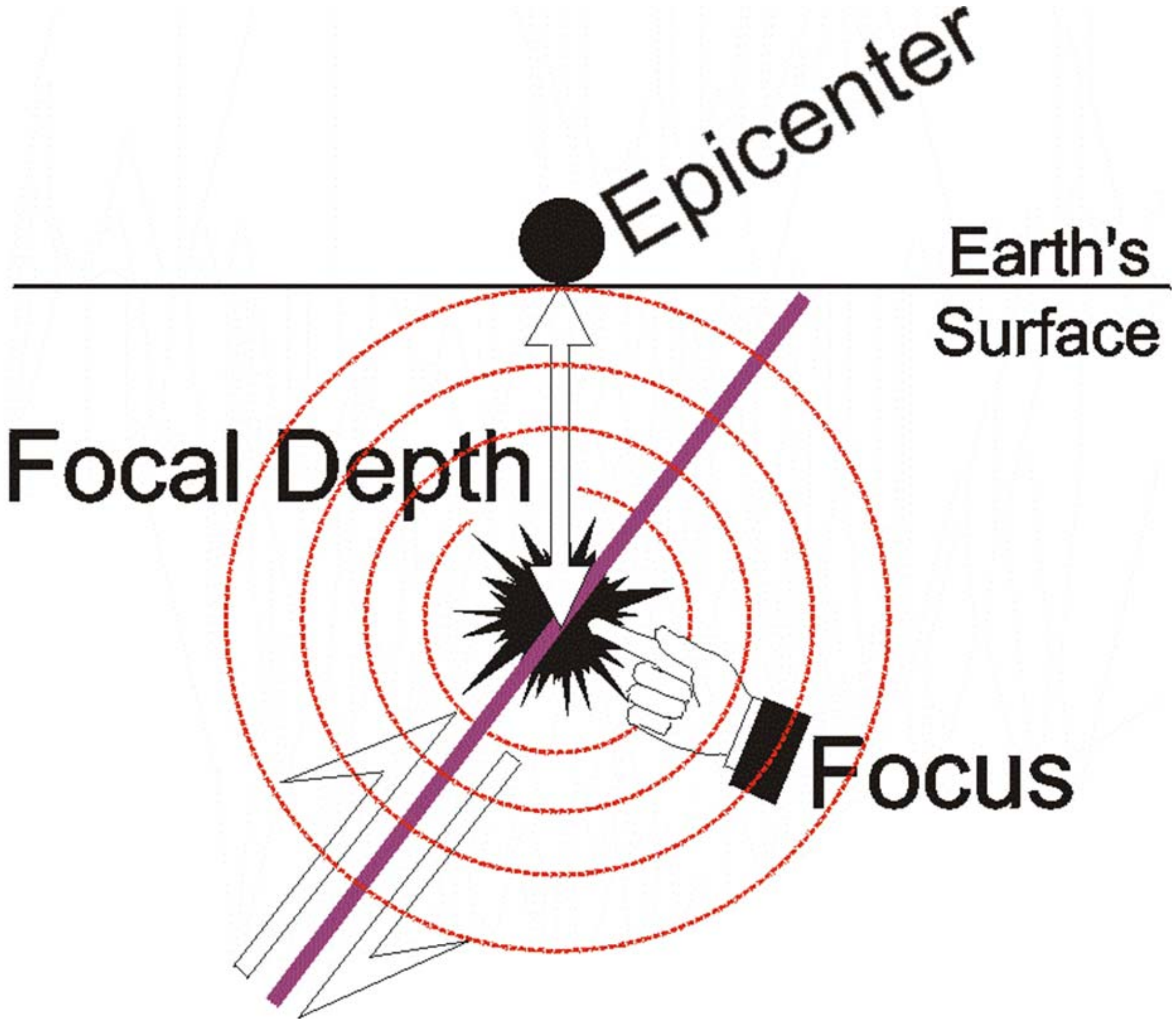
©2001 Brooks/Cole - Thomson Learning
Epicenter
Focus
Wave front
Fault

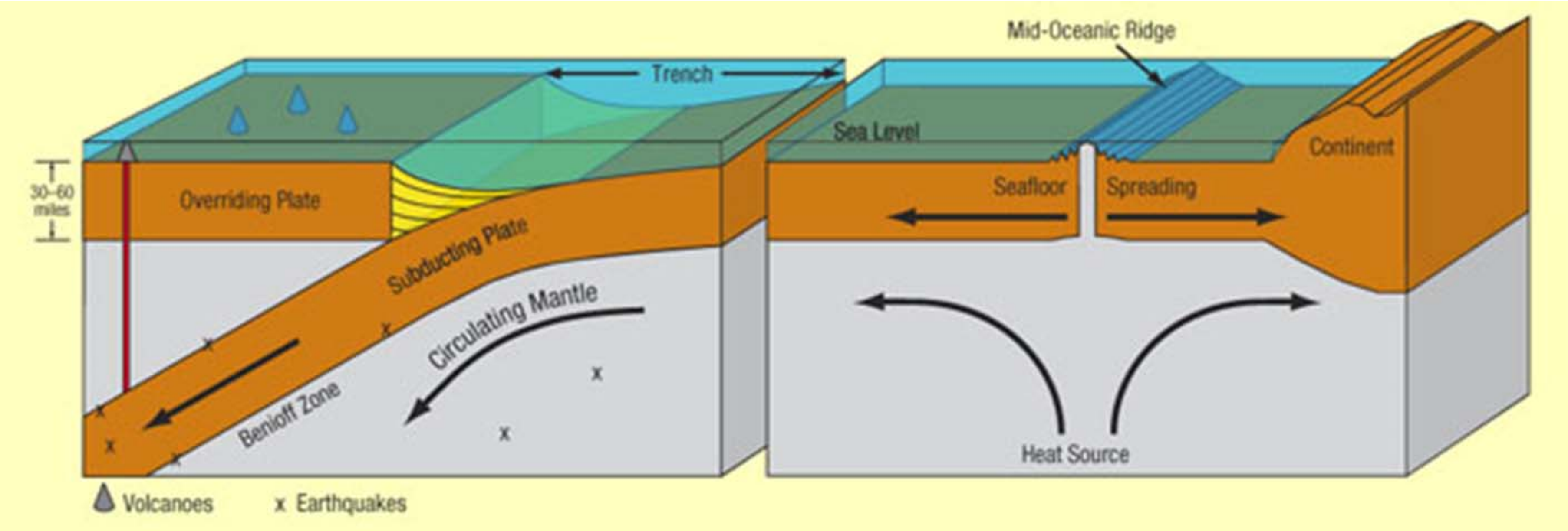

Earth's
Surface
Fault


Earth's Surface
Focus

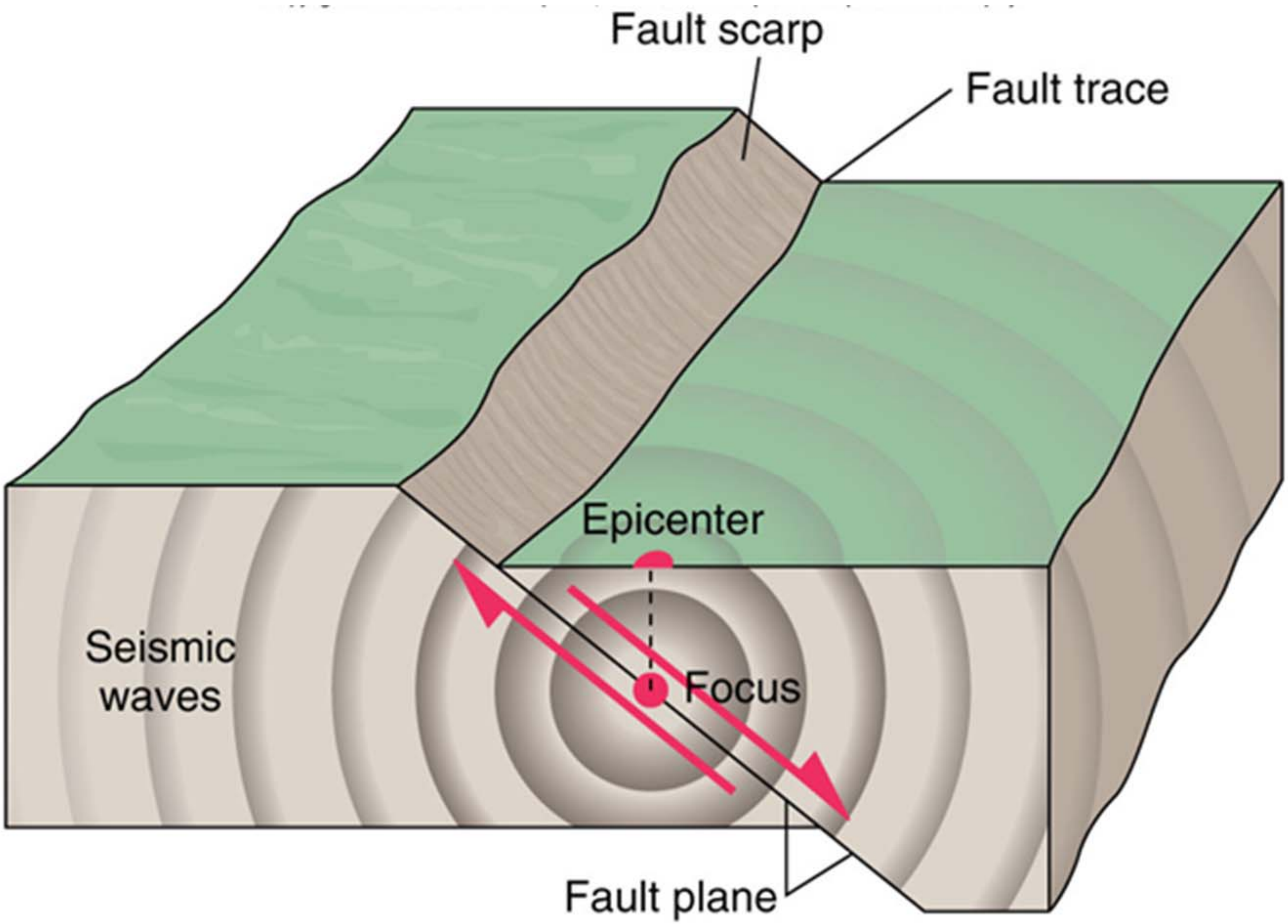

Earth's
Surface
Focus


Earth's
Surface
Focus


Epicenter
Earth's
Surface
Focal Depth
Focus



Mid-Oceanic Ridge
Trench
Sea Level
Continent
30–60 miles
Overriding Plate
Seafloor
Spreading
Subducting Plate
Circulating Mantle
Benioff Zone
Heat Source
Volcanoes
x Earthquakes


Fault scarp
Fault trace
Epicenter
Seismic waves
Focus
Fault plane

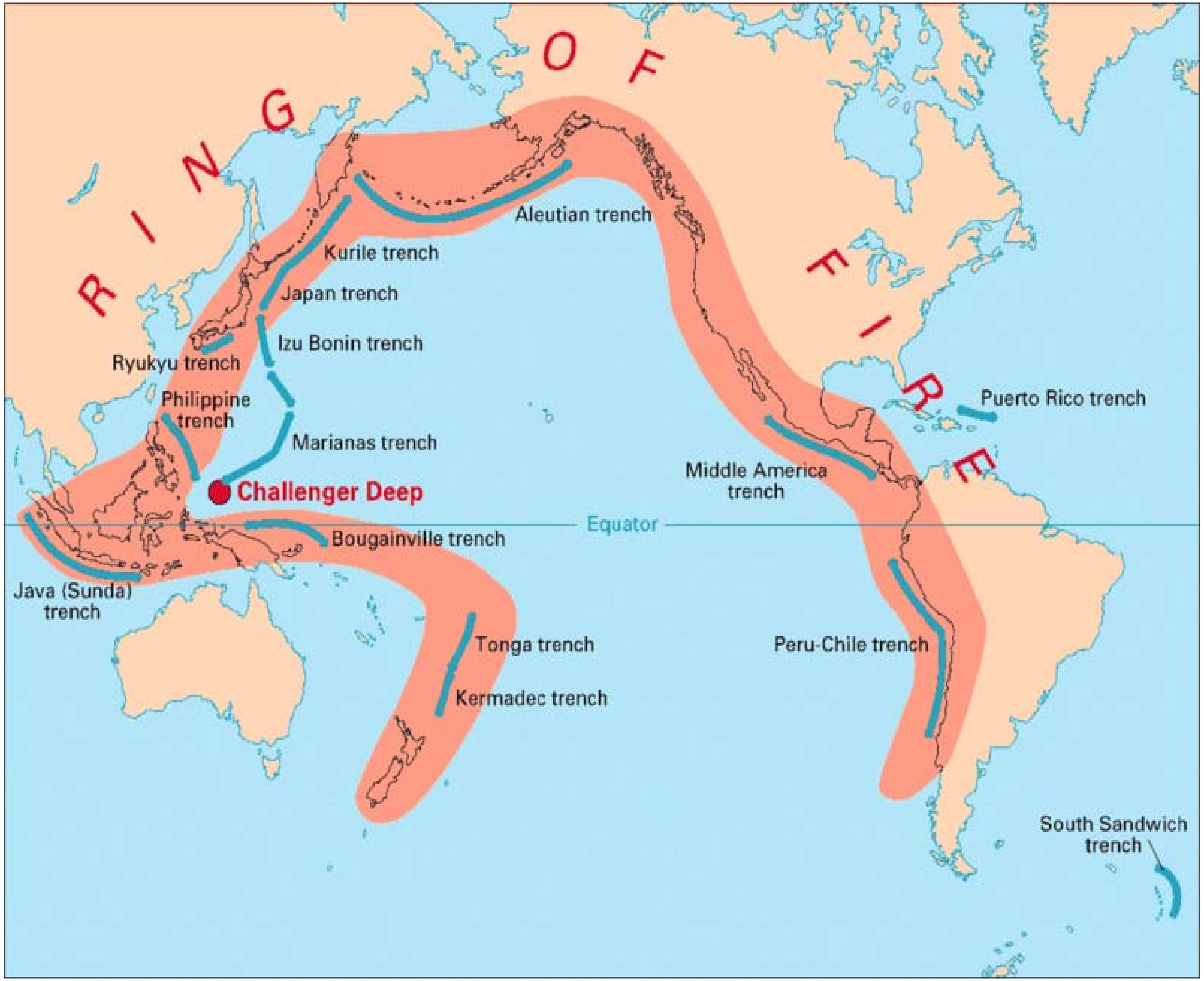
Types of earthquakes

There are many different types of earthquakes: tectonic, volcanic, and explosion. The type of earthquake depends on the region where it occurs and the geological make-up of that region.

1. **Tectonic earthquakes**. These occur when rocks in the earth's crust break due to geological forces created by movement of tectonic plates.
2. **Volcanic earthquakes** occur in conjunction with volcanic activity.
3. **Collapse earthquakes** are small earthquakes in underground caverns and mines.
4. **Explosion earthquakes** result from the explosion of nuclear and chemical devices.

Q. Earthquakes, why and where do they occur?

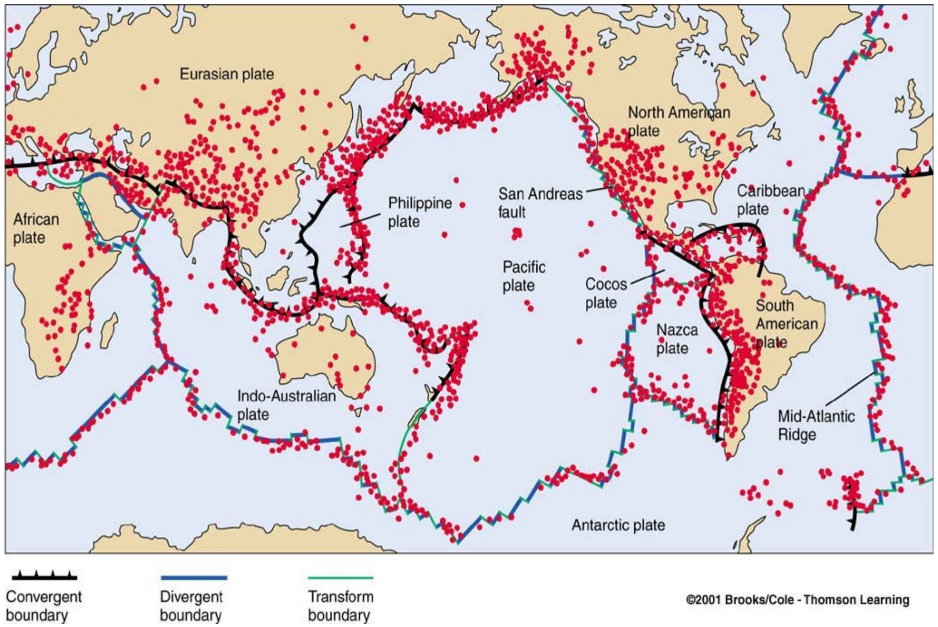
- It has long been recognized that earthquakes are not evenly distributed over the earth.
- The eventual correlation of the earthquake pattern with the earth's major surface features was a key to the evolution of the plate tectonics theory.
- The basic idea is that the earth's outermost part (Lithosphere) consists of several large and fairly stable slabs of solid and relatively rigid rock called plates.


RING OF FIRE
Aleutian trench
Kurile trench
Japan trench
Izu Bonin trench
Ryukyu trench
Philippine trench
Marianas trench
Challenger Deep
Equator
Bougainville trench
Java (Sunda) trench
Tonga trench
Kermadec trench
Puerto Rico trench
Middle America trench
Peru-Chile trench
South Sandwich trench

Where Do Earthquakes Occur and How Often?

~80% of all earthquakes occur in the circum-Pacific belt

- most of these result from convergent margin activity
- ~15% occur in the Mediterranean-Asiatic belt
- remaining 5% occur in the interiors of plates and on spreading ridge centers
- more than 150,000 quakes strong enough to be felt are recorded each year



1. Shallow earthquakes:

(Depth between 0 and 70 Km)

2. Intermediate earthquake:

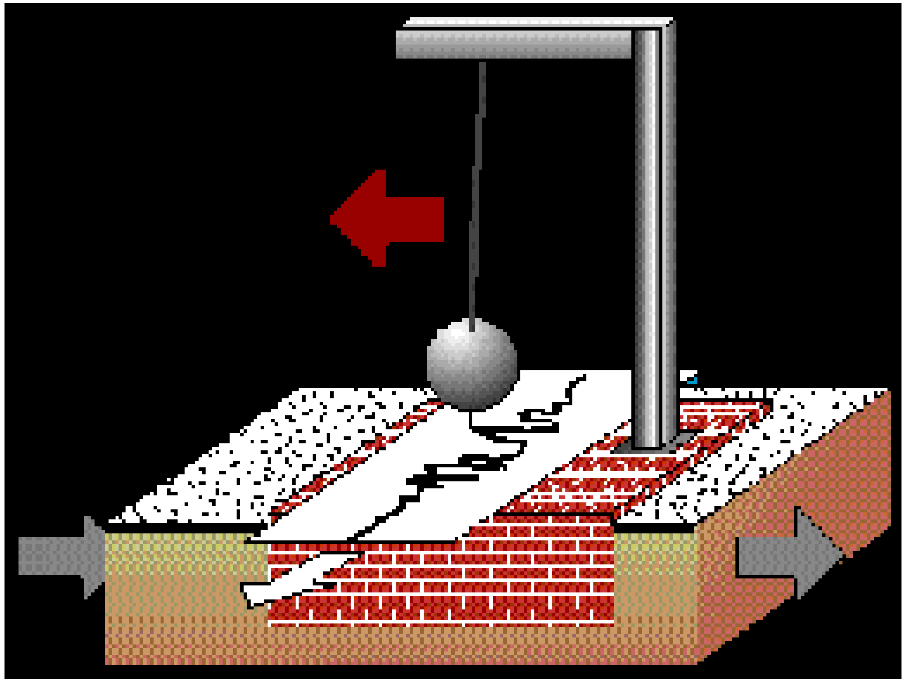
(Depth between 70 and 300 Km)

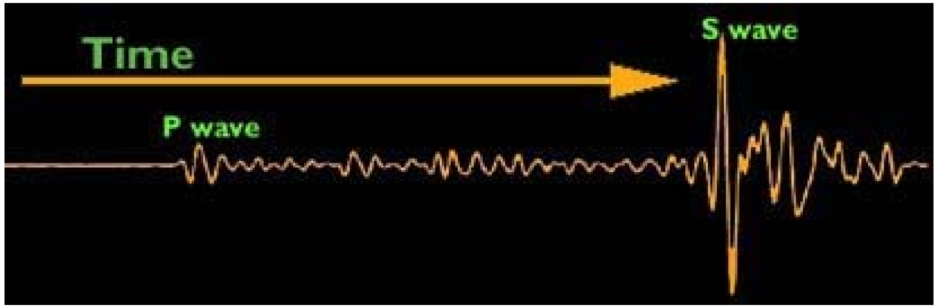
3. Deep earthquakes:

(Depth is greater than 300 Km)

Measuring earthquakes

- **Seismometers:** instruments that detect seismic waves
- **Seismographs** Record intensity, height and amplitude of seismic waves

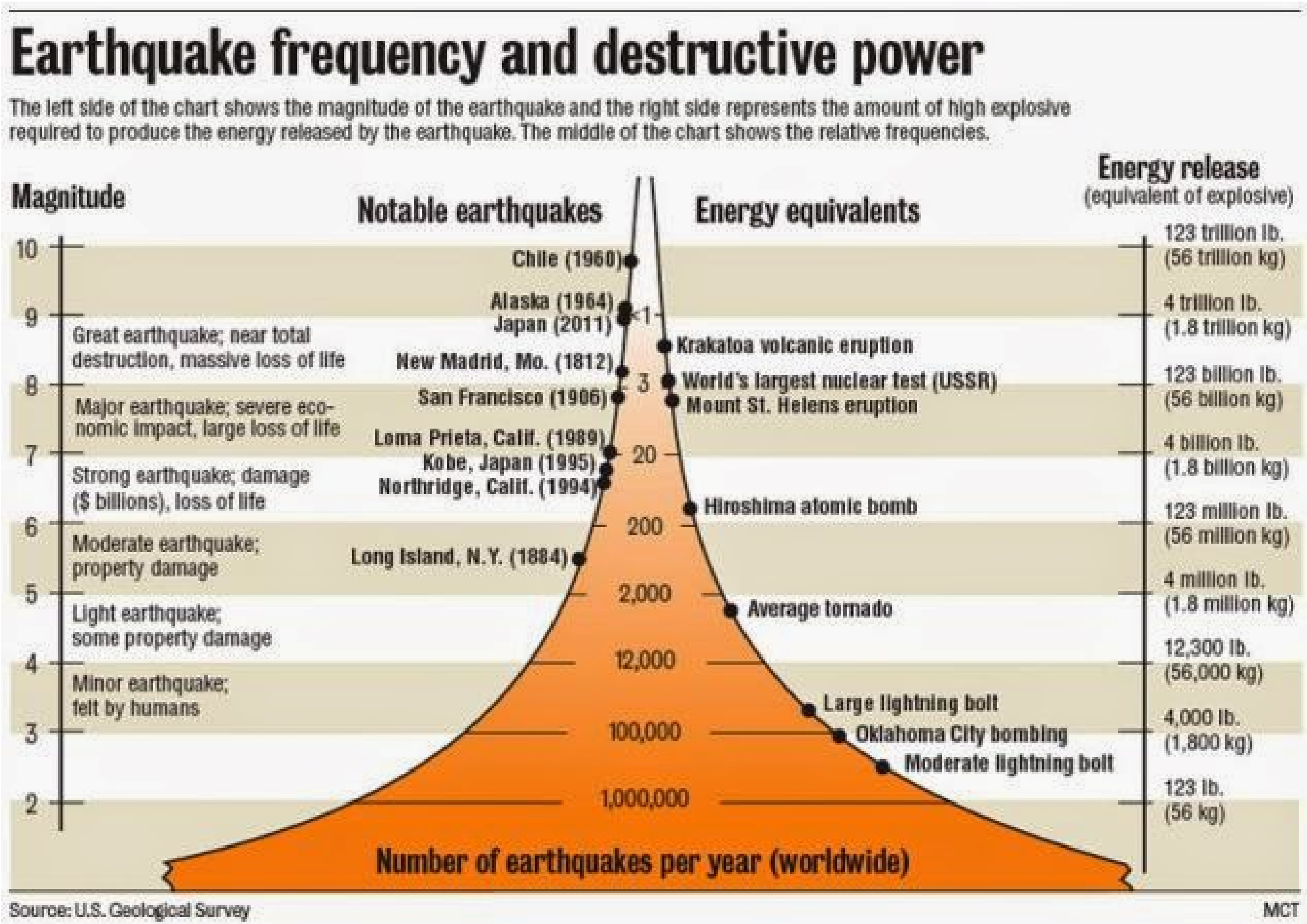


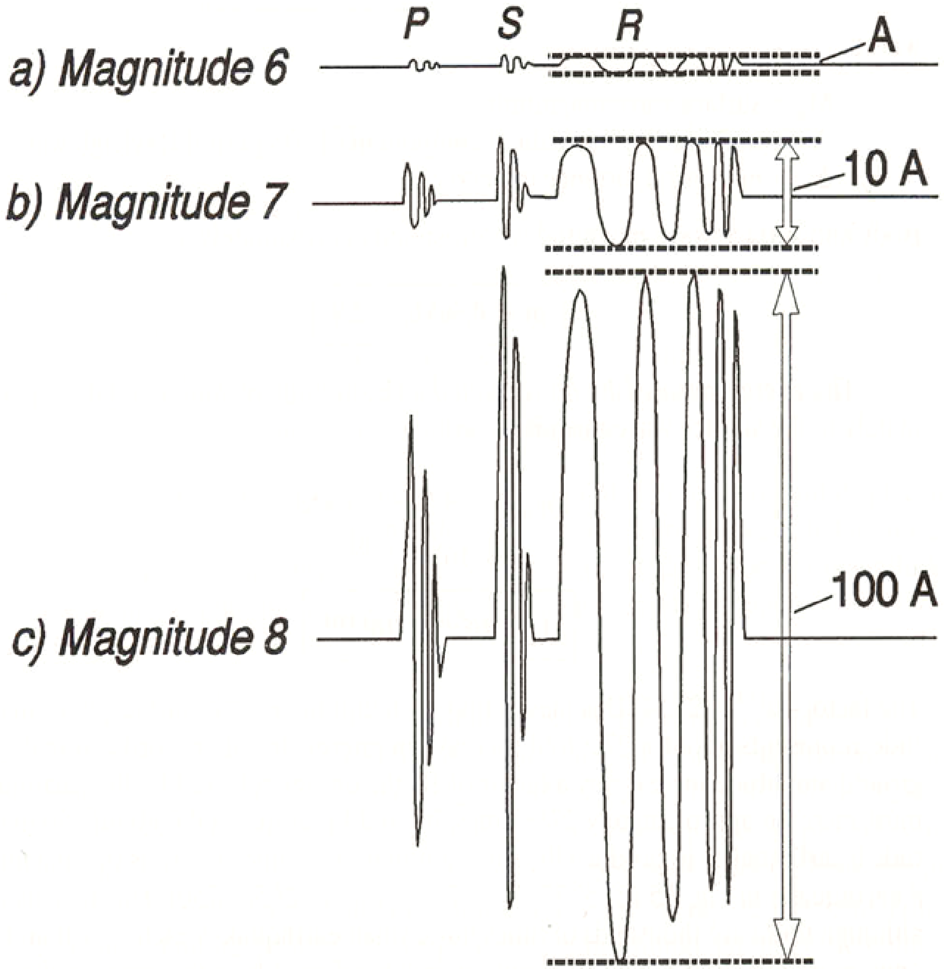


Earthquake size: two ways to measure

1) **Magnitude**: Richter Scale

- Measures the energy released by fault movement
- related to the maximum amplitude of the S wave measured from the seismogram
- Logarithmic-scale; **quantitative** measure
- For each whole number there is a 31.5 times increase in energy
  - eg. an increase from 5 to 7 on the Richter scale = an increase in energy of 992 times!!


Earthquake frequency and destructive power
The left side of the chart shows the magnitude of the earthquake and the right side represents the amount of high explosive required to produce the energy released by the earthquake. The middle of the chart shows the relative frequencies.
Magnitude
Notable earthquakes
Energy equivalents
Energy release
(equivalent of explosive)
10
9
8
7
6
5
4
3
2
Great earthquake; near total destruction, massive loss of life
Major earthquake; severe economic impact, large loss of life
Strong earthquake; damage ($ billions), loss of life
Moderate earthquake; property damage
Light earthquake; some property damage
Minor earthquake; felt by humans
Chile (1960)
Alaska (1964)
Japan (2011)
New Madrid, Mo. (1812)
San Francisco (1906)
Loma Prieta, Calif. (1989)
Kobe, Japan (1995)
Northridge, Calif. (1994)
Long Island, N.Y. (1884)
1
3
20
200
2,000
12,000
100,000
1,000,000
Krakatoa volcanic eruption
World's largest nuclear test (USSR)
Mount St. Helens eruption
Hiroshima atomic bomb
Average tornado
Large lightning bolt
Oklahoma City bombing
Moderate lightning bolt
123 trillion lb. (56 trillion kg)
4 trillion lb. (1.8 trillion kg)
123 billion lb. (56 billion kg)
4 billion lb. (1.8 billion kg)
123 million lb. (56 million kg)
4 million lb. (1.8 million kg)
12,300 lb. (56,000 kg)
4,000 lb. (1,800 kg)
123 lb. (56 kg)
Number of earthquakes per year (worldwide)
Source: U.S. Geological Survey
MCT


P
S
R
A
a) Magnitude 6
10 A
b) Magnitude 7
100 A
c) Magnitude 8

2) **Intensity:** Mercalli Scale:

- *What did you feel?*
- Assigns an intensity or rating to measure an earthquake at a particular location (**qualitative)**
- I (not felt) to XII (buildings nearly destroyed)
- Measures the destructive effect

- Intensity is a function of:
    - Energy released by fault
    - Geology of the location
    - Surface substrate: can magnify shock waves e.g. Mexico City (1985) and San Francisco (1989)

Modified Mercalli Scale	
I	Only felt by sensitive instruments
II	Felt by few persons at rest, especially on upper floors, delcate suspended objects may swing
III	Felt indoors, but may not be recognized as earthquake, vibrations like large passing truck
IV	Felt indoors by many, some outdoors, may awaken some sleeping persons; dishes, windows, doors may move, cars rock.
V	Felt by most; some windows, dishes break; tall objects may fall.
VI	Felt by by all, falling plaster and chimneys, light damage but some fear.
VII	Very noticeable, damage to weaker buildings on fill; driving automobiles notice.
VIII	Walls, monuments, chimneys, bookcases fall; liquifaction; driving is difficult
IX	Buildings shifted off foundations, cracked and twisted; ground is cracked and underground pipes are broken.
X	Most structures severely damaged to destroyed; ground is cracked, rails are bent, landslides on steep slopes
XI	Few structures standing; bridges and roads severely damaged or destroyed, large fissures in ground
XII	Total damage; can see the earthquake wave move through the ground; gravity overcome and objects thrown into the air

Richter Magnitude Scale
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0

Largest earthquake in the world

Chile:
1960 May 22
19:11:14 UTC
Magnitude 9.5

- More than 2,000 killed, 3,000 injured, 2,000,000 homeless, and $550 million damage in southern Chile
- tsunami caused 61 deaths
- $75 million damage in Hawaii;
- 138 deaths and $50 million damage in Japan;
- 32 dead and missing in the Philippines; and $500,000 damage to the west coast of the United States.

Table 12.2 A Sampling of Significant Earthquakes**

Year	Date	Location	Number of Deaths	Mercalli Intensity	Moment Magnitude (Richter)
1556	Jan. 23	Shaanxi Province, China	830,000	*	*
1737	Oct. 11	Calcutta, India	300,000	*	*
1812	Feb. 7	New Madrid, Missouri	Several	XI–XII	*
1857	Jan. 9	Fort Tejon, California	*	X–XI	*
1870	Oct. 21	Montreal to Québec, Canada	*	IX	*
1886	Aug. 31	Charleston, South Carolina	*	IX	6.7
1906	Apr. 18	San Francisco, California	3,000	XI	7.7 (8.25)
1923	Sept. 1	Kwanto, Japan	143,000	XII	7.9 (8.2)
1939	Dec. 27	Erzincan, Turkey	40,000	XII	7.6 (8.0)
1960	May 22	Southern Chile	5,700	XII	9.5 (8.6)
1964	Mar. 28	Southern Alaska	131	X–XII	9.2 (8.6)
1970	May 31	Northern Peru	66,000	*	7.9 (7.8)
1971	Feb. 9	San Fernando, California	65	VII–IX	6.7 (6.5)
1972	Dec. 23	Managua, Nicaragua	5,000	X–XII	6.2 (6.2)
1976	Jul. 28	Tangshan, China	250,000	XI–XII	7.4 (7.6)
1978	Sept. 16	Iran	25,000	X–XII	7.8 (7.7)
1985	Sept. 19	Mexico City, Mexico	7,000	IX–XII	8.1 (8.1)
1988	Dec. 7	Armenia–Turkey border	30,000	XII	6.8 (6.9)
1989	Oct. 17	Loma Prieta (near Santa Cruz, California)	66	VII–IX	7.0 (7.1)
1991	Oct. 20	Uttar Pradesh, India	1,700	IX–XI	6.2 (6.1)
1994	Jan. 17	Northridge (Reseda), California	66	VII–IX	6.8
1995	Jan. 17	Kobe, Japan	5,500	XII	6.9
1996	Feb. 17	Indonesia	110	X	8.1
1997	Feb. 28	Armenia–Azerbaijan	1,100	XII	6.1
1997	May 10	Northern Iran	1,600	XII	7.3
1998	May 30	Afghanistan–Tajikistan	4,000	XII	6.9
1998	Jul. 17	Papua, New Guinea	2,200	X	7.1
1999	Jan. 26	Armenia, Colombia	1,000	VIII–IX	6.0
1999	Aug. 17	Izmit, Turkey	17,100	VIII–XI	7.4
1999	Sept. 7	Athens, Greece	150	VI–VIII	5.9
1999	Sept. 20	Chi-Chi, Taiwan	2,500	VI–X	7.6
1999	Sept. 30	Oaxaca, Mexico	33	VI	7.5
1999	Oct. 16	Hector Mine, California	0	*	7.1
1999	Nov. 12	Düzce, Turkey	700	VI–X	7.2
2001	Jan. 26	Gujarat state, India	19,998	X–XII	7.7

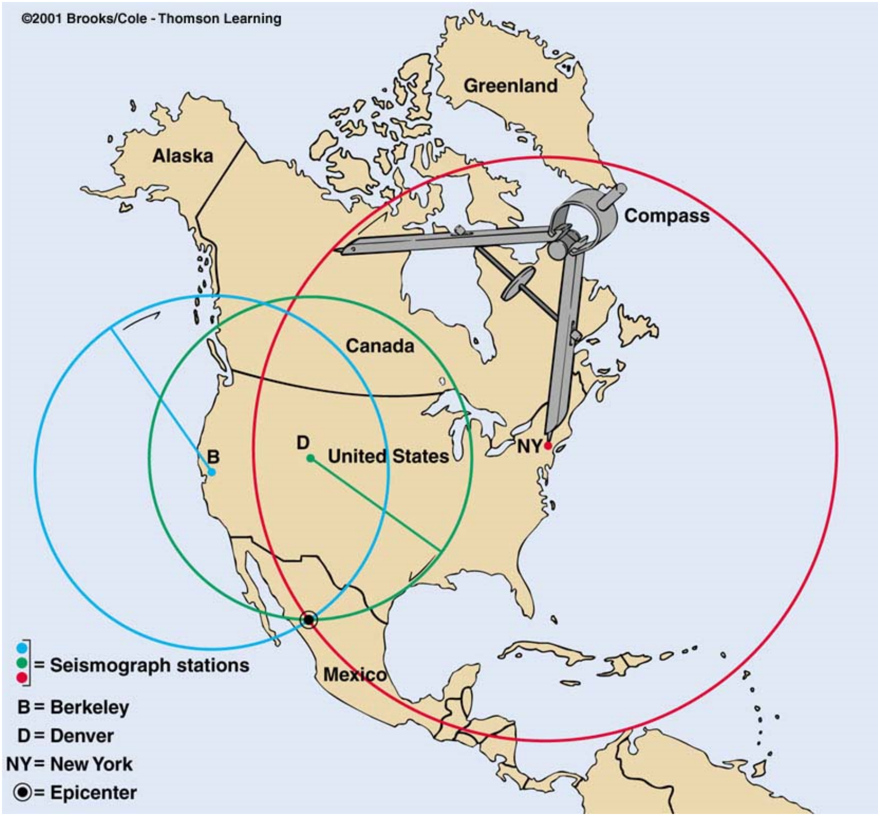
*Data not available.
**There is not a recent increase in earthquakes; this table merely reflects more detail on the recent record.

Q. How to locate the epicenter of an earthquake?

- P waves and S waves travel at different velocities.
- The first P wave will arrive at a seismic station before the first S wave.
- By using the difference in their arrival times you can determine the distance between the epicenter of any earthquake and a seismic station.
- Once you have determined that distance, you can use it as the radius of a circle and can draw a circle around the seismic station.
- You need two other seismic stations doing the same thing.
- Where the three circles intersect is approximately where the epicenter of the Earthquake is.

How is an Earthquake's Epicenter Located?

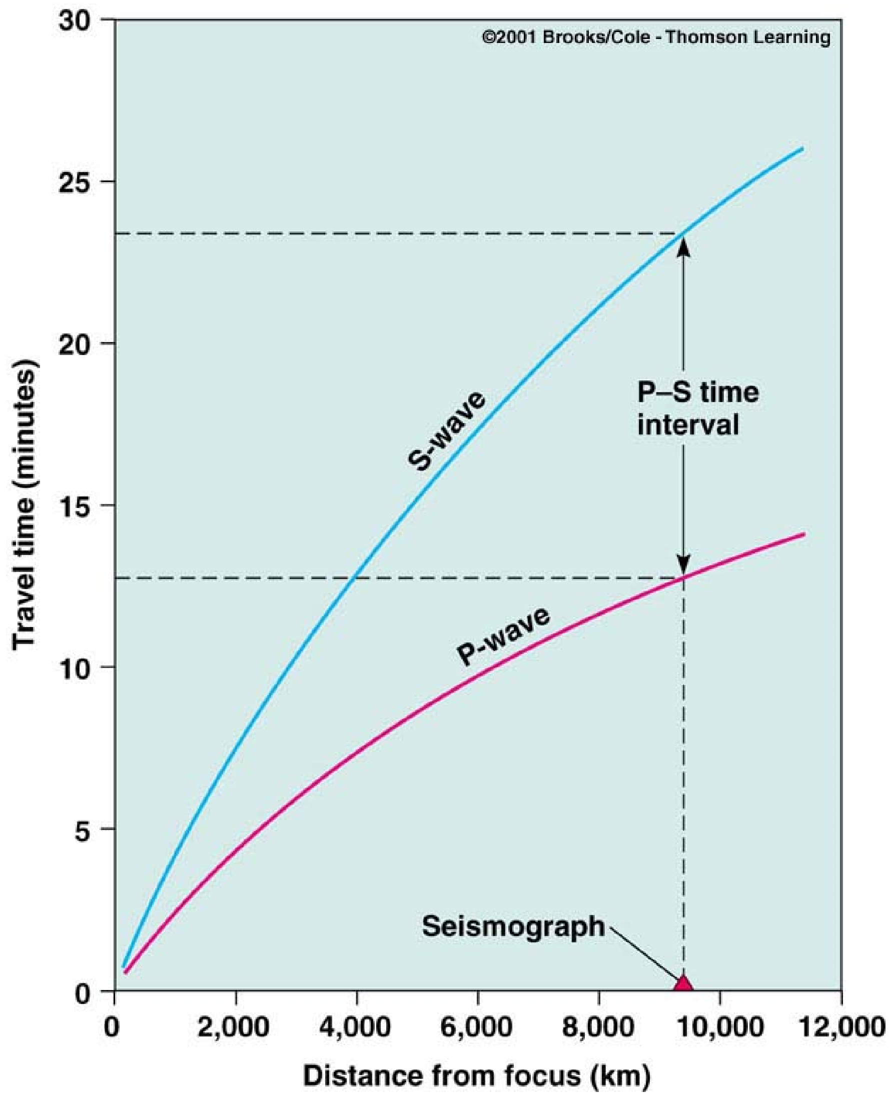
- Three seismograph stations are needed to locate the epicenter of an earthquake
- A circle where the radius equals the distance to the epicenter is drawn
- The intersection of the circles locates the epicenter

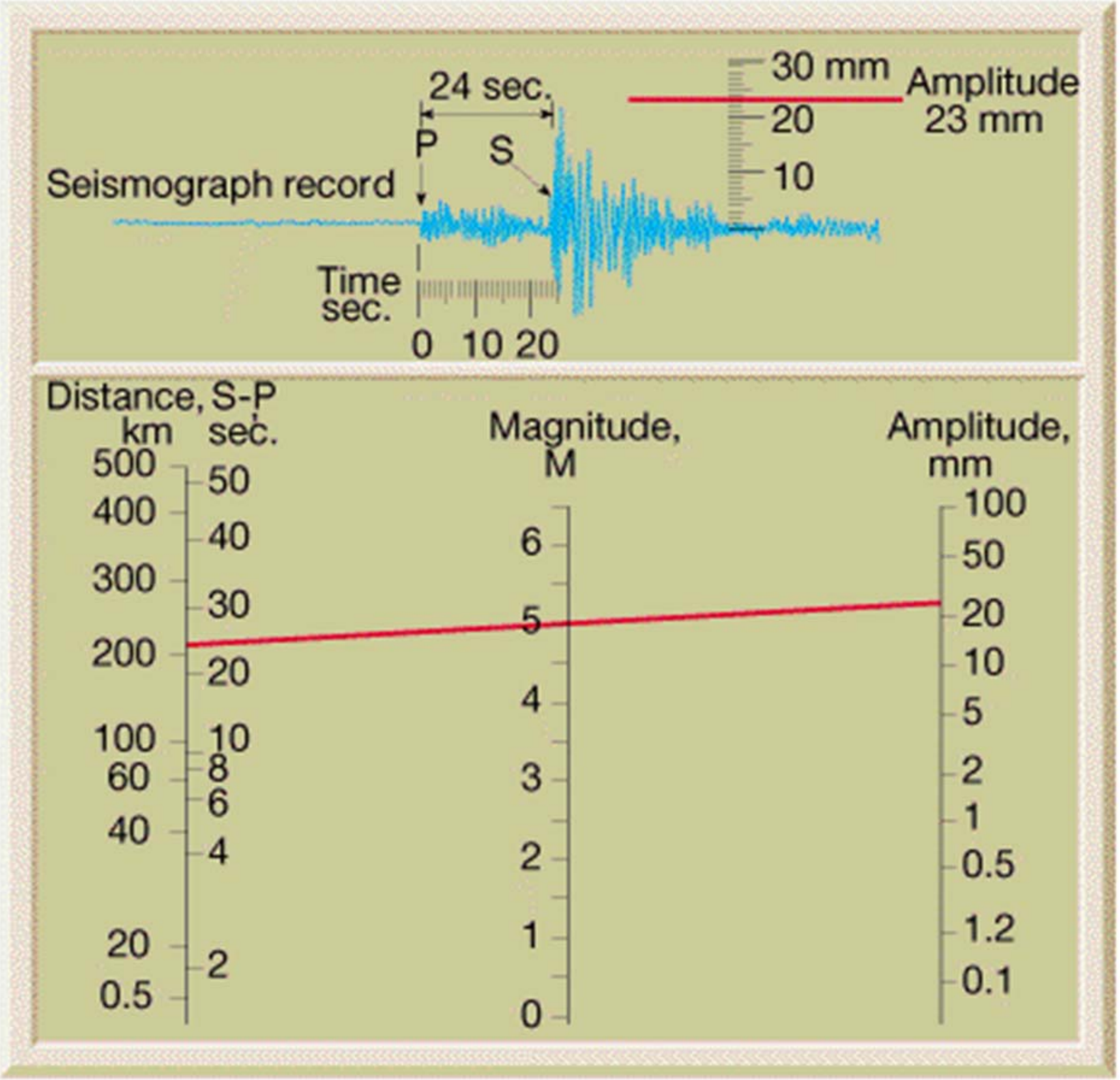


How is an Earthquake's Epicenter Located?

Time-distance graph showing the average travel times for P- and S-waves.

The farther away a seismograph is from the focus of an earthquake, the longer the interval between the arrivals of the P- and S-waves




24 sec.
30 mm
Amplitude
23 mm
20
10
P
S
Seismograph record
Time sec.
0 10 20
Distance, km
S-P sec.
500
400
300
200
100
60
40
20
0.5
50
40
30
20
10
8
6
4
2
Magnitude, M
6
5
4
3
2
1
0
Amplitude, mm
100
50
20
10
5
2
1
0.5
1.2
0.1

Types of magnitudes

Nowadays there are different ways to determine the magnitude of an earthquake:

Body wave magnitude (m_b) depends on the amplitude of a particular P or S wave :

$$m_b = \log_{10} (A/T) + \alpha$$

where : **m_b** - body wave magnitude

A- ground displacement in microns (10-6m)

T-period of selected(P or S) wave in seconds

α-factor correcting the epicentral distance, focal depth, and type of wave

Types of magnitudes

Surface wave magnitude (M_s) is a function of the observed amplitude of Rayleigh waves :

$$M_s = \log_{10} A + 1.656 \log_{10} \Delta + 1.818$$

where : **M_s** - surface wave magnitude

A- Amplitude of horizontal component of 20s period Rayleigh wave

Δ- Epicentral distance in degrees period of selected surface wave

Body and surface wave magnitudes are related by the relationship :

$$m_b = 0.56\, M_s + 2.9$$

Energy of earthquakes (E)

The energy released by an earthquake (**E**, in units of Joules) relates to the surface wave magnitude $\mathbf{M_s}$:

$$\log_{10} E = 5.24 + 1.44\, M_s$$

or :

$$E = 10^{(5.24 + 1.44\, Ms)}$$

Moment magnitude

For very large earthquakes , M_b and M_s saturate: amplitudes cease to increase dramatically with increasing energy. It is more useful to use moment magnitude (M_w)

$$M_w = [(\log_{10} M_o)/1.5] - 10.73$$

where :

$$M_o = (A)(u)(\mu)$$

represents seismic moment

A -area of fault that ruptures during earthquake

u -average displacement across the fault during earthquake

μ -shear modulus (rigidity) of the rock

This equation illustrates that the larger the area of rupture(**A**) and fault displacement(**u**), the larger the earthquake.