Unit 3

Earthquakes and Plate Tectonics

We are floating right now!

We are floating right now!

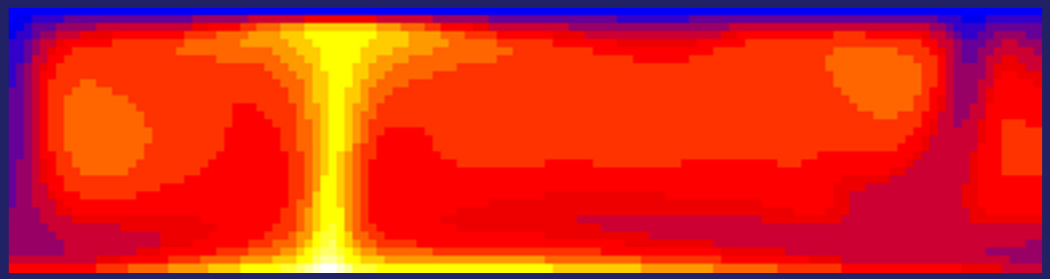
Convection cell –

-a stream of heated material that is moving because of differences in _____.

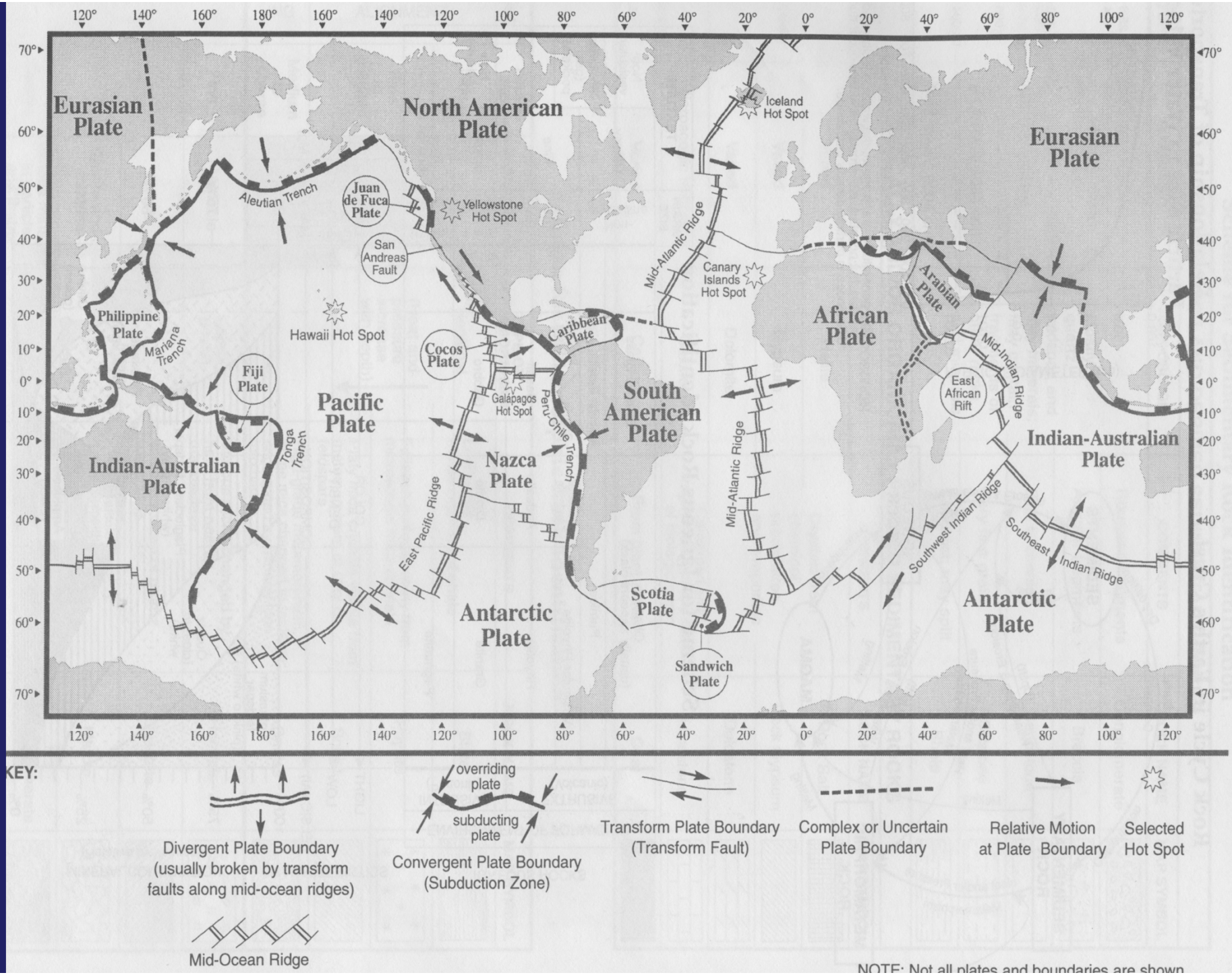
Convection cell –

-a stream of heated material that is moving because of differences in ___density___.

-convection cells exist in the upper mantle (called the asthenosphere)



This animation shows how the hot silicate rock of the Earth's mantle is stirred by heat trying to escape. The heat is generated by the radioactive decay of natural elements like uranium. The hot rock (yellow) rises slowly as the denser cold rock (blue) sinks. The layer is at least 700 km thick, and could be as thick as 2900 km. The rock is at temperatures of order 1000 to 2000°C and creeps like a very viscous fluid. Its viscosity is about 20 orders of magnitude greater than that of water so velocity is only centimeters per year, and the time interval of this animation is of order 10 million years


Eurasian Plate
North American Plate
Eurasian Plate
Iceland Hot Spot
Aleutian Trench
Juan de Fuca Plate
Yellowstone Hot Spot
San Andreas Fault
Mid-Atlantic Ridge
Canary Islands Hot Spot
Arabian Plate
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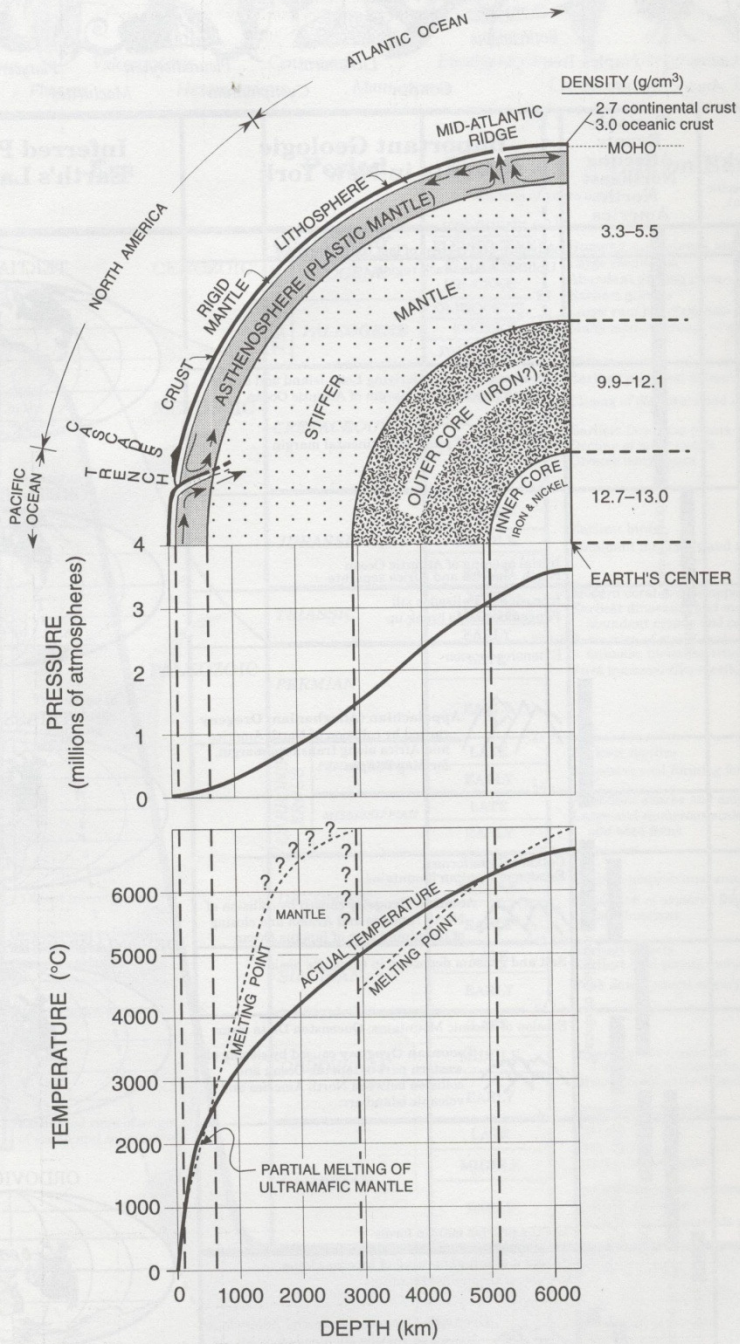
KEY:
Divergent Plate Boundary (usually broken by transform faults along mid-ocean ridges)
overriding plate
subducting plate
Convergent Plate Boundary (Subduction Zone)
Transform Plate Boundary (Transform Fault)
Complex or Uncertain Plate Boundary
Relative Motion at Plate Boundary
Selected Hot Spot
Mid-Ocean Ridge
NOTE: Not all plates and boundaries are shown

Tectonic plates - solid pieces of the earth's lithosphere that hold both land and oceans

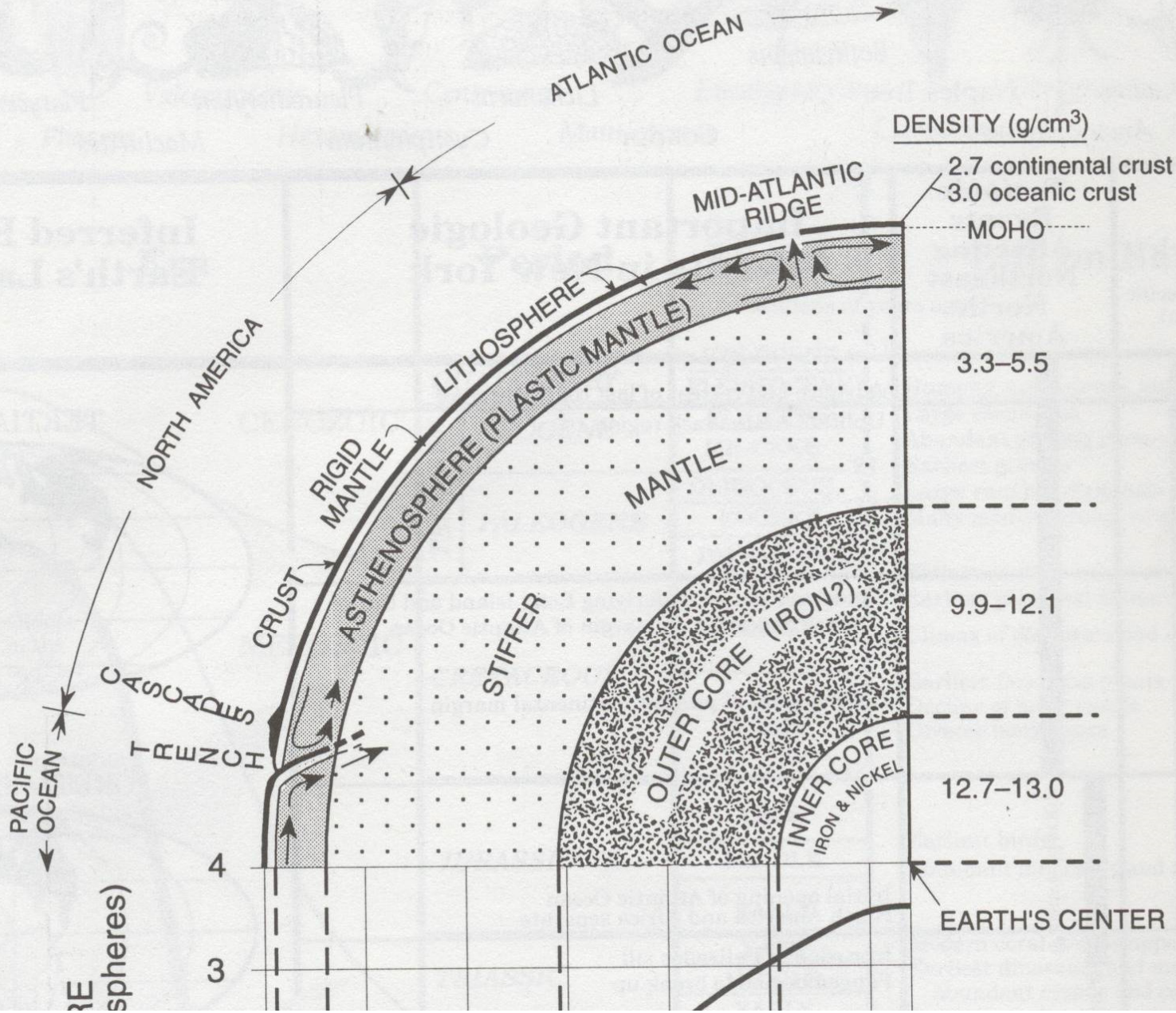
Lithosphere – includes the crust and the upper (hard) part of the mantle

Asthenosphere – includes the lower gooey (plastic) part of the mantle

Inferred Properties of Earth's Interior



Inferred Properties of Earth's Interior



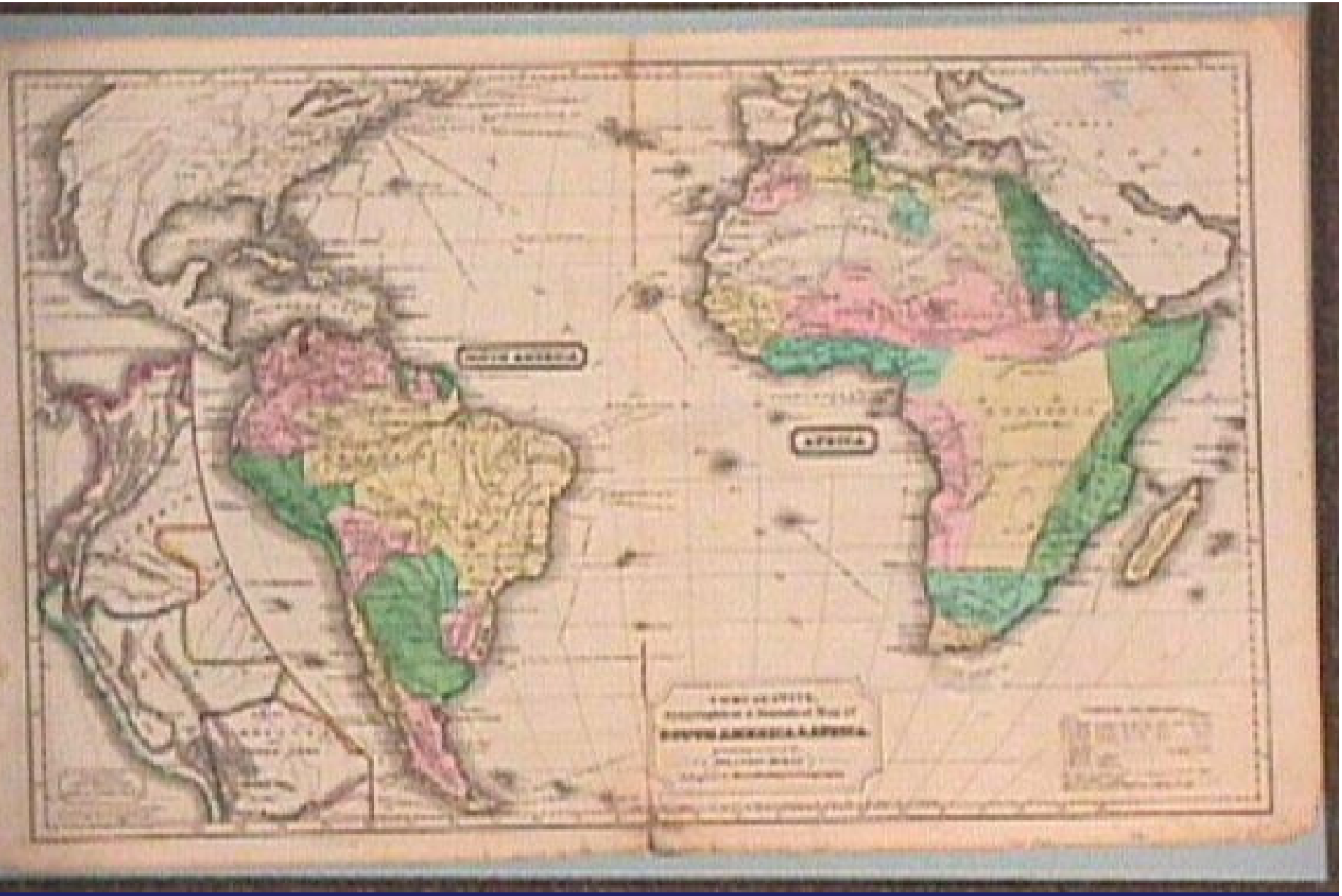
Continental drift – the idea that the plates are floating on top of the asthenosphere

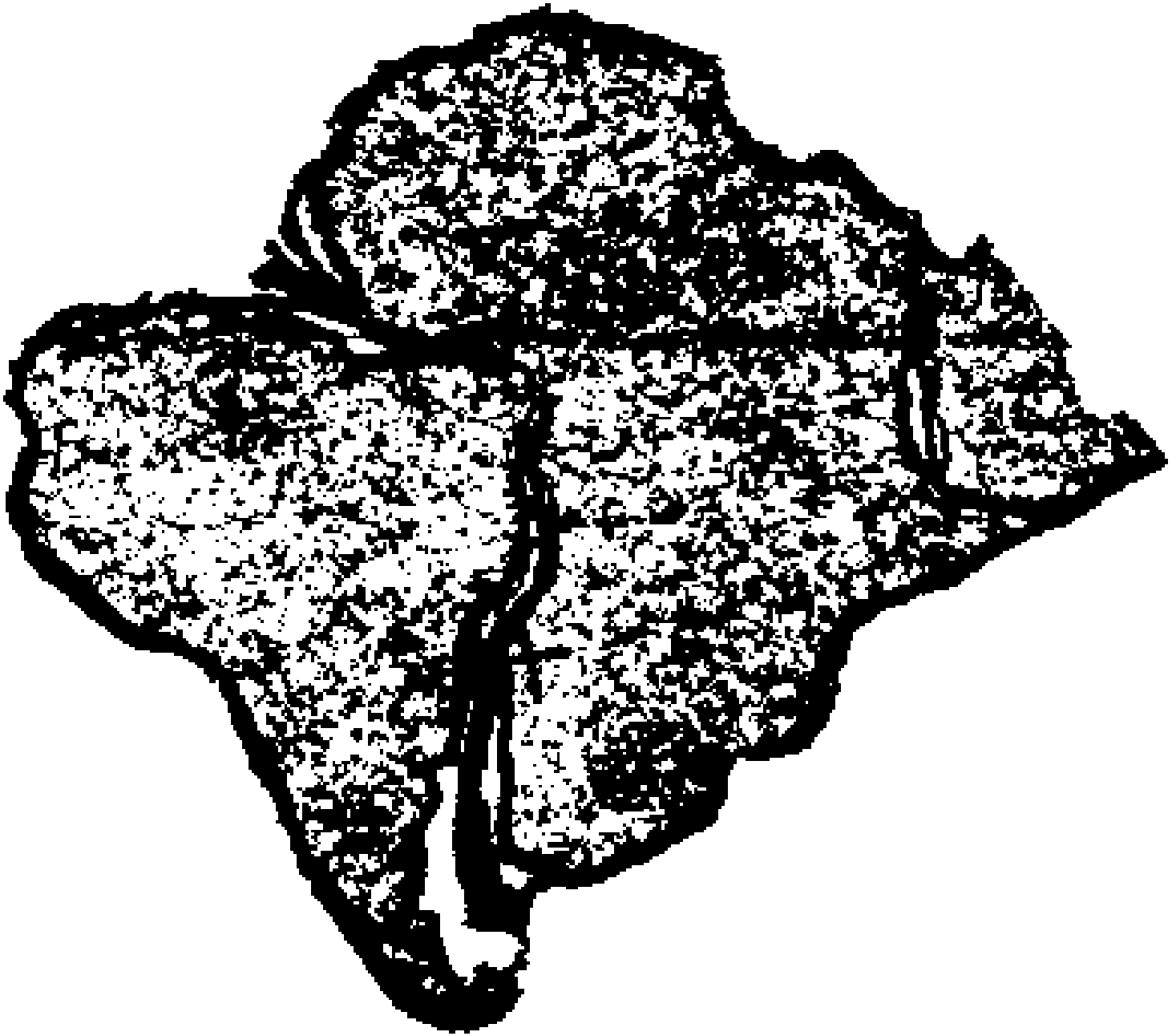
Alfred Wegener

nobody believed him :-(

Was he crazy?

His proof:

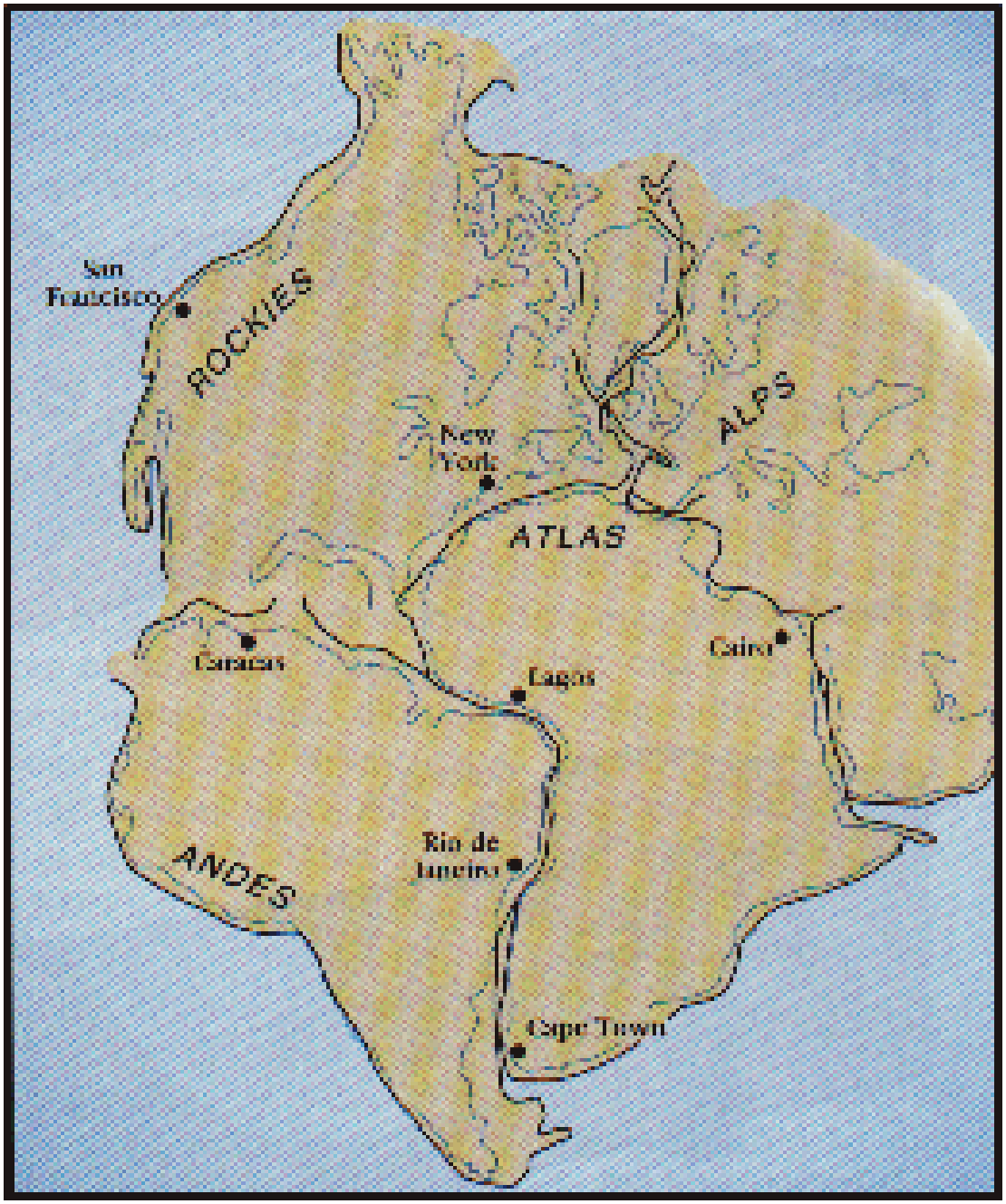

NORTH AMERICA
AFRICA

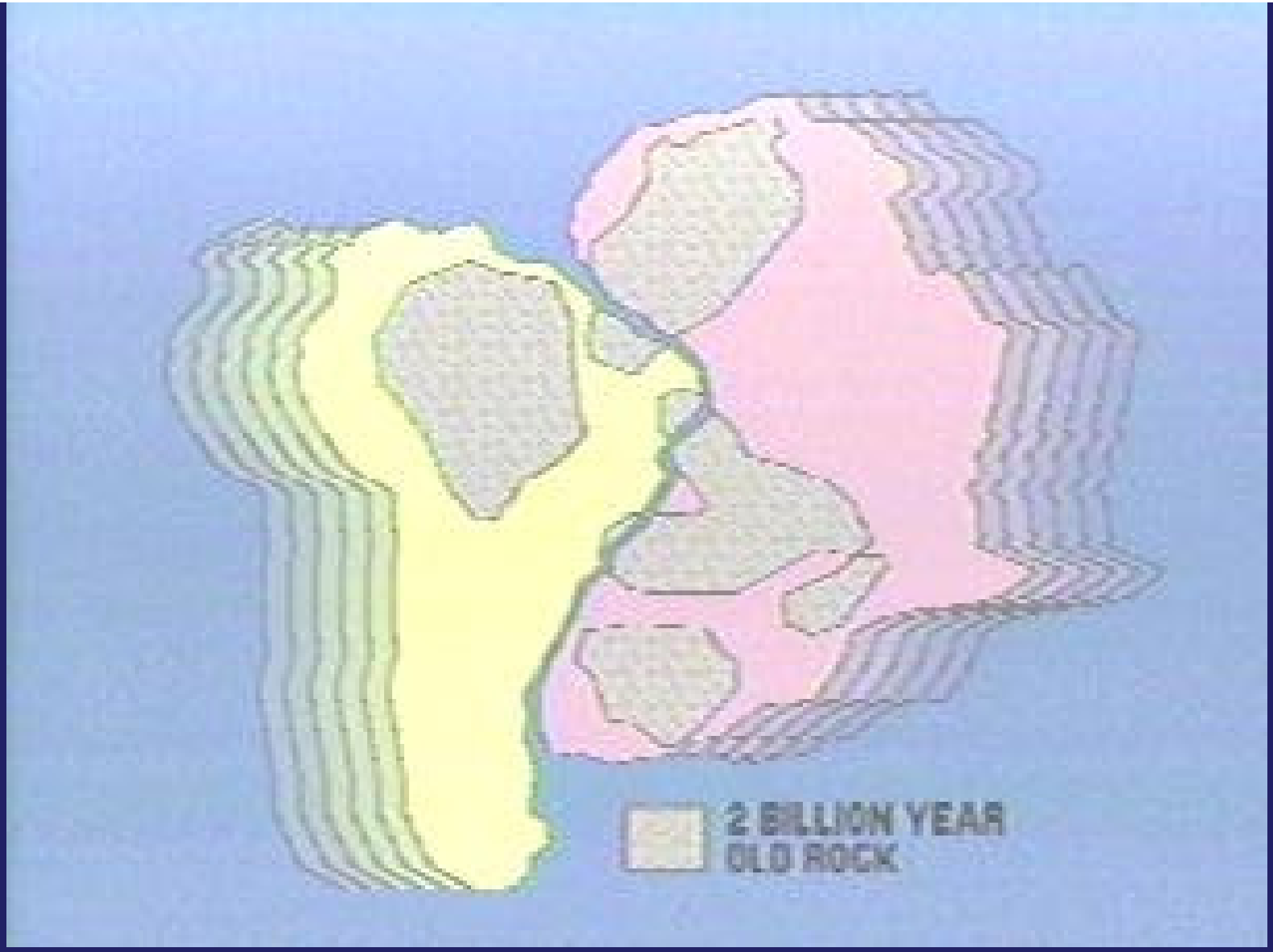


Was he crazy?

His proof:

1) South America and Africa fit together like a puzzle


San Francisco
ROCKIES
New York
ALPS
ATLAS
Caracas
Lagos
Cairo
Rio de Janeiro
ANDES
Cape Town

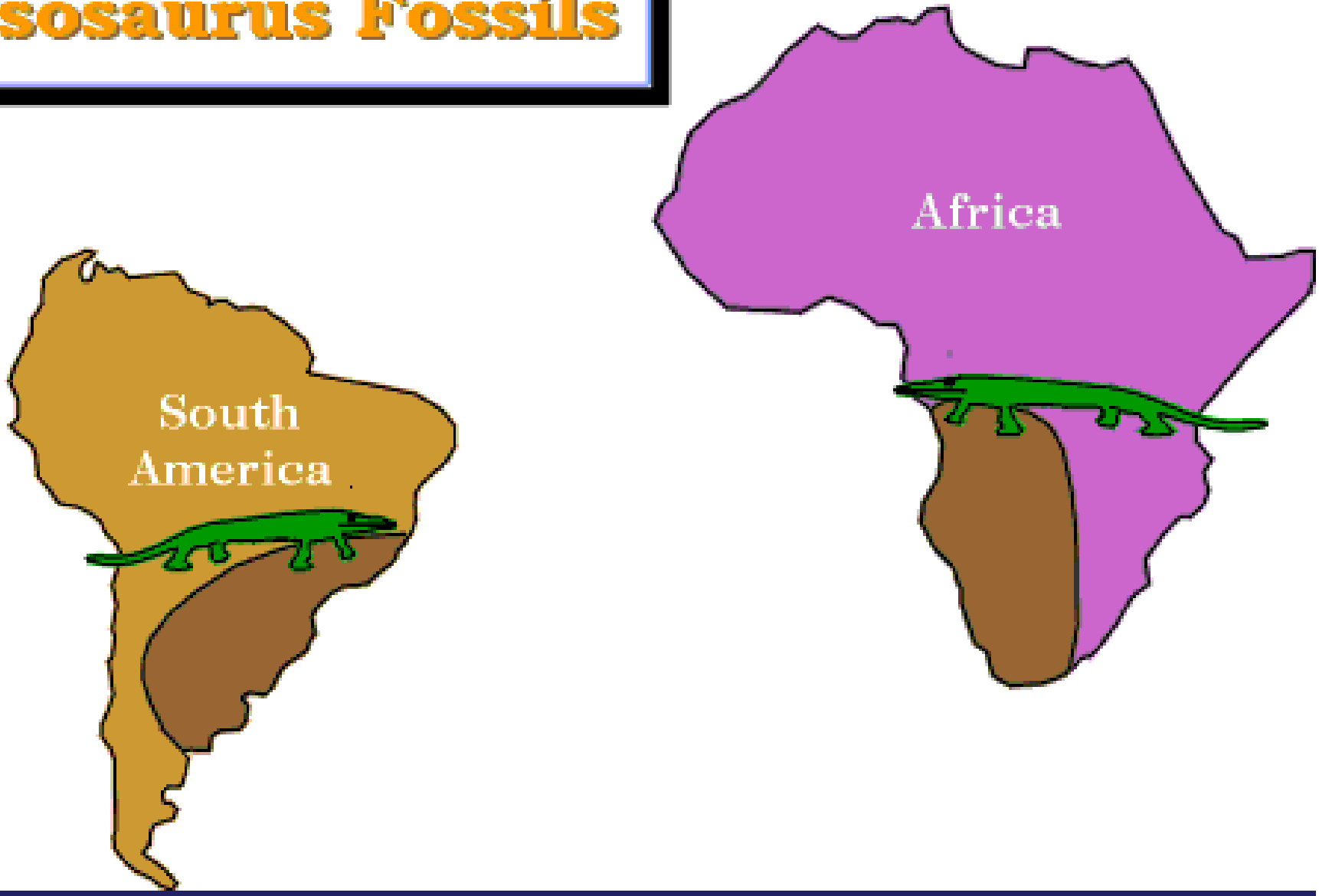

2 BILLION YEAR
OLD ROCK

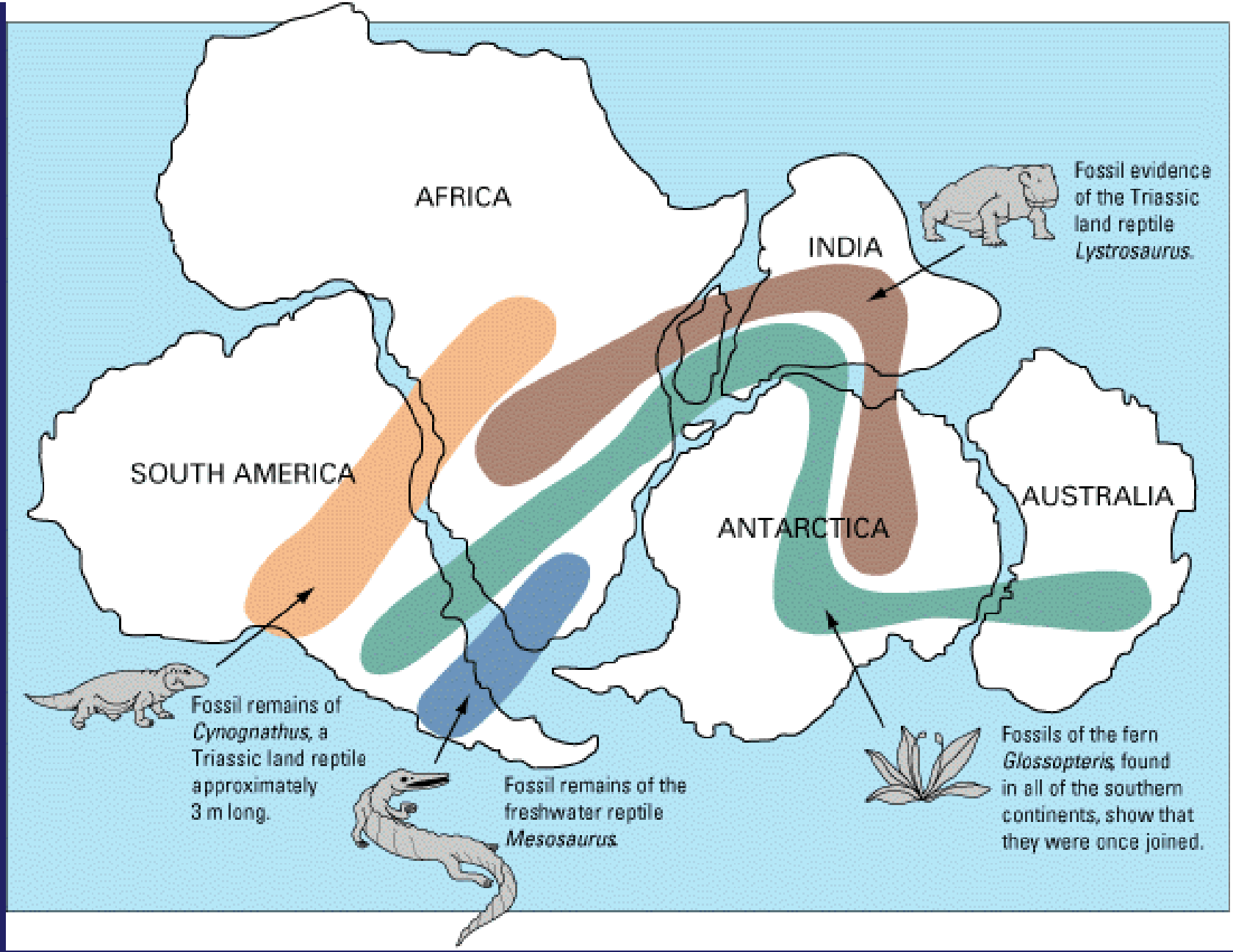
His proof:

1) South America and Africa fit together like a puzzle

2) if you fit the continents together, rock types match up

Locations Yielding Mesosaurus Fossils




AFRICA
INDIA
SOUTH AMERICA
ANTARCTICA
AUSTRALIA
Fossil evidence of the Triassic land reptile *Lystrosaurus*.
Fossil remains of *Cynognathus*, a Triassic land reptile approximately 3 m long.
Fossil remains of the freshwater reptile *Mesosaurus*.
Fossils of the fern *Glossopteris*, found in all of the southern continents, show that they were once joined.

His proof:

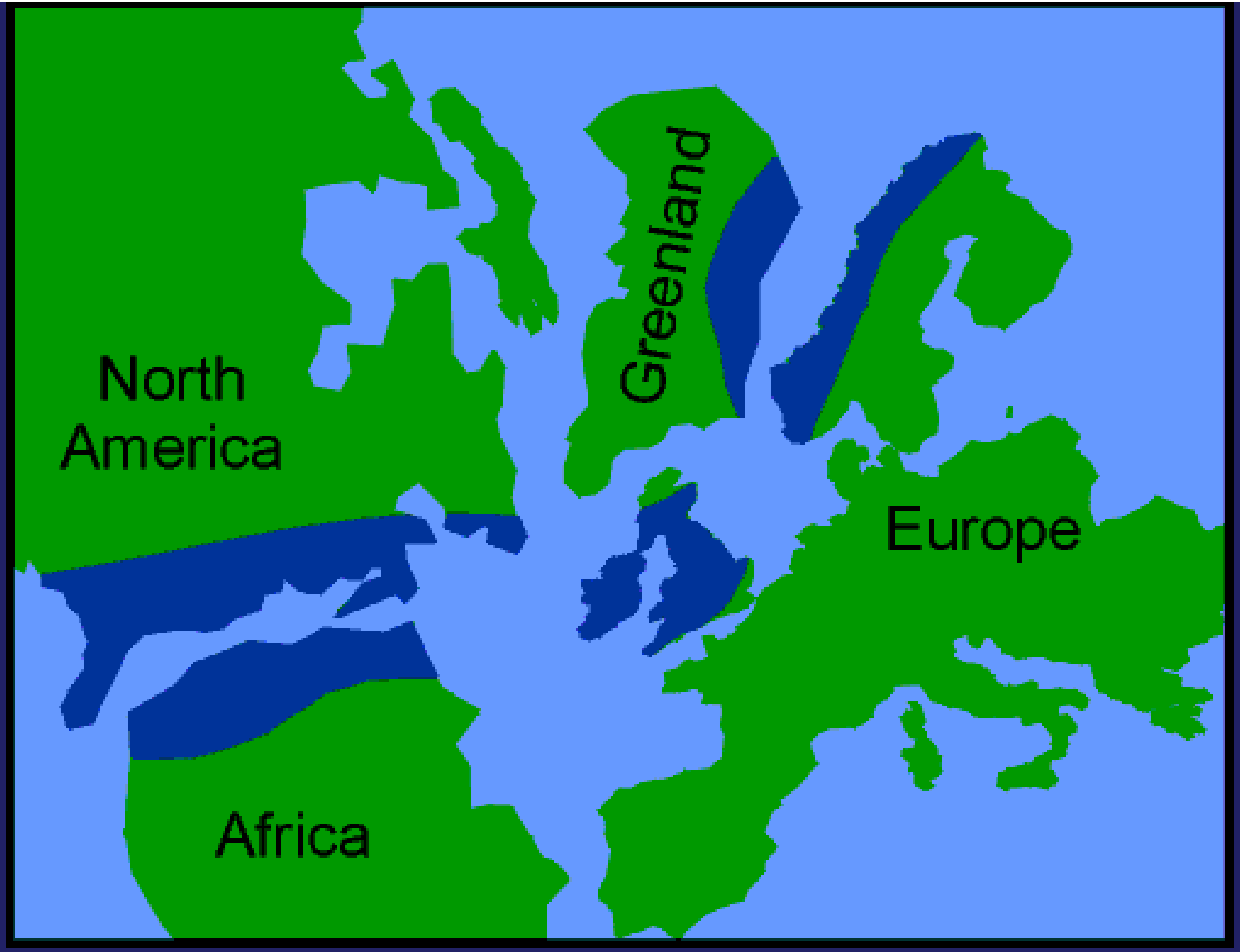
1) South America and Africa fit together like a puzzle

2) if you fit the continents together, rock types match up

3) fossils also match up

Still think he’s crazy?

There’s more…


North America
Greenland
Europe
Africa

His proof:

4) mountain chains are continuous from continent to continent

His proof:

4) some mountain chains are continuous from continent to continent

5) ancient climates are much different in some locations than they are today

<u>example</u>: palm tree fossils found in upstate NY show that it used to be warmer

6) magnetic polarity

6) magnetic polarity:

Compass magnets always point _____

6) magnetic polarity:

Compass magnets always point __north___

But that's not always the case

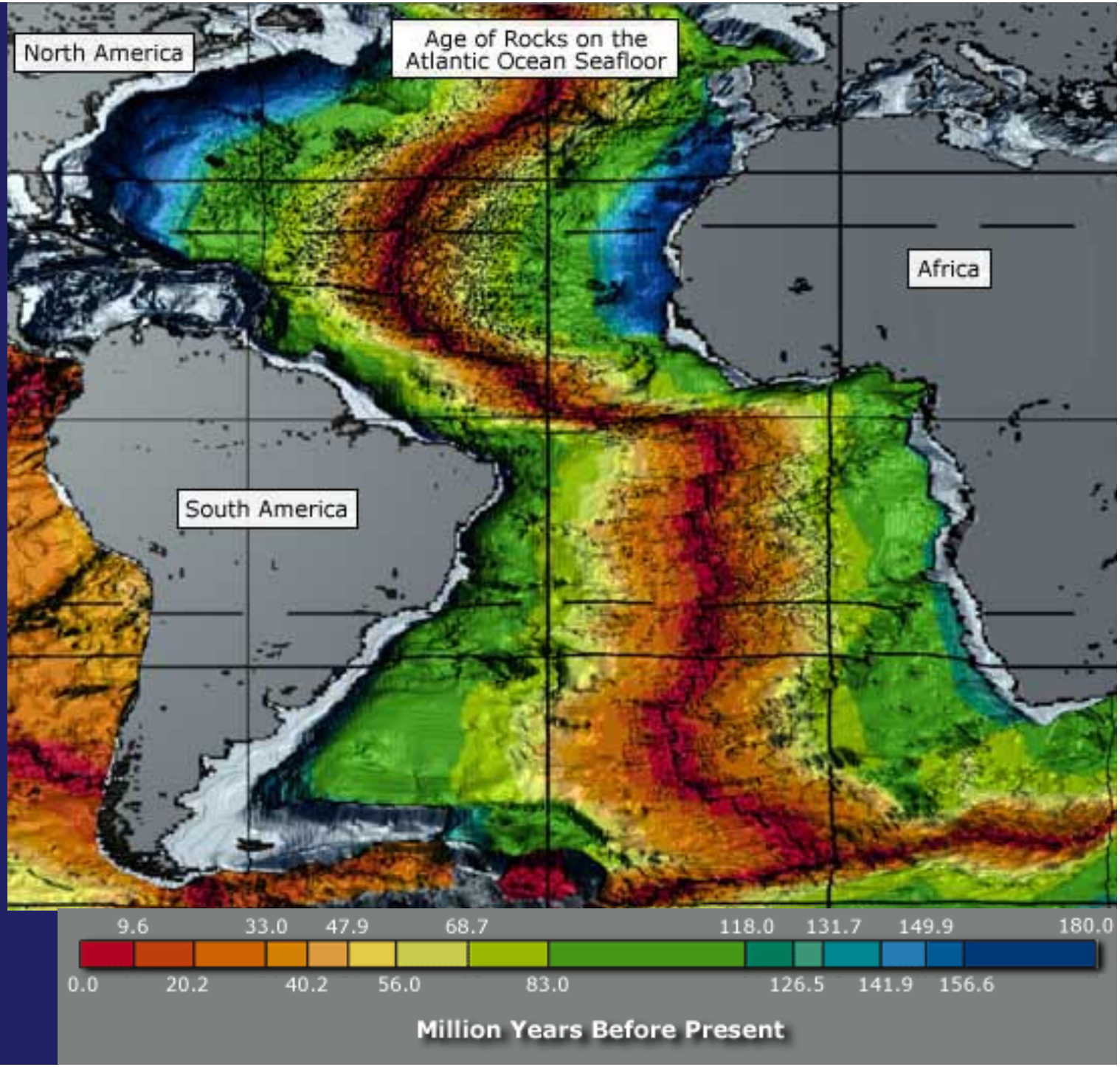
Every million years or so, magnetic polarity reverses and compasses point south!

When new rocks harden at the Mid Atlantic Ridge, they contain an imprint of the current magnetic polarity

http://www.wwnorton.com/earth/earth/

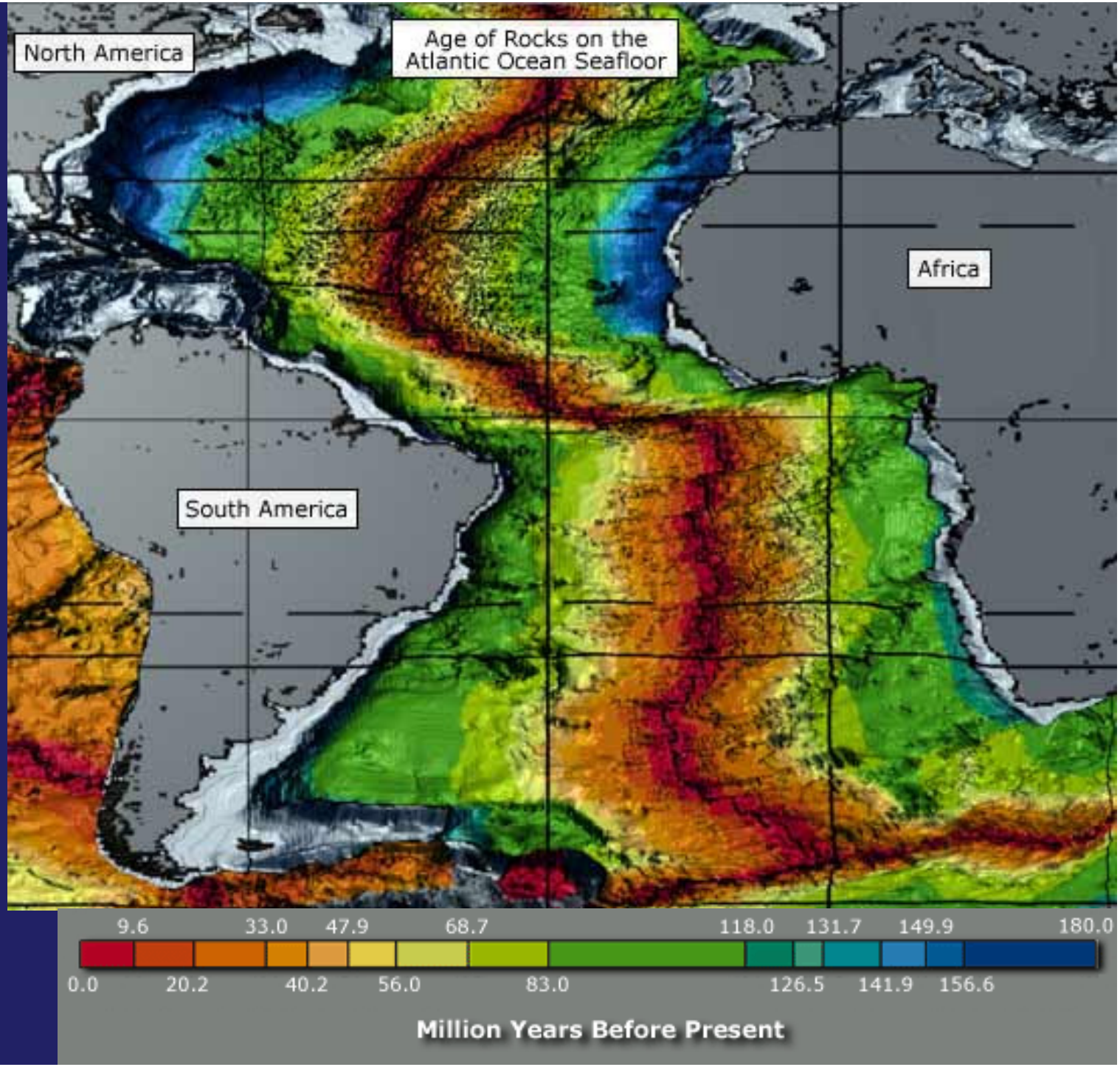
(wegener-continental drift)

(magnetic reversals

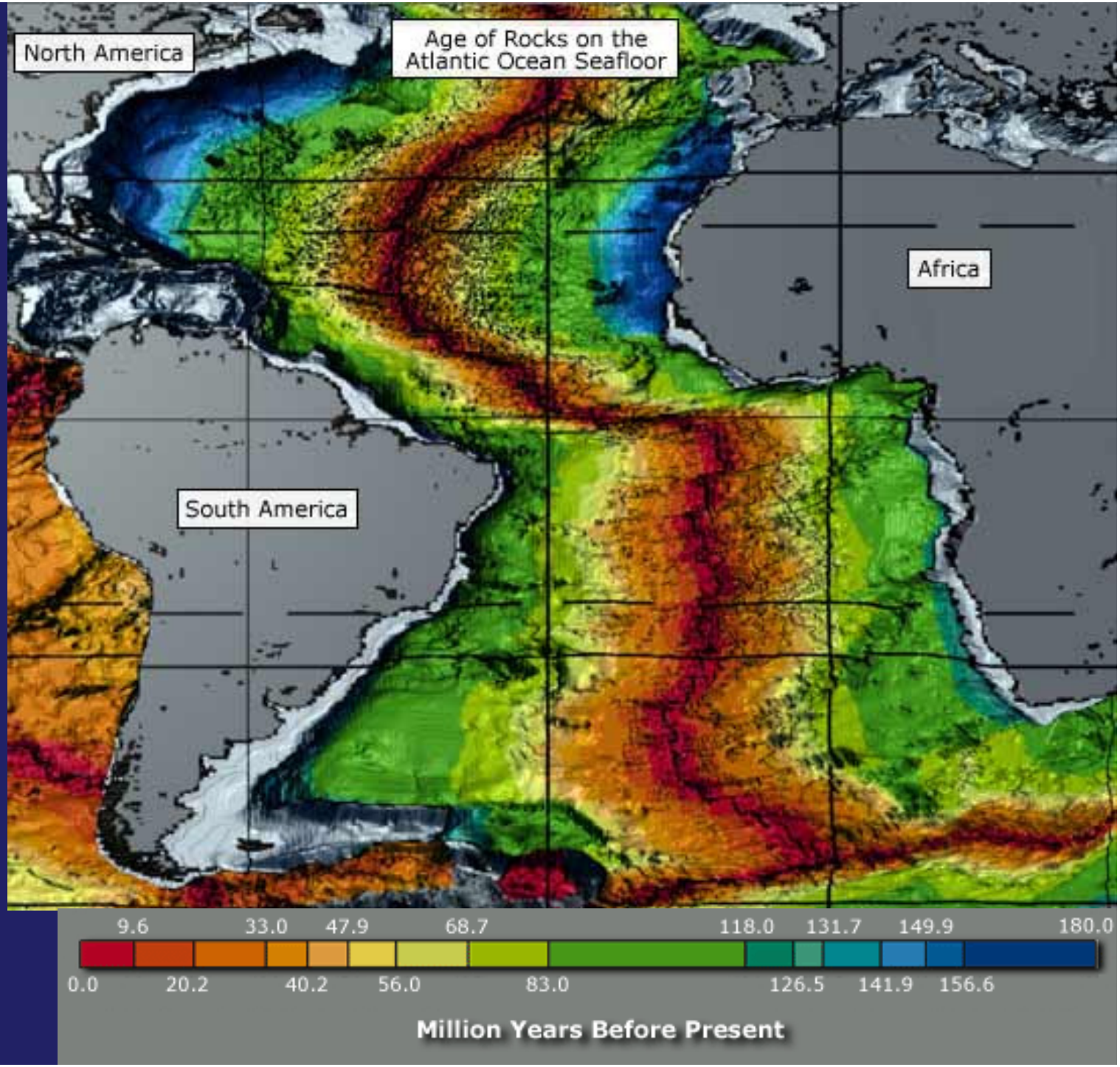

North America
Age of Rocks on the Atlantic Ocean Seafloor
Africa
South America
9.6
33.0
47.9
68.7
118.0
131.7
149.9
180.0
0.0
20.2
40.2
56.0
83.0
126.5
141.9
156.6
Million Years Before Present

What areas of the Atlantic seafloor have the youngest rocks?

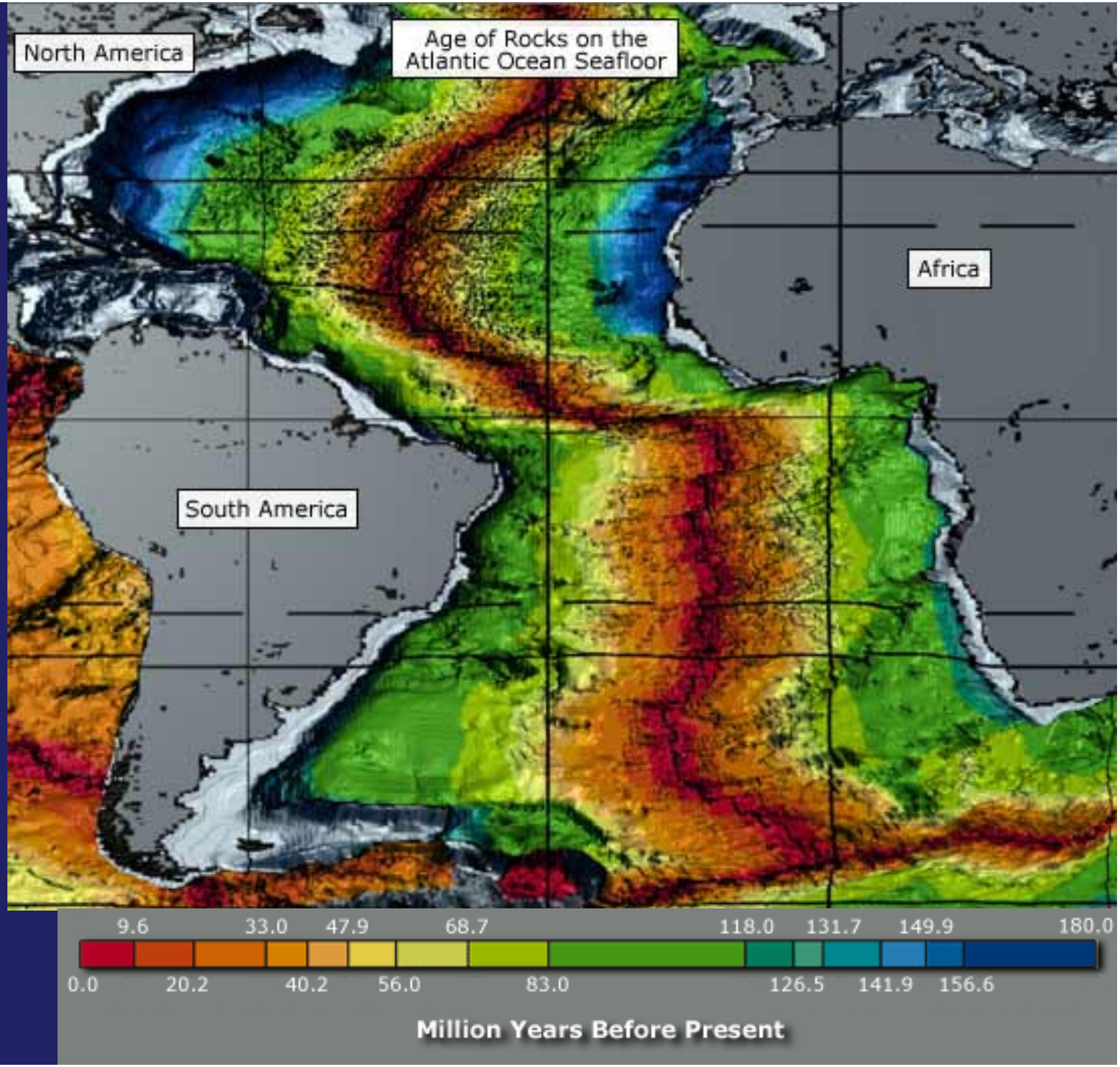
...the oldest?



How old are the very oldest rocks on the Atlantic seafloor? Where are they?



Based on the age of the oldest rocks between South America and Africa, when did the two continents split?



"I wouldn't worry. With continental drift, Africa or South America should come by eventually."

Now do you believe him?

Plate motions:

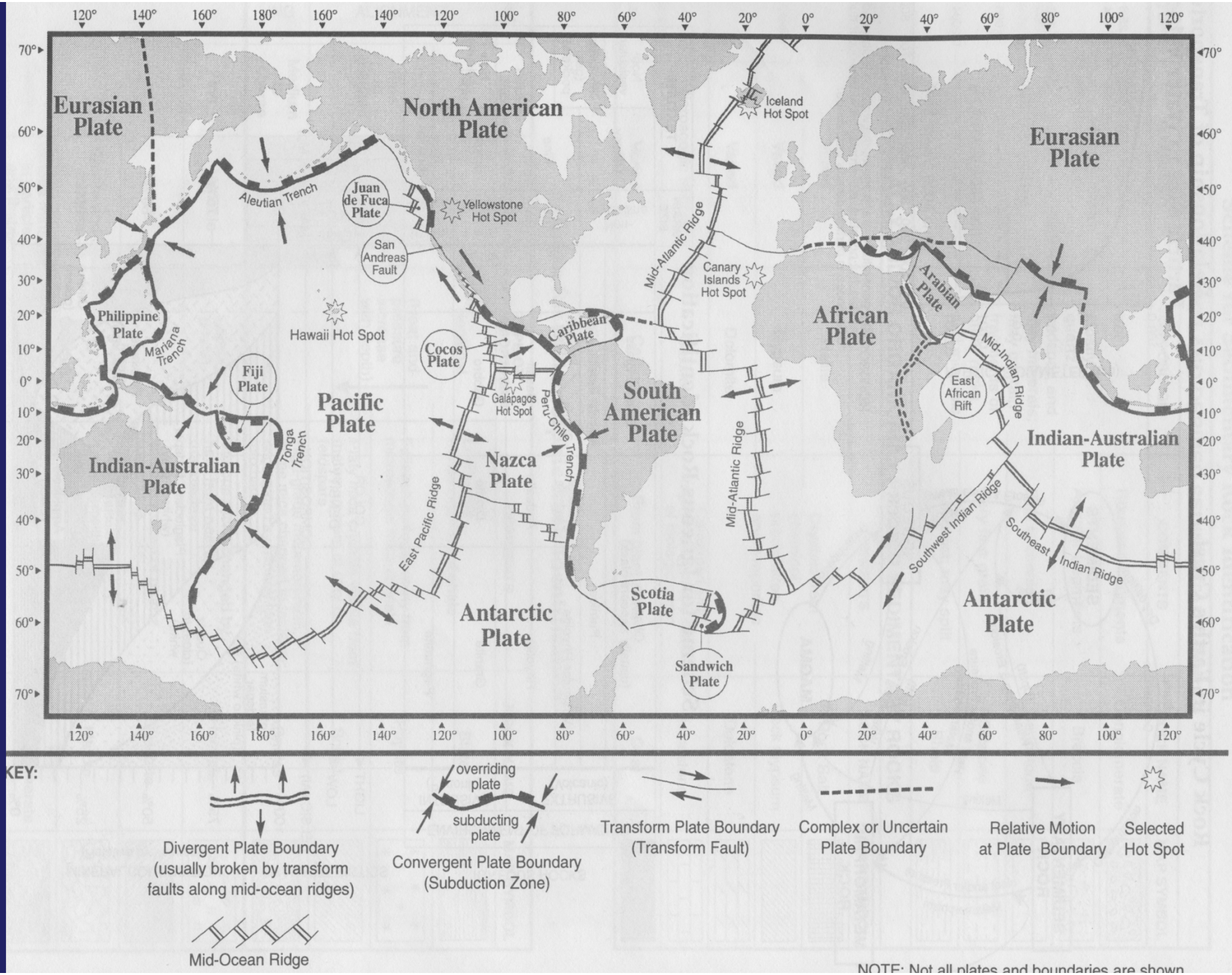

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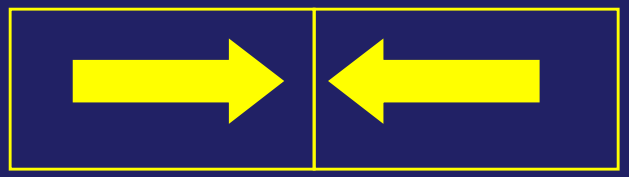
Plate motions:

1) convergent boundary



- Plates collide with each other
- Results in mountain building and/or subduction (sinking)

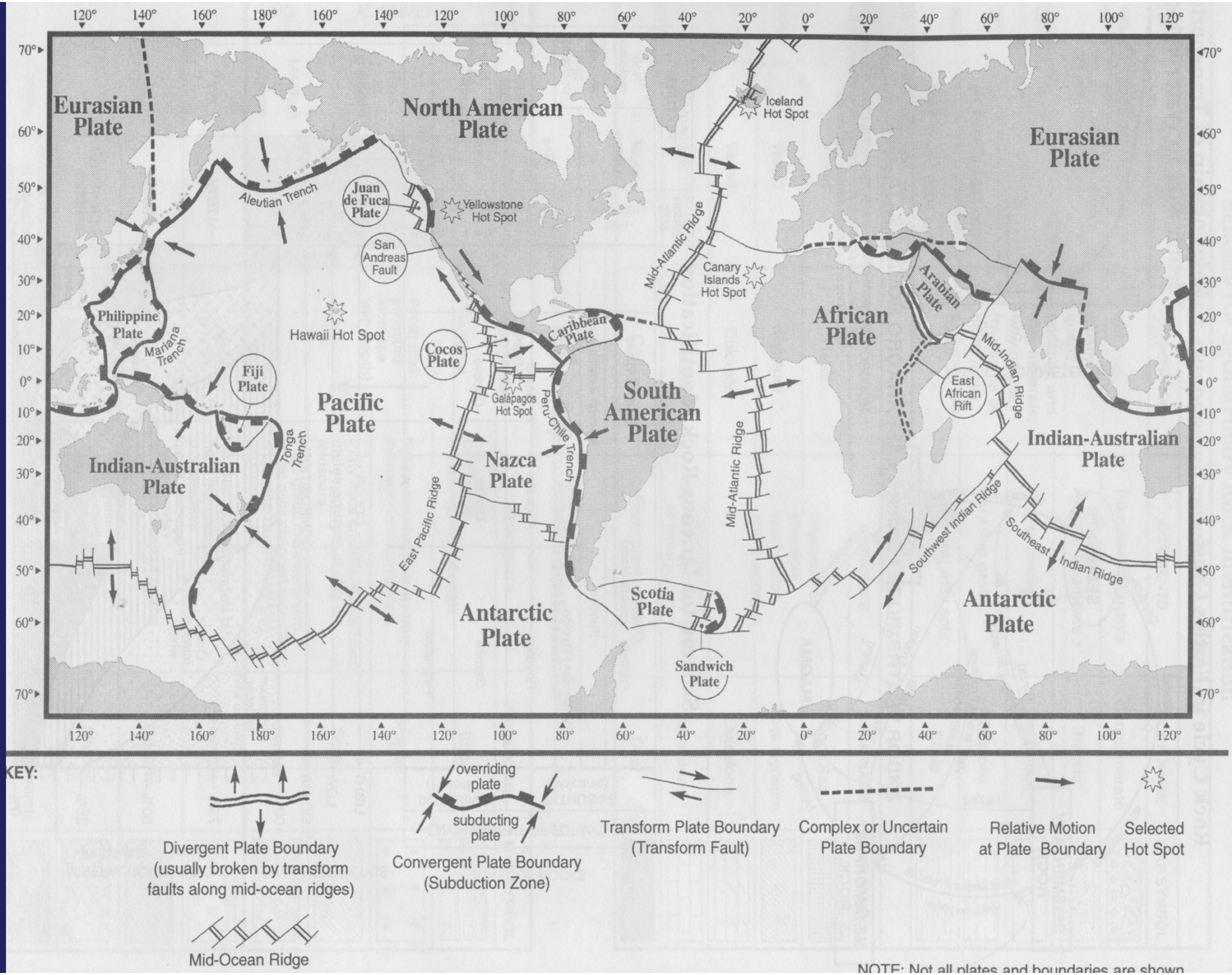

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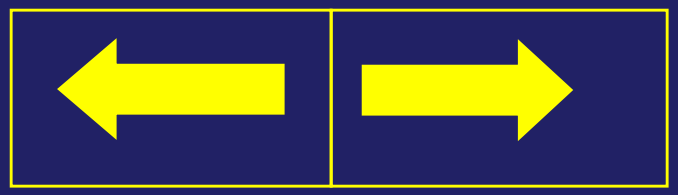
Plate motions:

2) divergent boundary



-plates move apart allowing magma to rise up in the center

-new rocks form in center (ridge)

-Mid Atlantic Ridge

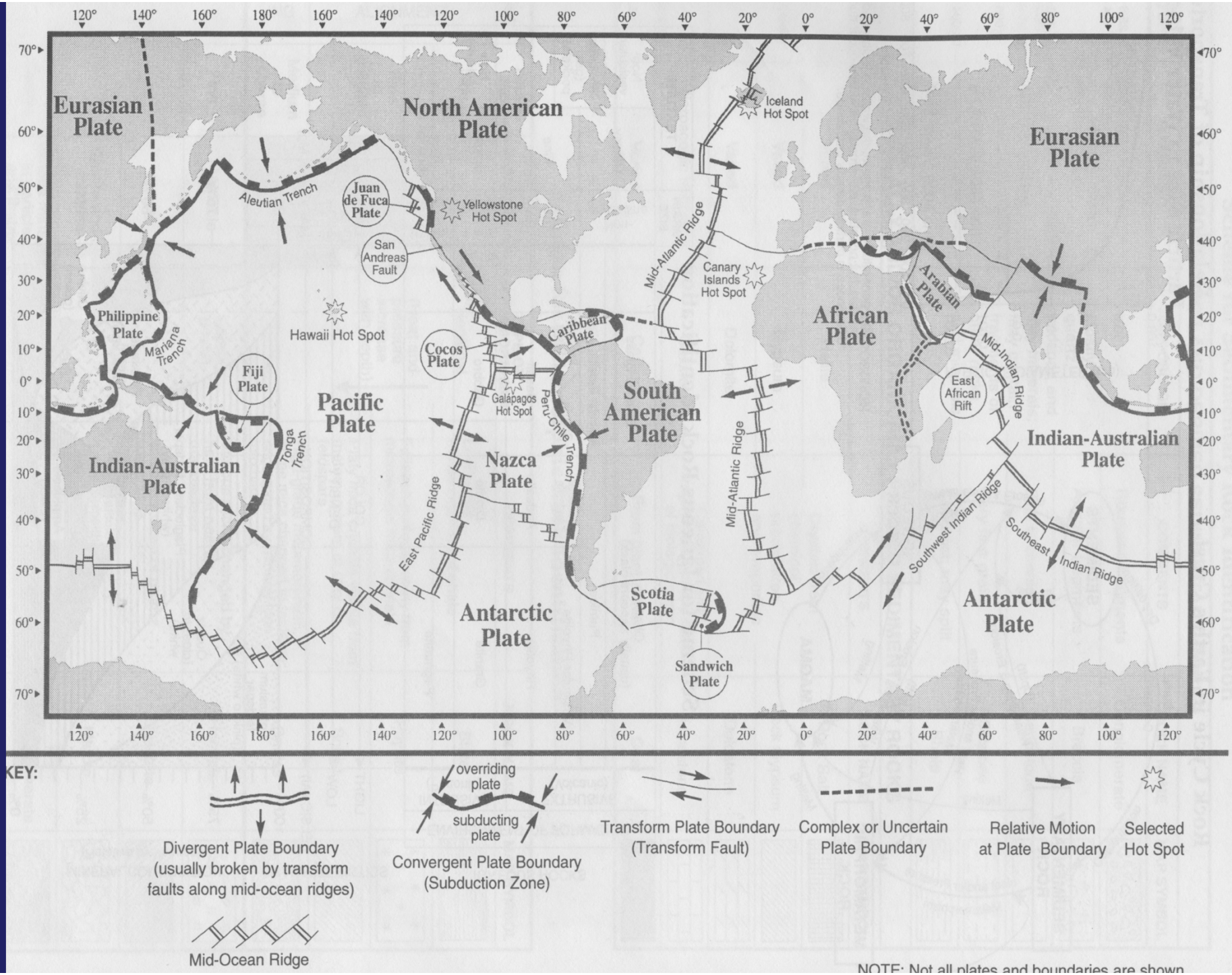

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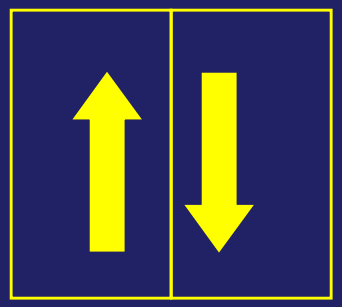
Plate motions:

3) transform boundary



- plates slide past each other
- California (San Andreas Fault)
- also called a strike-slip boundary


SAN ANDREAS
FAULT
NOW ENTERING
PACIFIC
PLATE

Plate motions cause crustal movement:

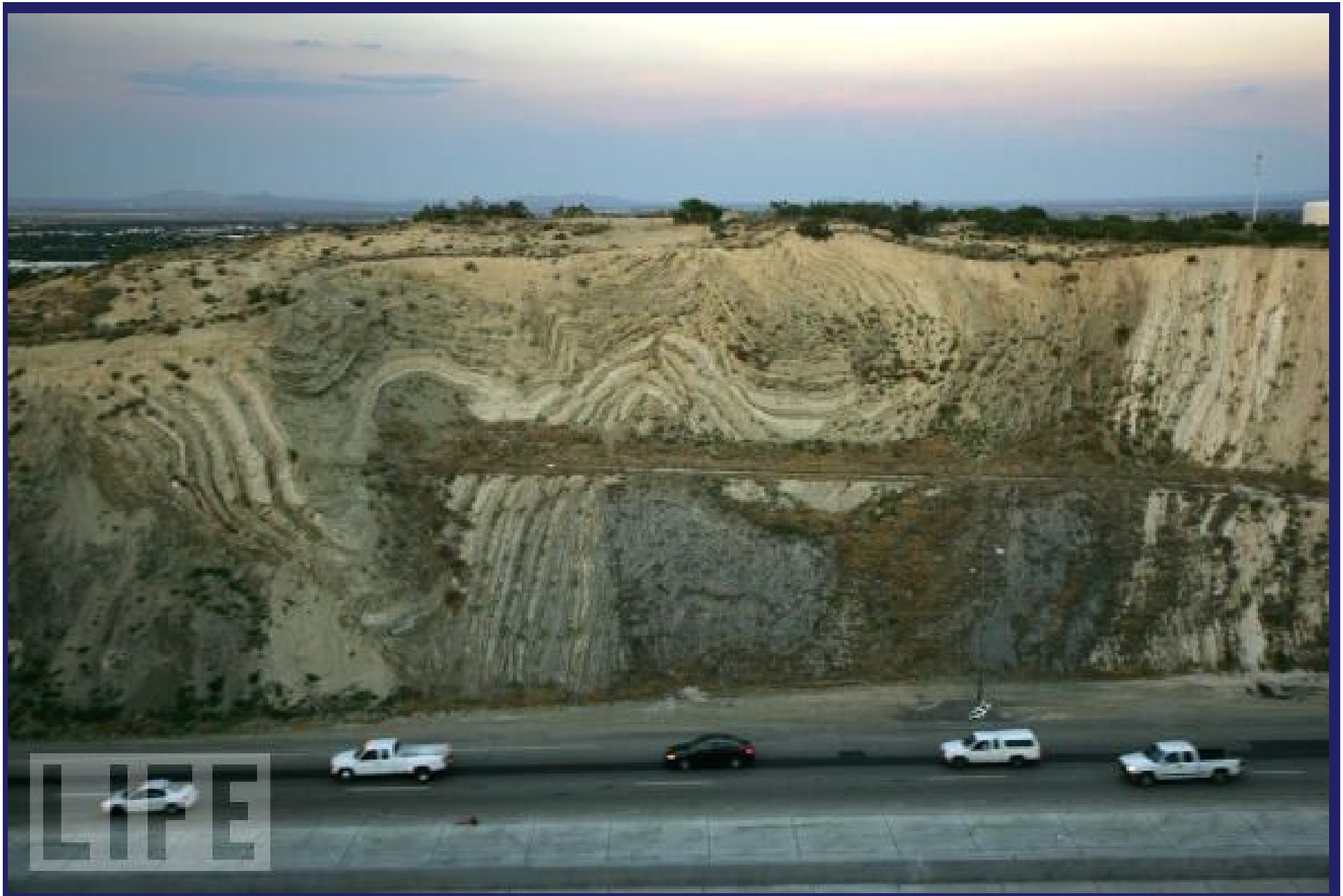
1) tilting of crust

Plate motions cause crustal movement:

2) folding of crust

Plate motions cause crustal movement:

3) faulting of crust


LIFE

Proof of crustal movement:

1) Ocean life fossils found on mountain tops (uplift)

2) Shallow water fossils found deep under water (subsidence – sinking)

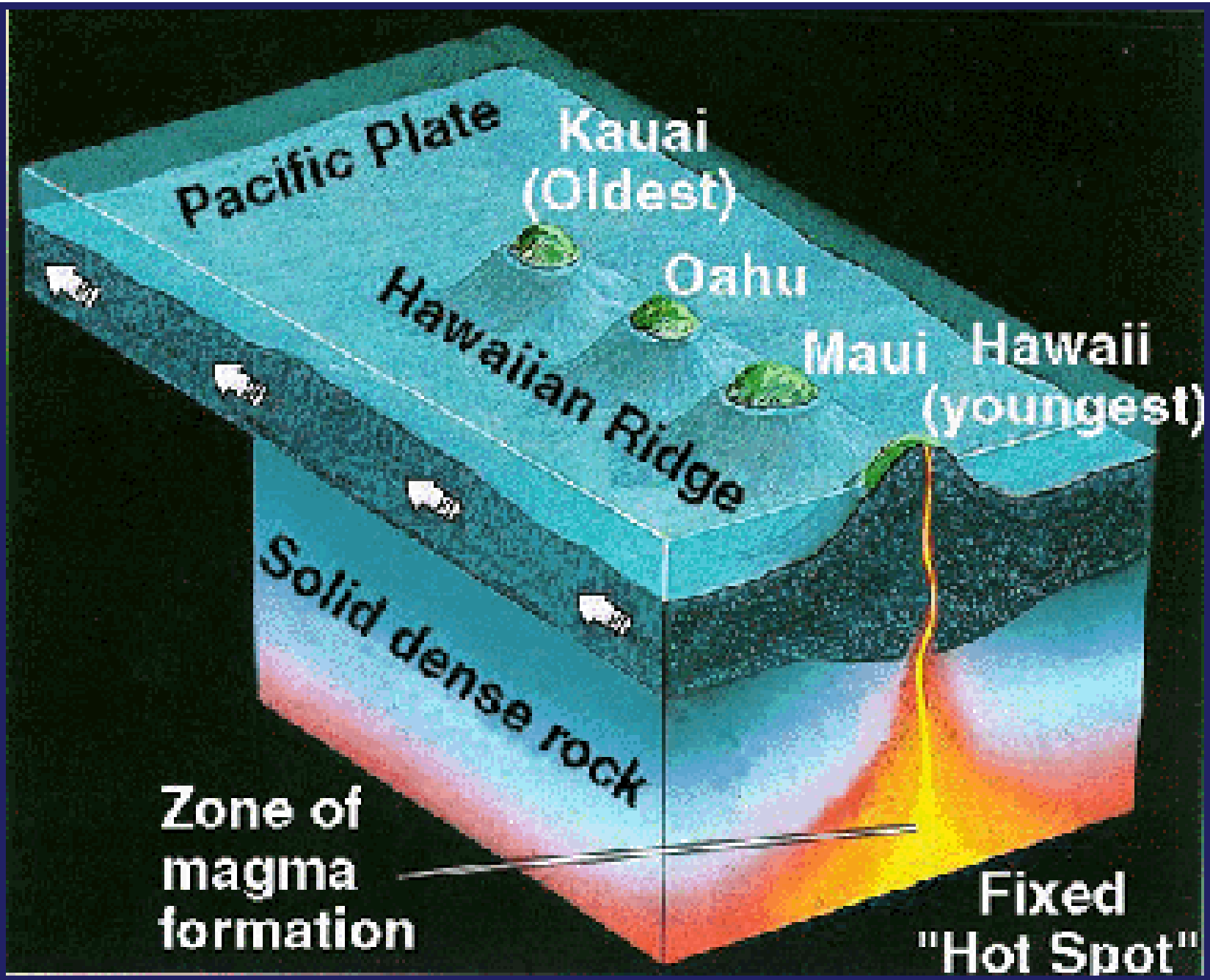
http://www.wwnorton.com/earth/earth/

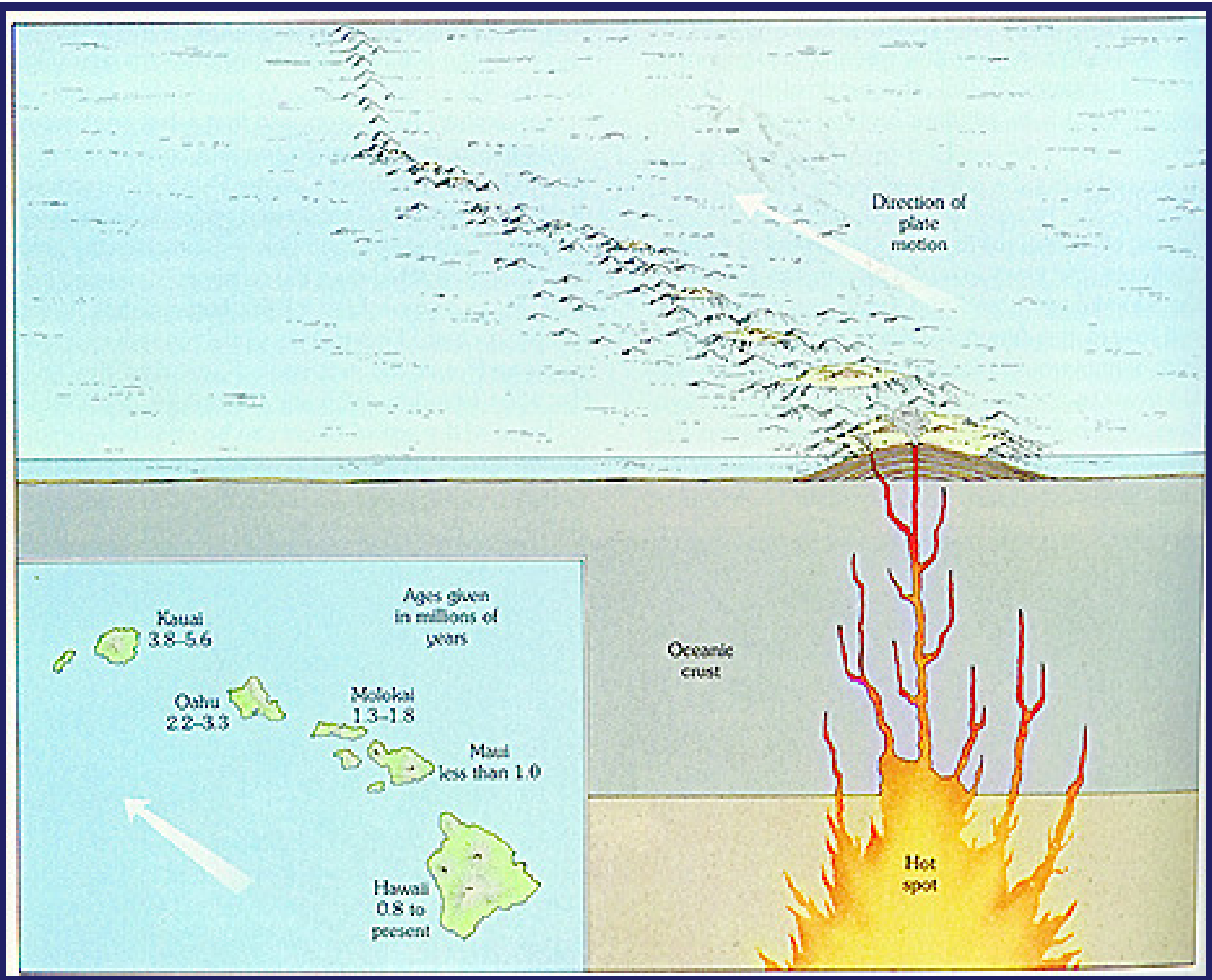
-Animations
-Basic plate boundaries

Hot spots –

-places, not on a plate boundary, where magma rises to the surface

Examples: Hawaii, Yellowstone Park


Pacific Plate
Kauai
(Oldest)
Oahu
Maui
Hawaii
(youngest)
Hawaiian Ridge
Solid dense rock
Zone of
magma
formation
Fixed
"Hot Spot"


Direction of plate motion
Ages given in millions of years
Kauai 3.8–5.6
Oahu 2.2–3.3
Molokai 1.3–1.8
Maui less than 1.0
Hawaii 0.8 to present
Oceanic crust
Hot spot

Hot spot animation

http://www.classzone.com/books/earth_science/terc/content/investigations/es0810/es0810page03.cfm

Unit 3

Earthquakes

When plates move, they sometimes lock up and stick together…

stress builds up…

and more stress…

and more stress…

and eventually….

SNAP!

1964 Alaska Earthquake (mag 9.2)

1964 Alaska Earthquake (mag 9.2)

1964 Alaska Earthquake (mag 9.2)

1971 San Fernando Earthquake (just N of L.A.)

1964 Alaska Earthquake (mag 9.2)

1994 Loma Prieta Earthquake (just S of S.F.)

1994 Loma Prieta Earthquake (just S of S.F.)

1994 Northridge Earthquake (just N of L.A.)

1994 Northridge Earthquake (just N of L.A.)

2010 Japan (mag 9.0)


2010 Japan

2010 Haiti (mag 7.0)

2010 Chile (mag 8.8)

2012 Virginia (mag 5.8)

2012 Philippines (mag 6.9)

Earthquake-

-a sudden trembling or shaking of the ground

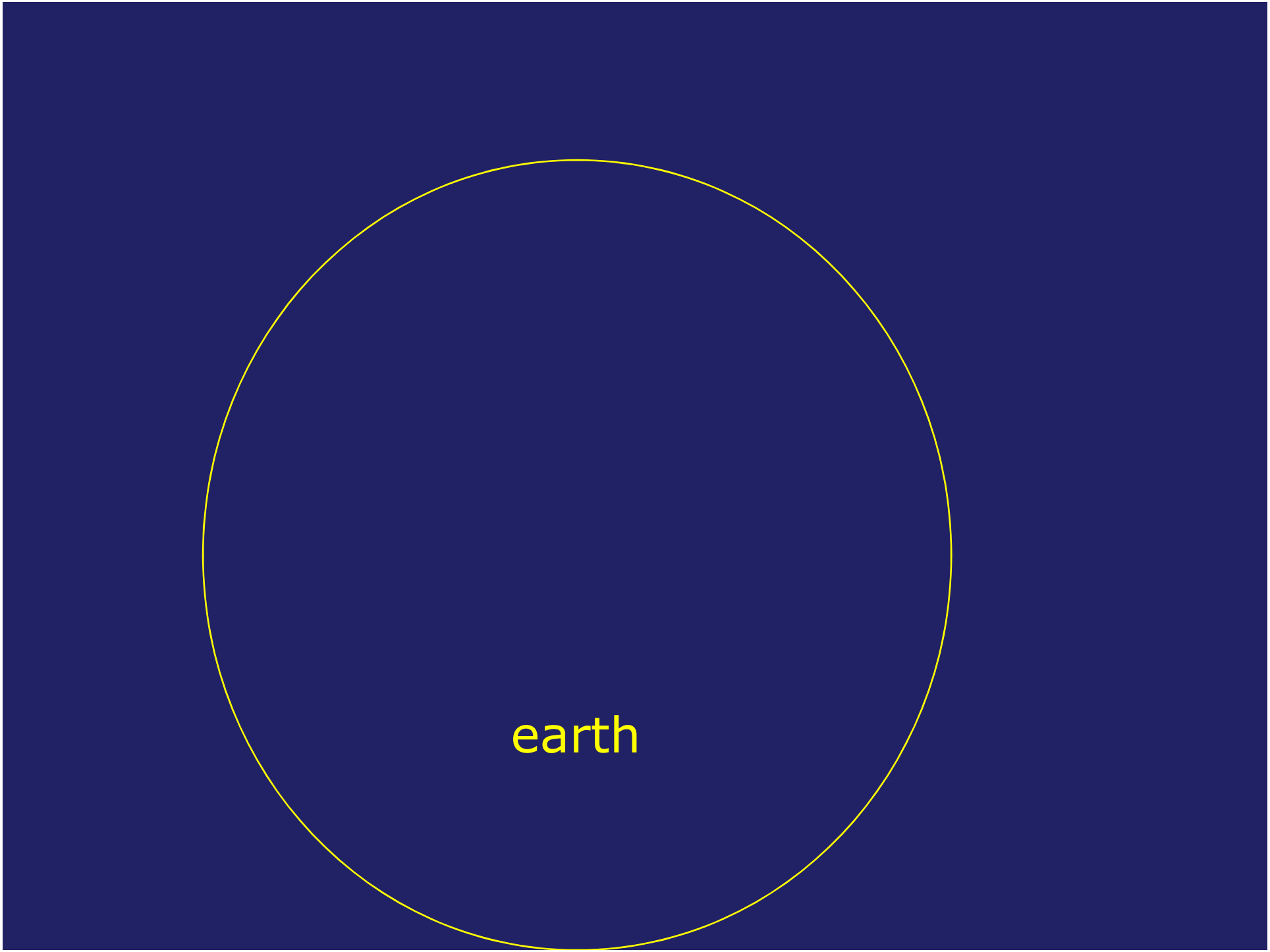
-usually caused by break or fault in rock layers

-occur mostly along plate boundaries

*The exact place where the earthquake occurs is called the focus.

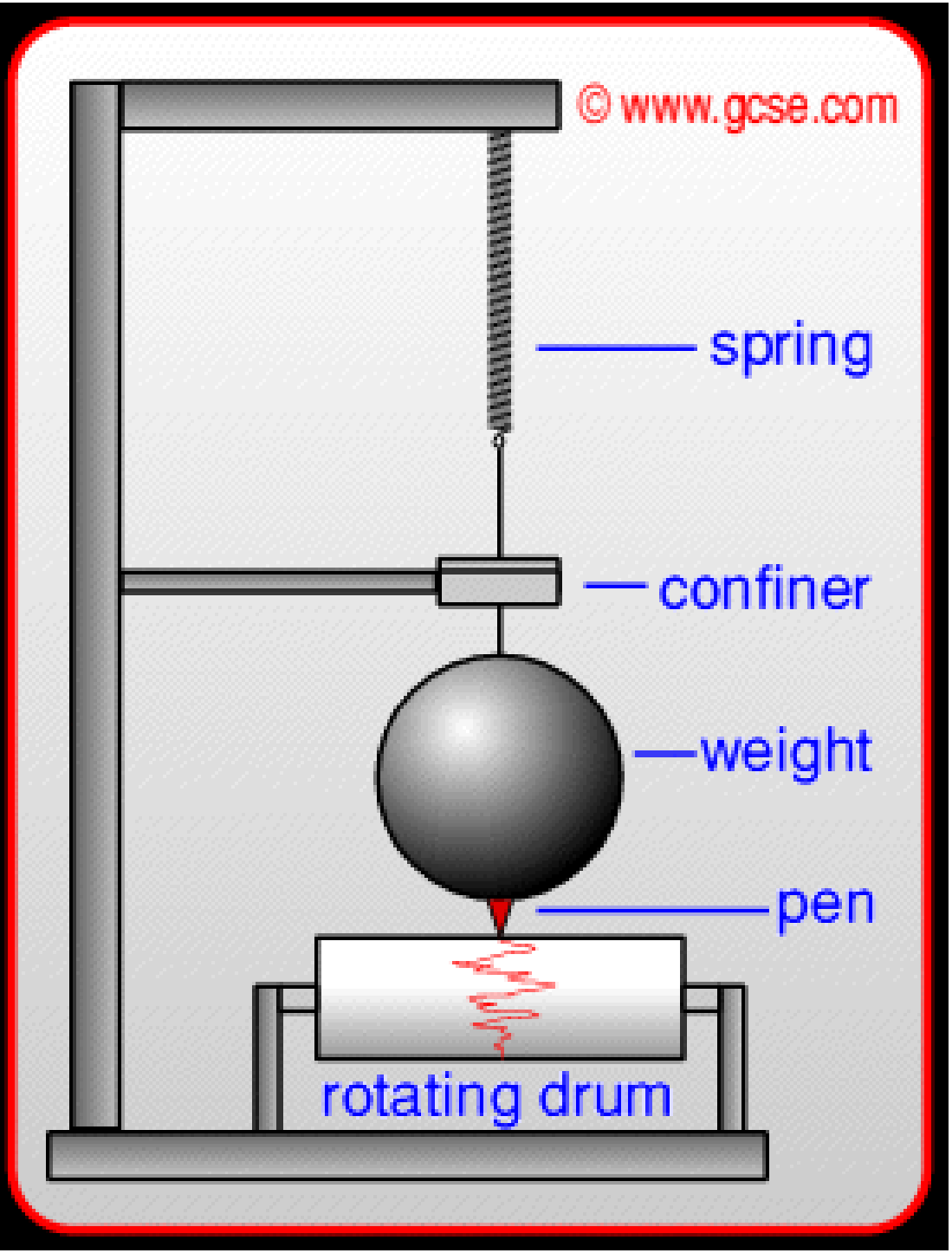
*The place on the earth's surface directly over the focus is called the epicenter.

Smithsonian demo


earth

Earthquakes-

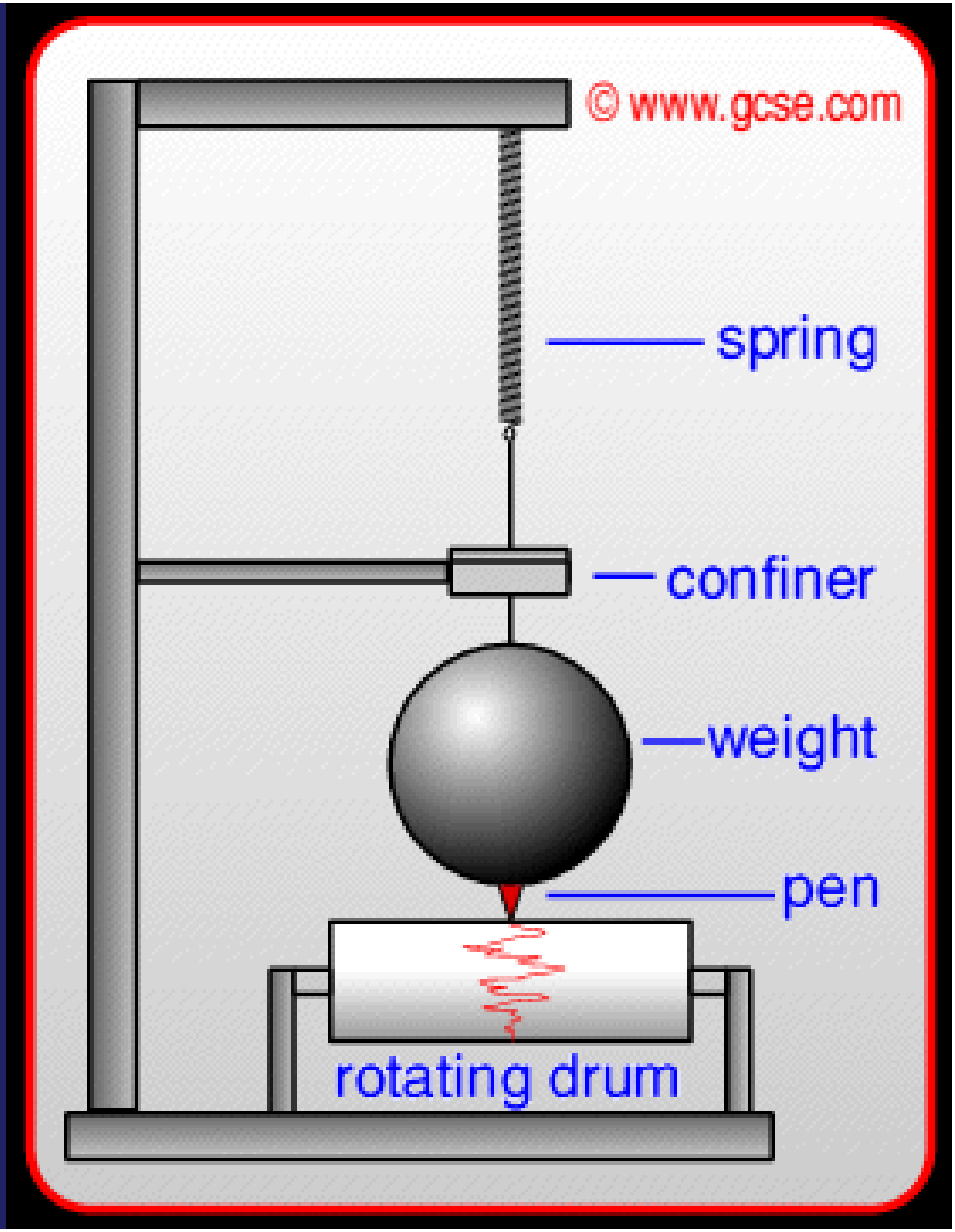
-are measured with a seismometer



Earthquake-

-are measured with a seismometer

-a seismometer produces a seismograph


© www.gcse.com
spring
confiner
weight
pen
rotating drum

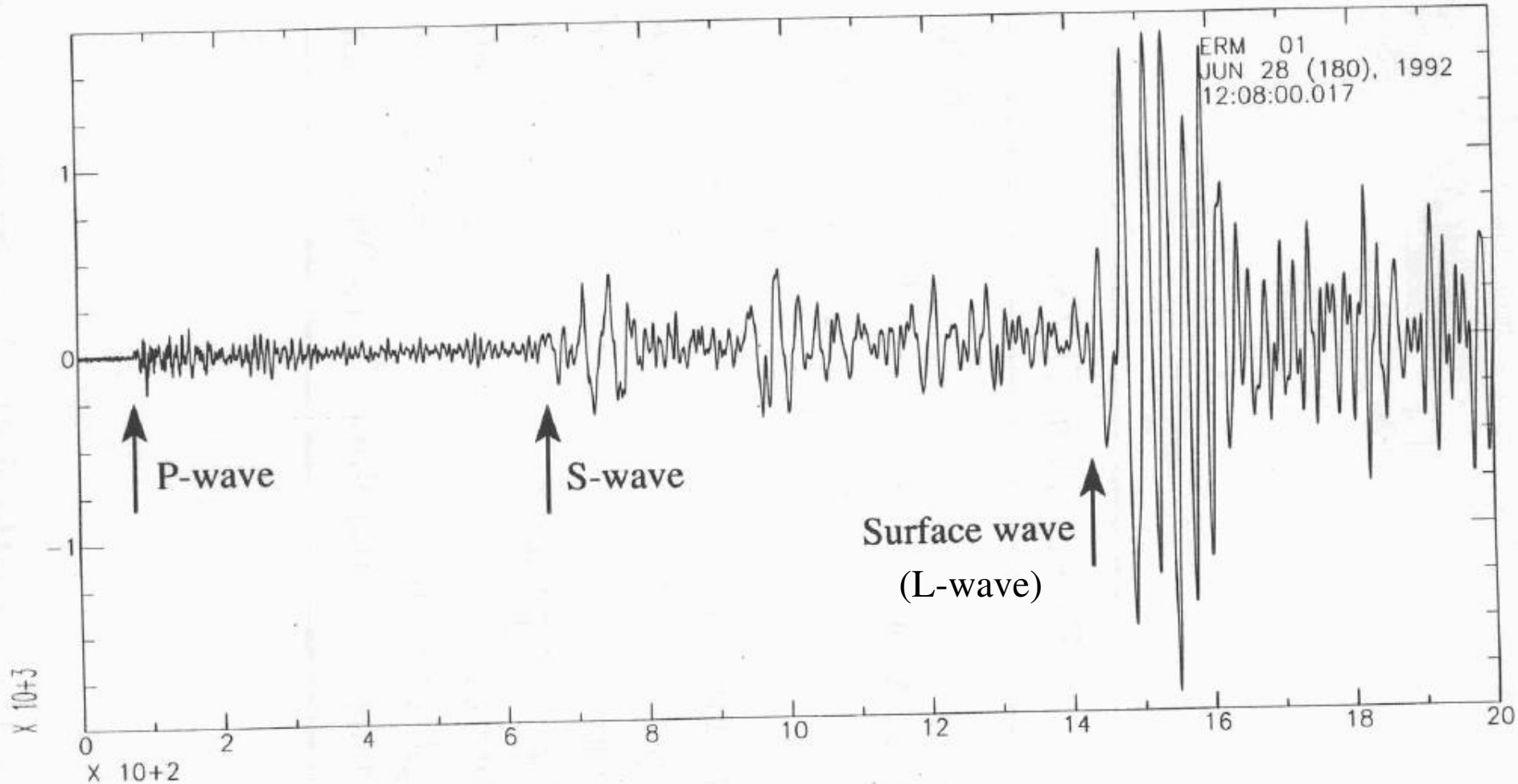


FIGURE 6.4 A seismogram.

When an earthquake occurs, it generates three types of waves: P, S, and L.

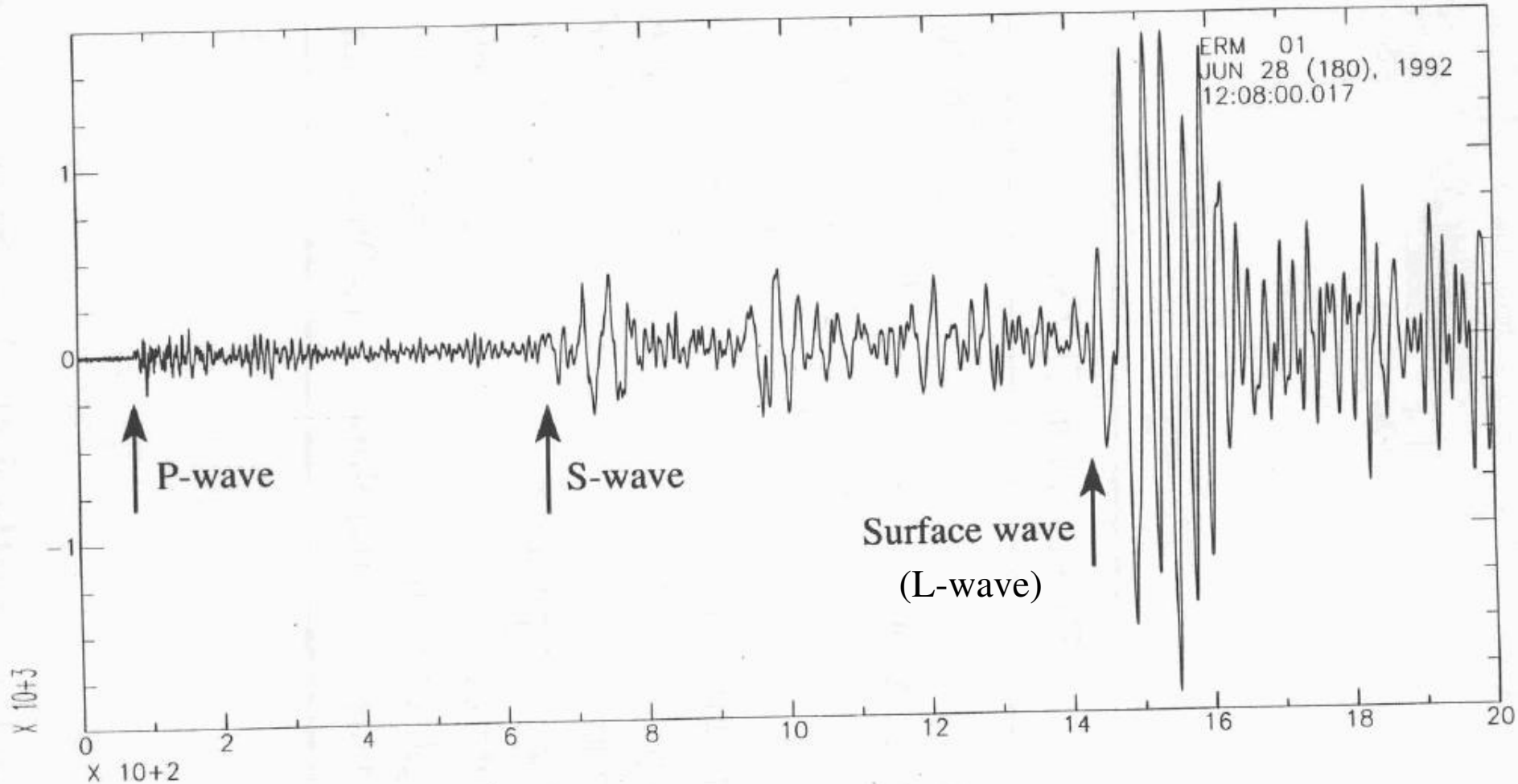


FIGURE 6.4 A seismogram.

When an earthquake occurs, it generates three types of waves: P, S, and L.

1) <u>P-waves</u>:

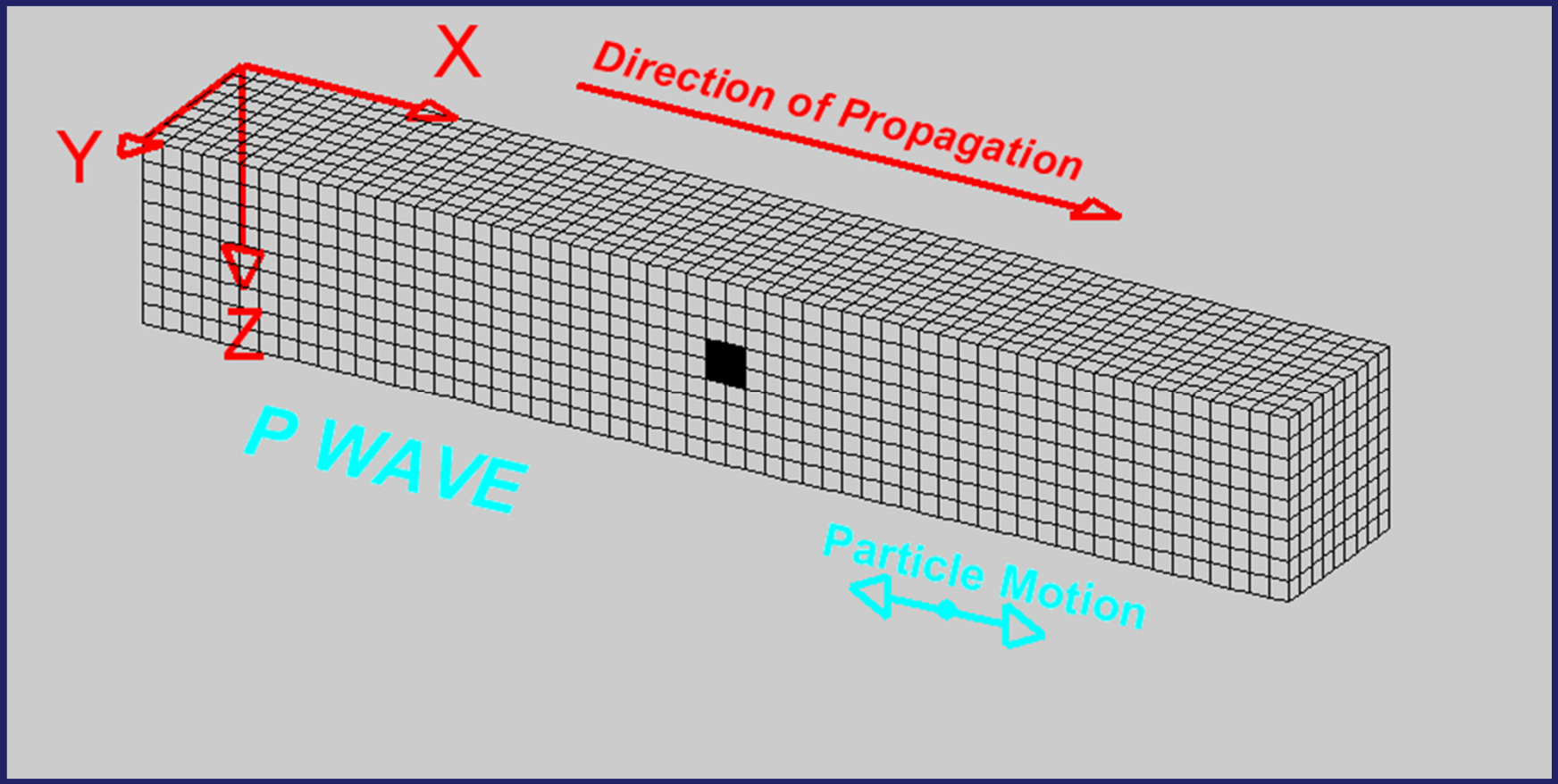
-primary waves

-also called <u>compressional waves</u>

-travel the fastest

-can travel through solid and liquid earth layers

-material they pass through vibrates in the same direction


X
Y
Z
Direction of Propagation
P WAVE
Particle Motion

When an earthquake occurs, it generates three types of waves: P, S, and L.

2) <u>S-waves</u>:

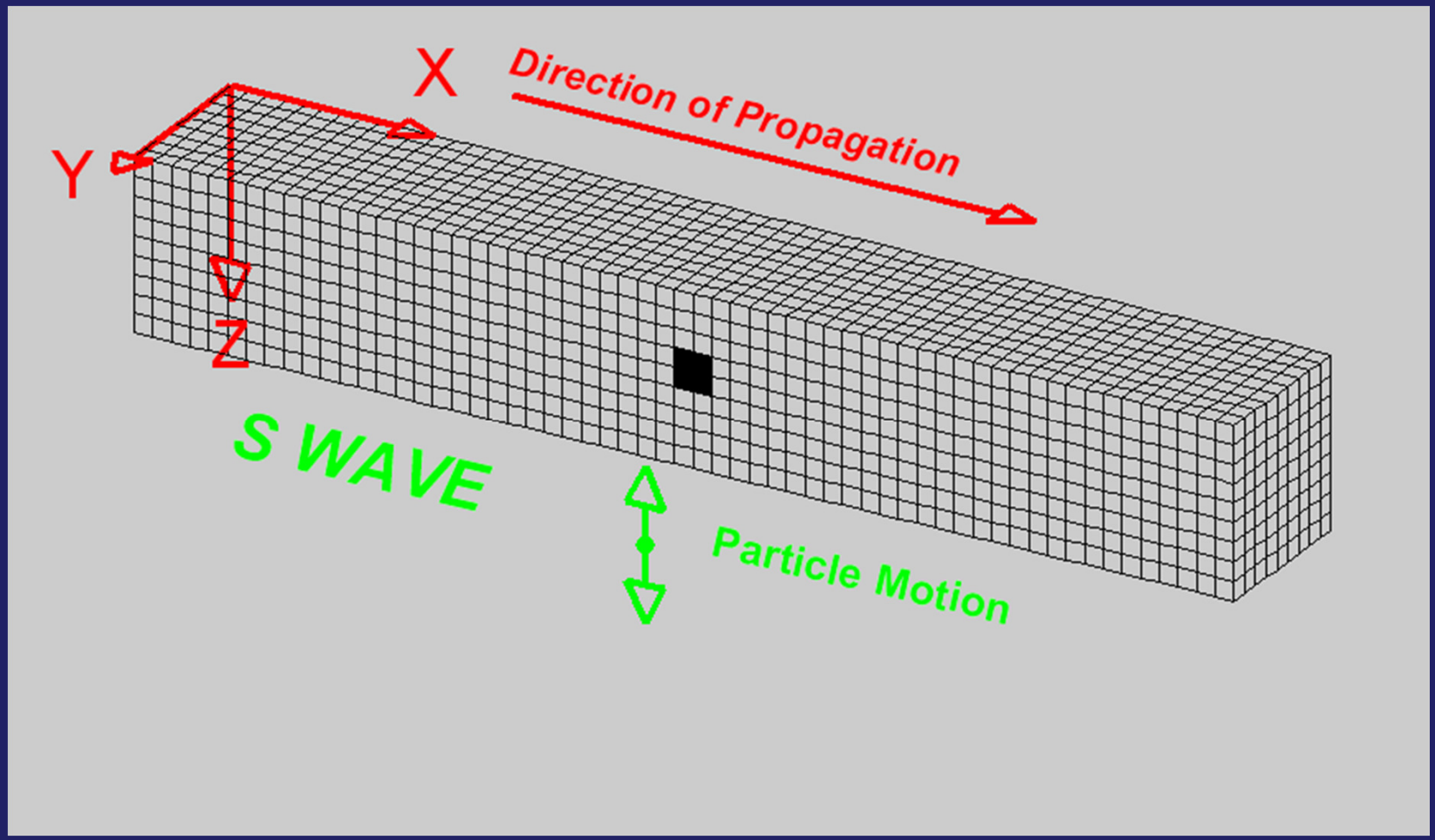
-secondary waves

-also called <u>shear waves</u>

-travel slower than P-waves

-can <u>only</u> travel through solid earth layers

-material they pass through vibrates at right angles to the direction of the wave

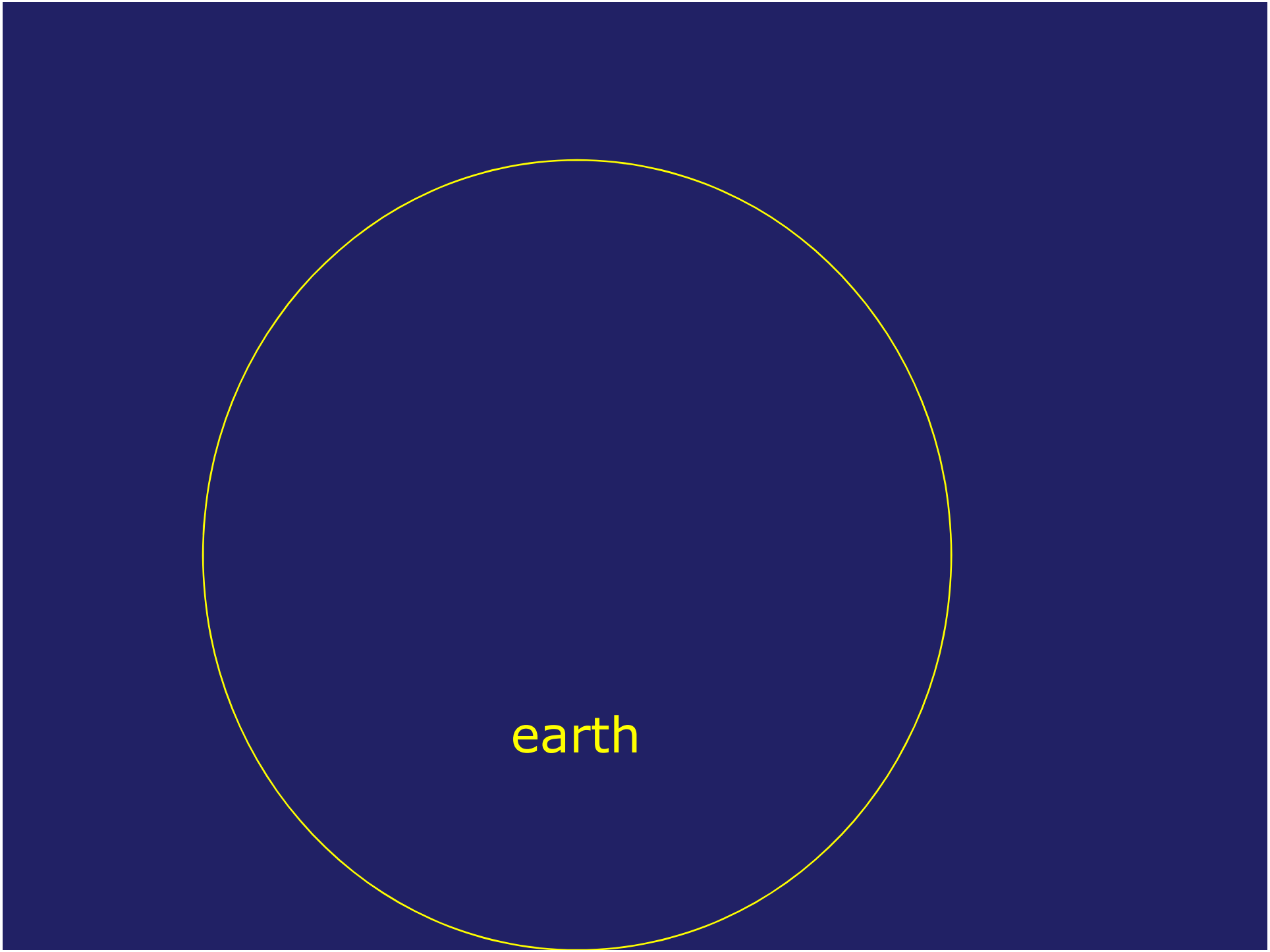

X
Direction of Propagation
Y
Z
S WAVE
Particle Motion

When an earthquake occurs, it generates three types of waves: P, S, and L.

3) <u>L-waves</u>:

-roll along the surface of the earth

- cause the most damage


earth

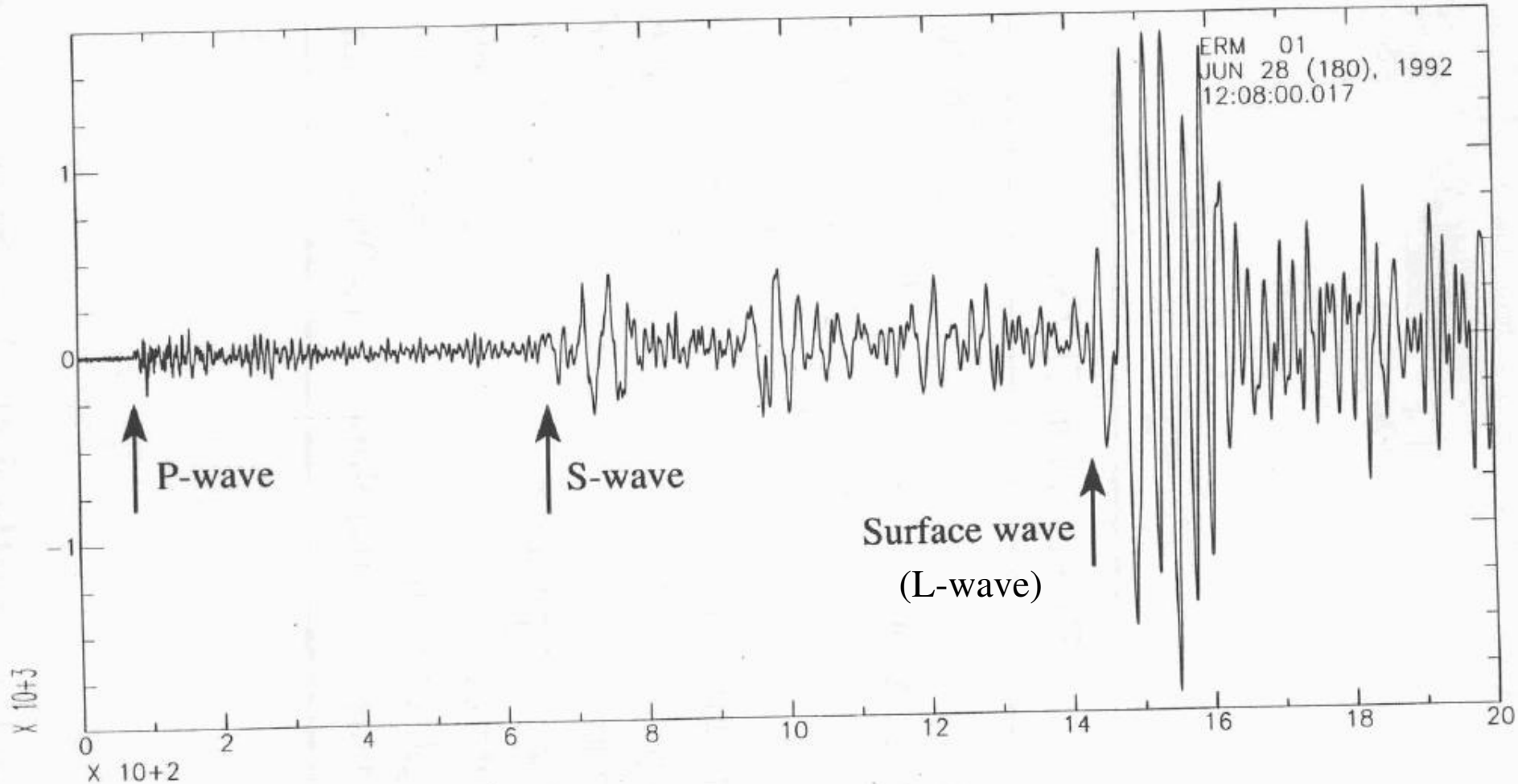
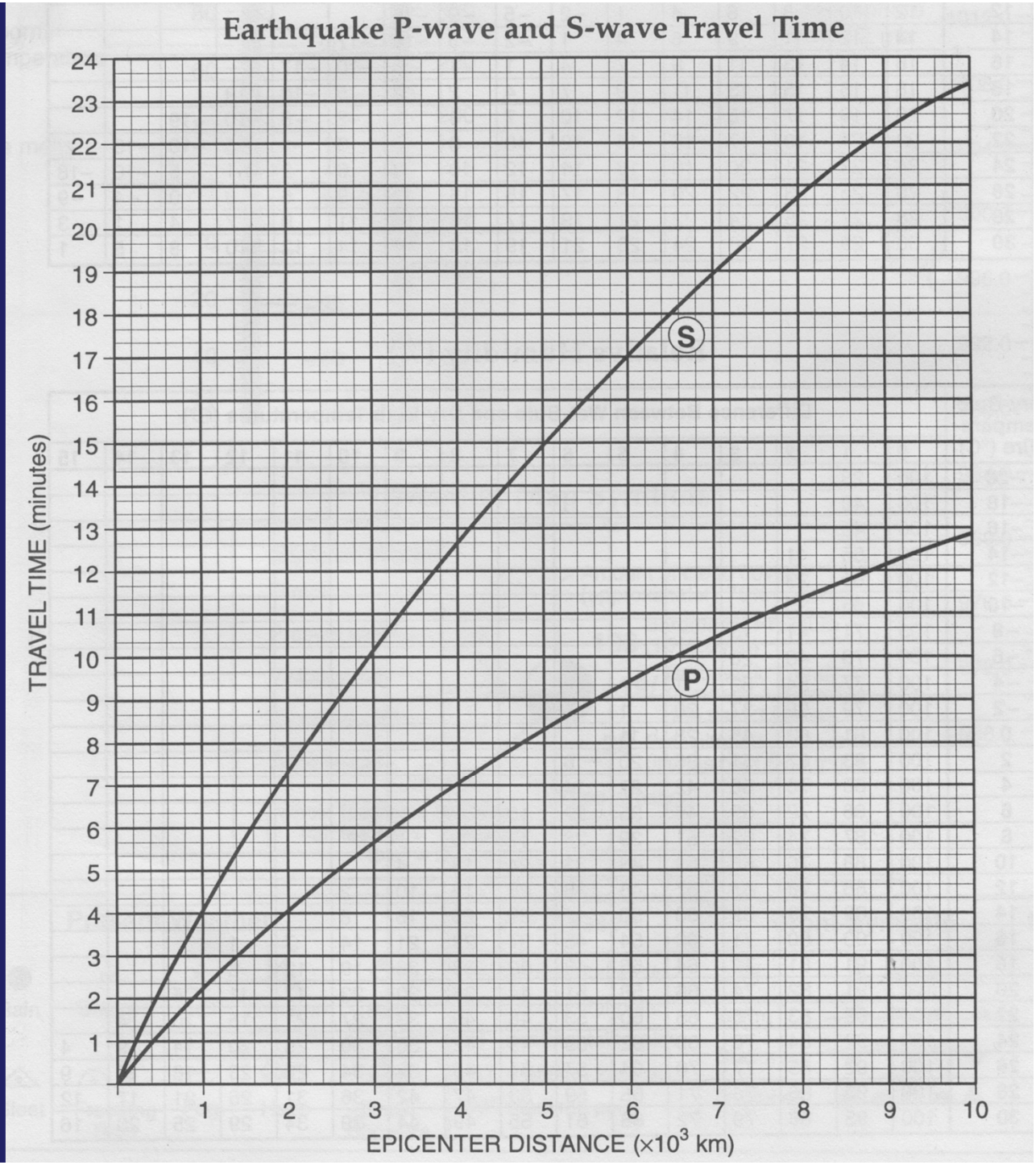


FIGURE 6.4 A seismogram.

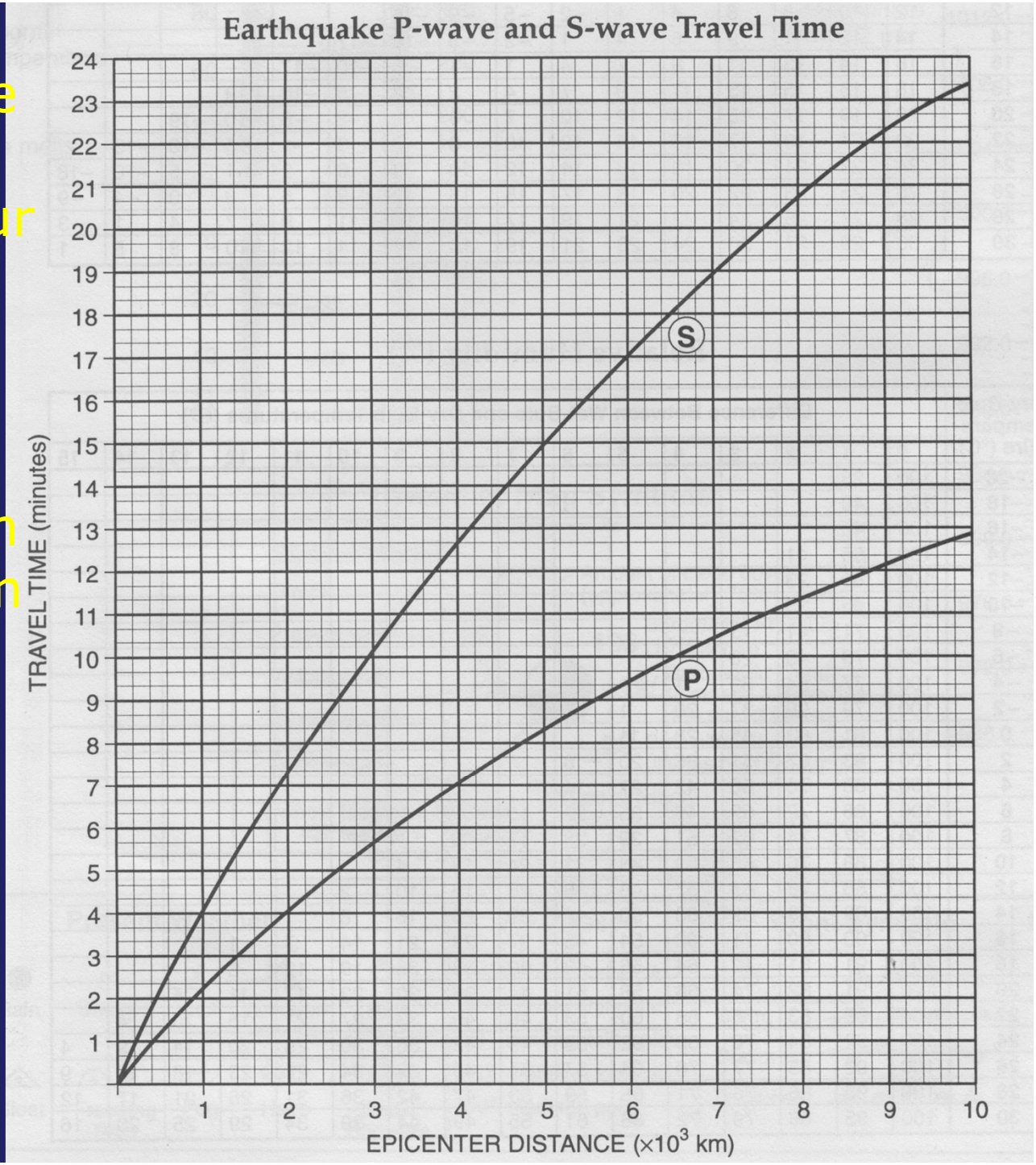
P & S Wave chart in reference tables

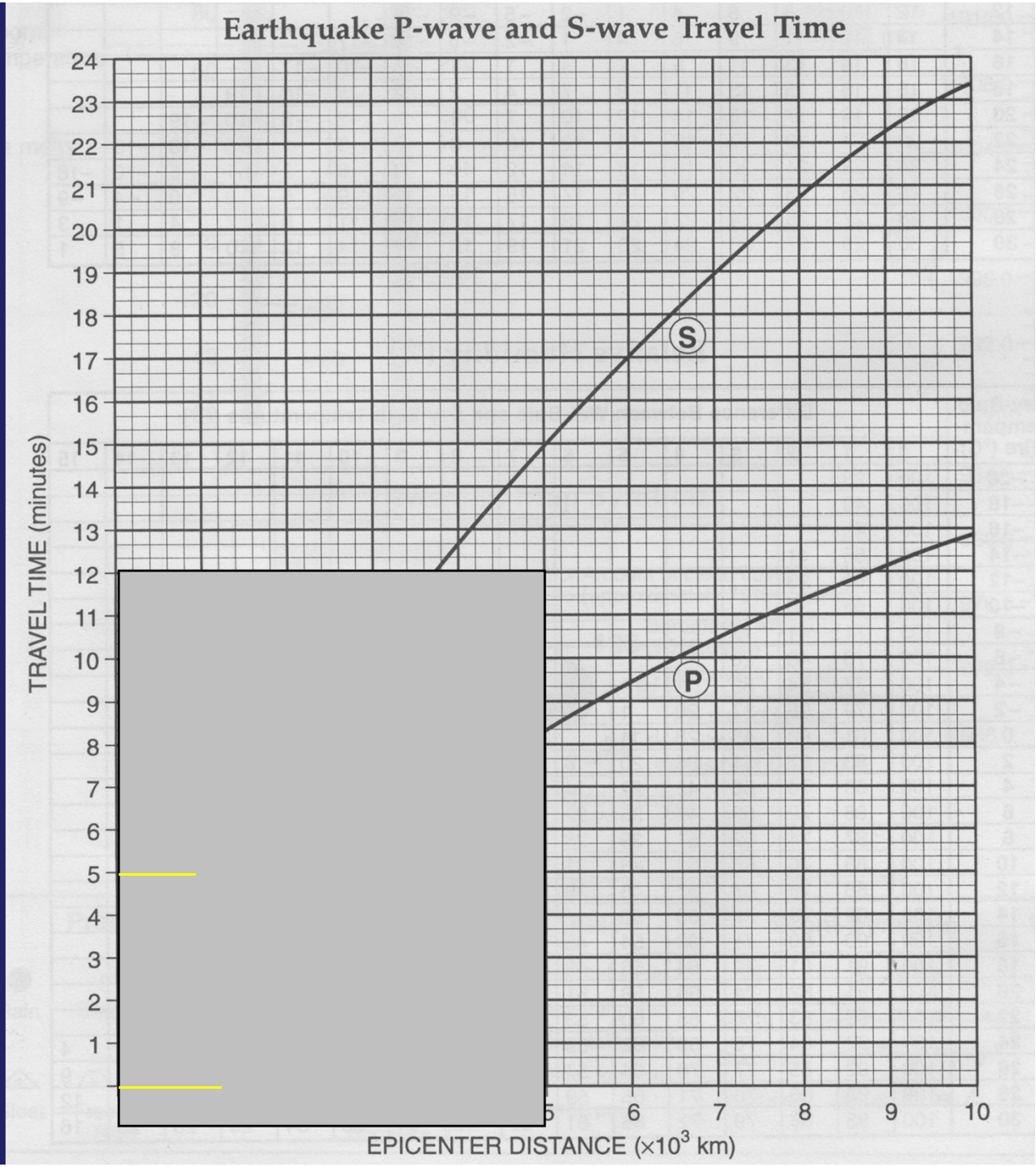
(page 11)


Earthquake P-wave and S-wave Travel Time
TRAVEL TIME (minutes)
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
S
P
1
2
3
4
5
6
7
8
9
10
EPICENTER DISTANCE (×10³ km)

How far away is the epicenter if the waves arrive at your station at the following times?

P-wave 5:42:30 pm
S-wave 5:47:30 pm




Earthquake P-wave and S-wave Travel Time
TRAVEL TIME (minutes)
24
23
22
21
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11
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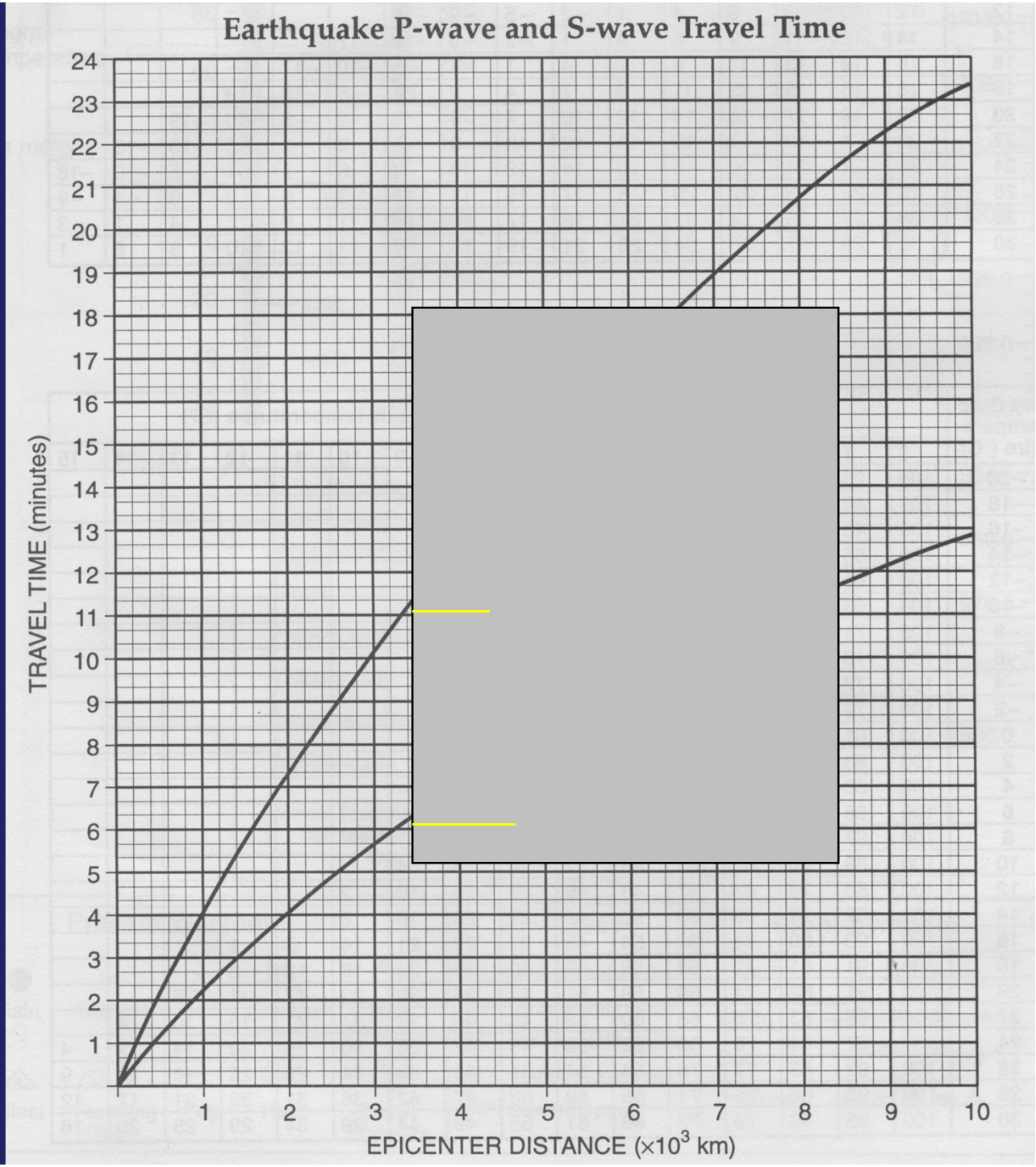
EPICENTER DISTANCE (×10³ km)


Earthquake P-wave and S-wave Travel Time
TRAVEL TIME (minutes)
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23
22
21
20
19
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17
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13
12
11
10
9
8
7
6
5
4
3
2
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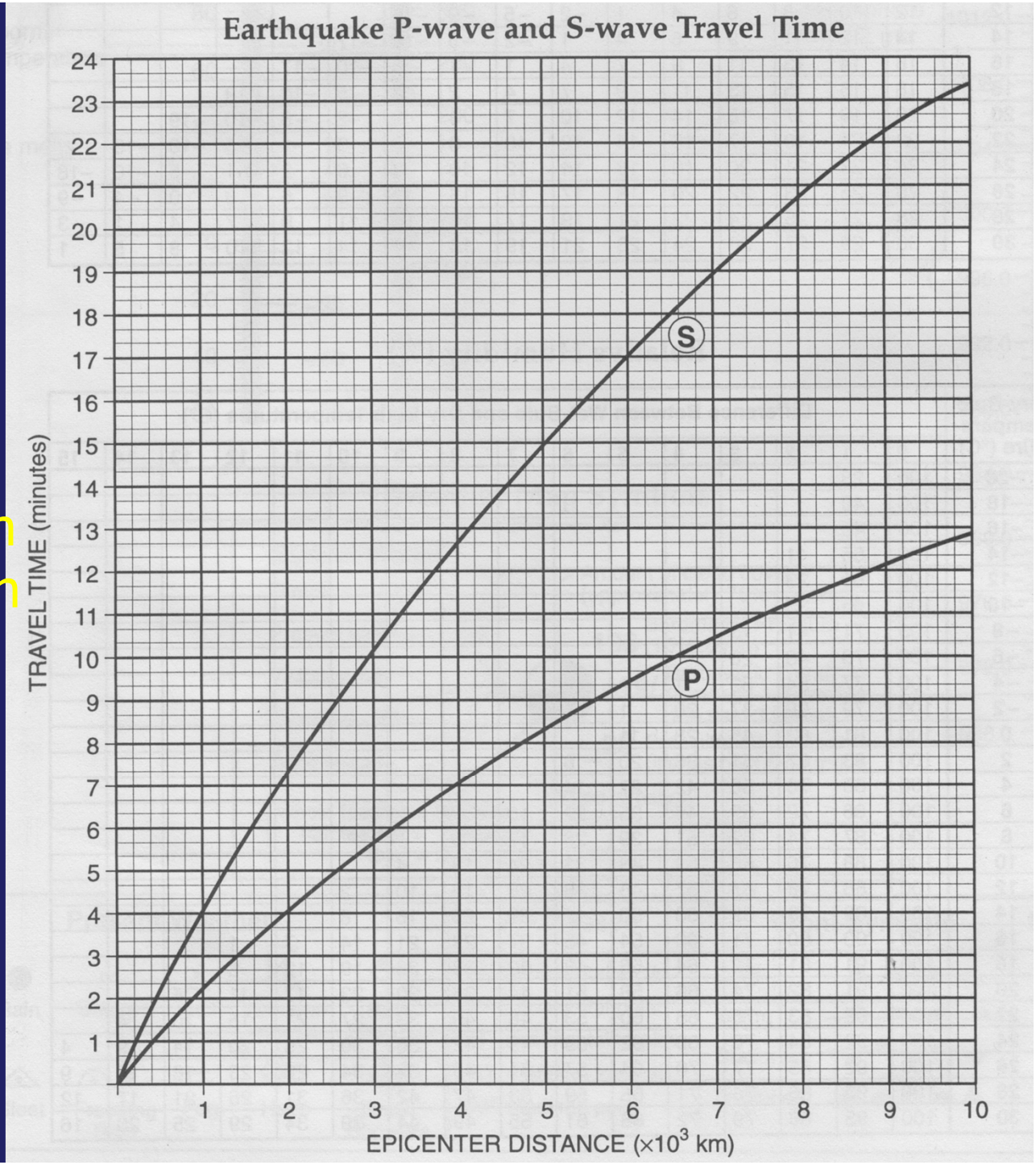
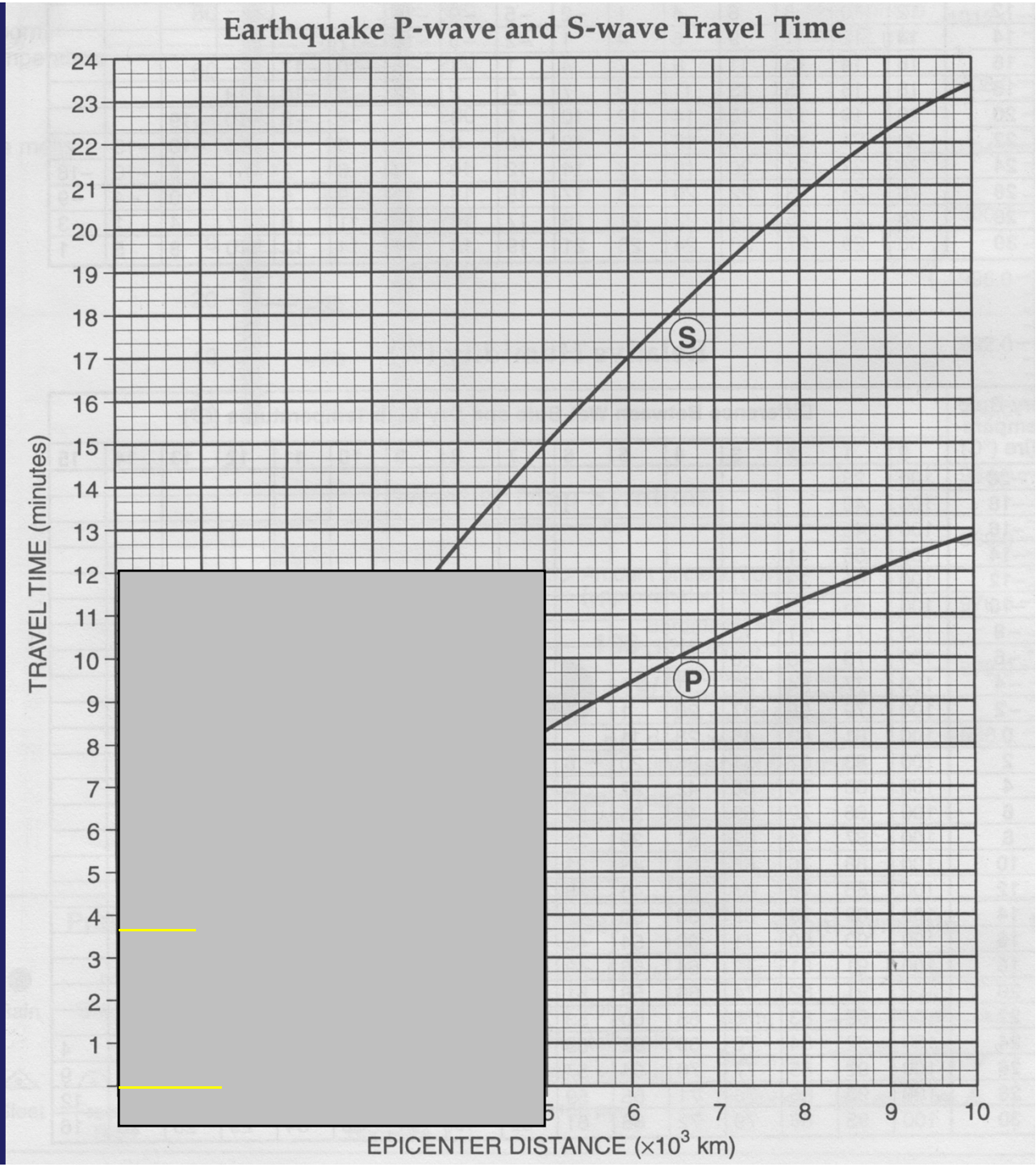
10
EPICENTER DISTANCE (×10³ km)

How far away is the epicenter if the waves arrive at your station at the following times?

P-wave 1:01:10 am
S-wave 1:04:50 am




Earthquake P-wave and S-wave Travel Time
TRAVEL TIME (minutes)
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1
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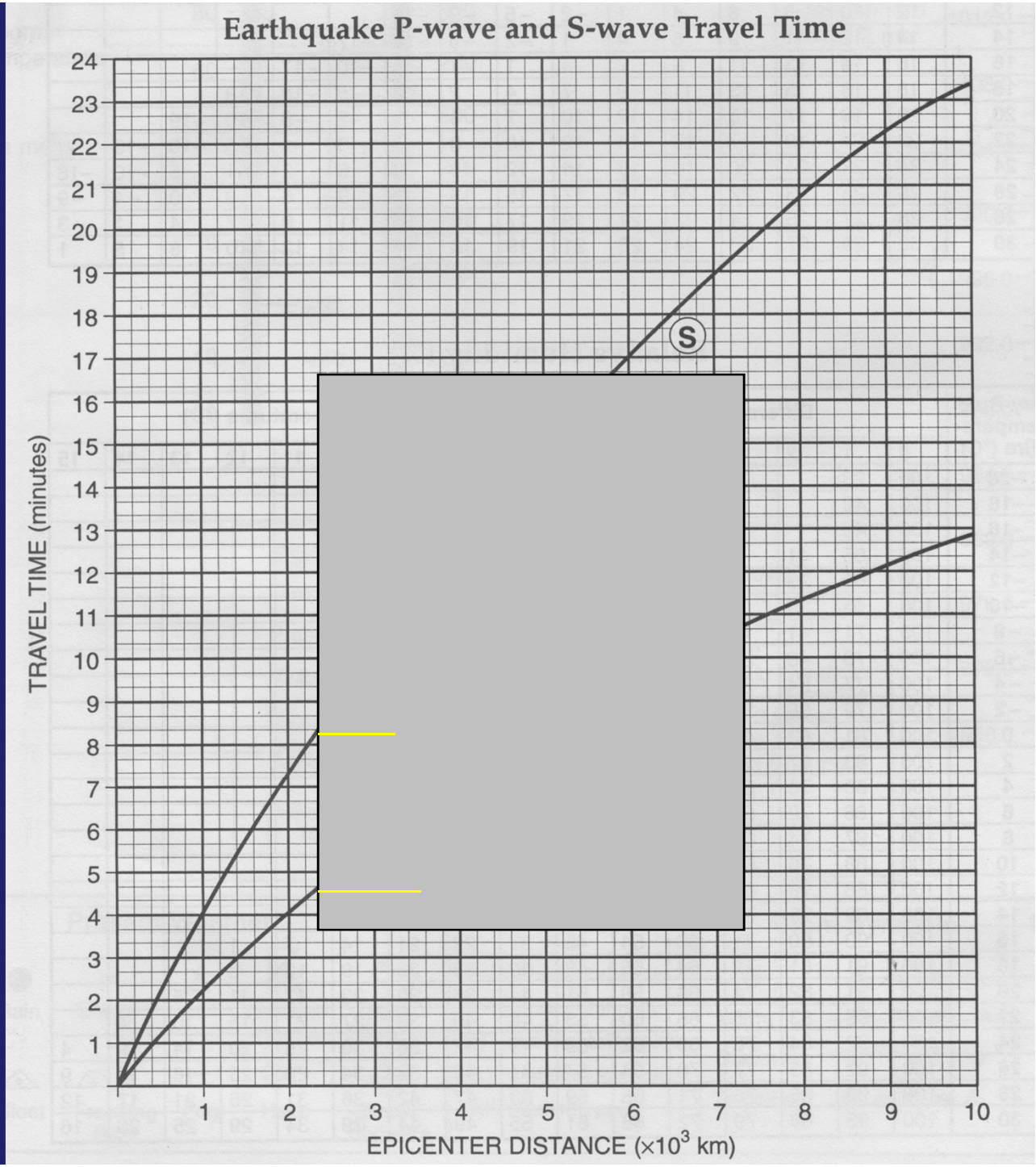
P
6
7
8
9
10
EPICENTER DISTANCE (×10³ km)


Earthquake P-wave and S-wave Travel Time
TRAVEL TIME (minutes)
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23
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21
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11
10
9
8
7
6
5
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3
2
1
S
1
2
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4
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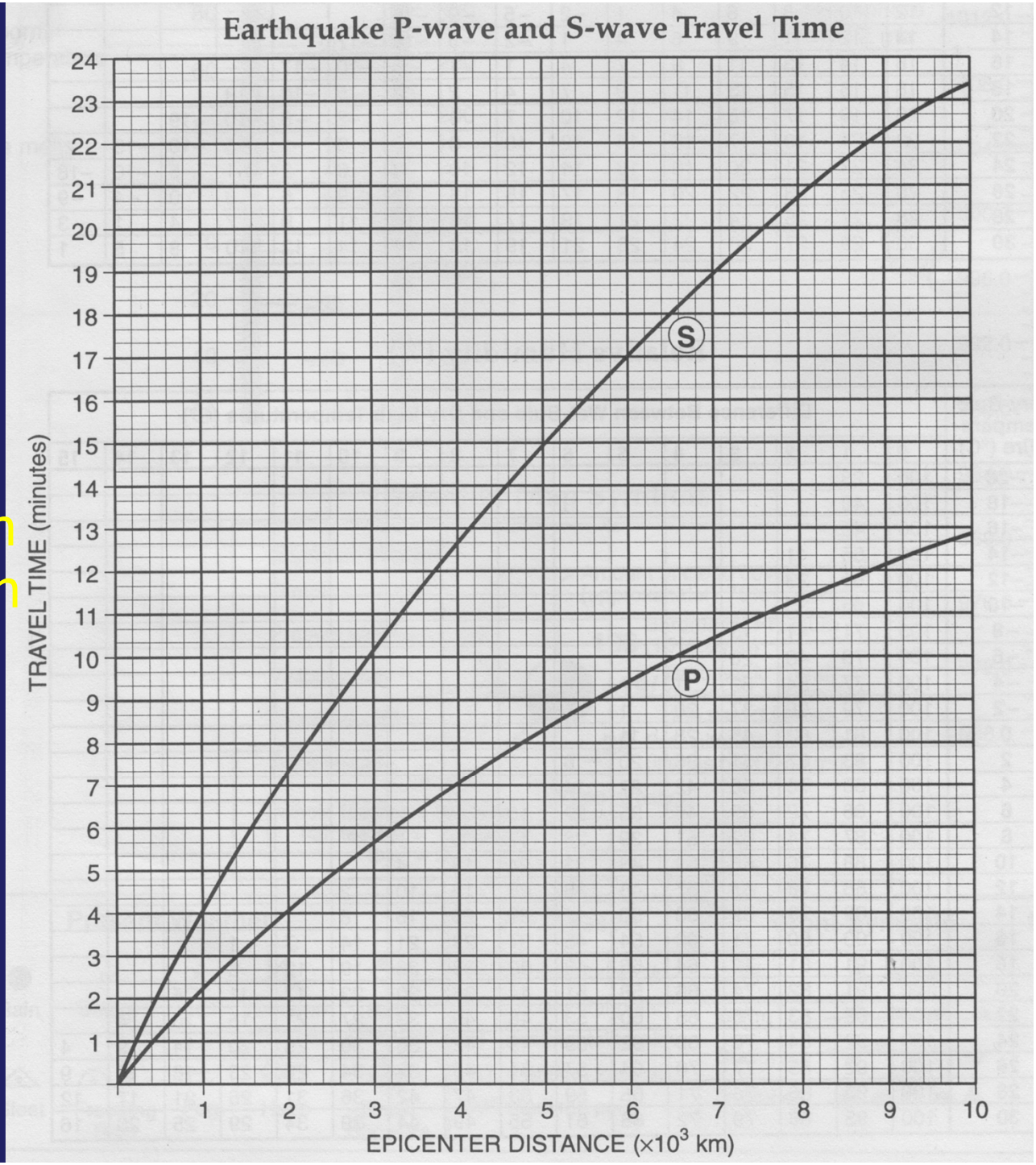
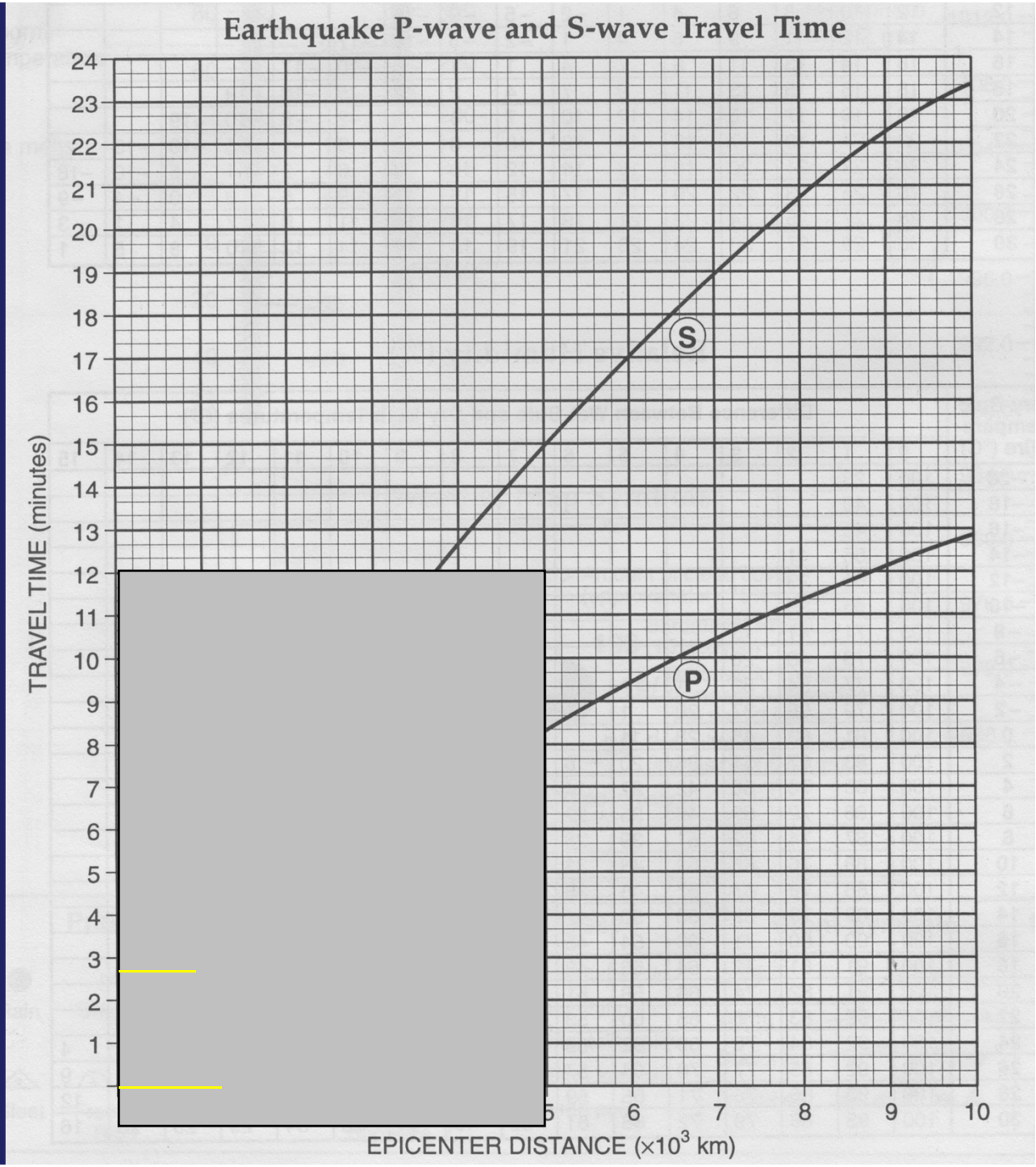
6
7
8
9
10
EPICENTER DISTANCE (×10³ km)

How far away is the epicenter if the waves arrive at your station at the following times?

P-wave 7:32:40 am
S-wave 7:35:20 am




Earthquake P-wave and S-wave Travel Time
TRAVEL TIME (minutes)
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P
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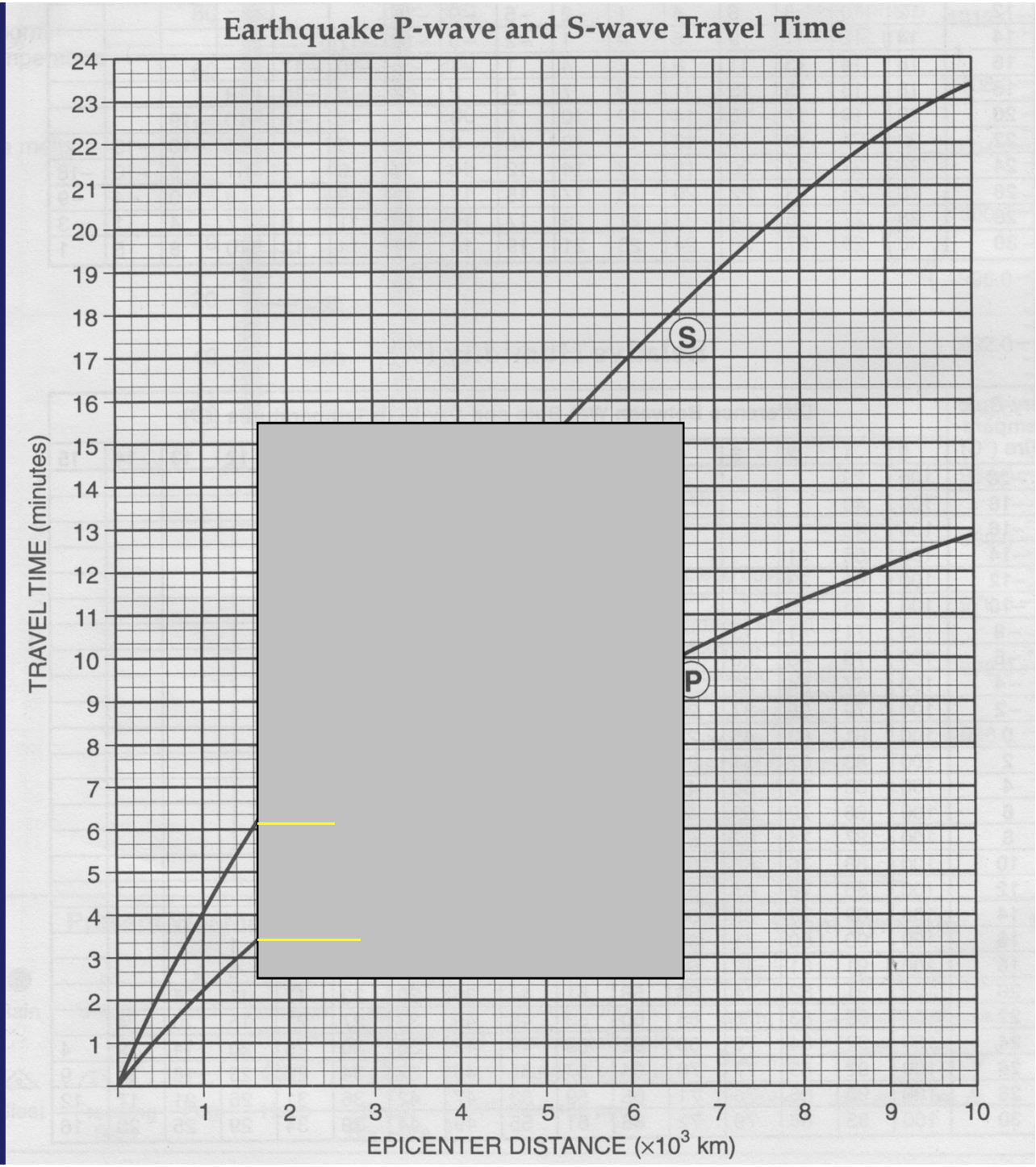
10
EPICENTER DISTANCE (×10³ km)


Earthquake P-wave and S-wave Travel Time
TRAVEL TIME (minutes)
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EPICENTER DISTANCE (×10³ km)

SEISMOGRAPH STATION	Arrival (clock time)		Difference in Arrival Time (min. and sec.)	Distance to Epicenter (km)	"P" Wave Travel Time (min. and sec.)	Time of Origin (hr., min. and sec.)
	"P" Wave	"S" Wave				
CHICAGO						
TAMPA						
WINK						

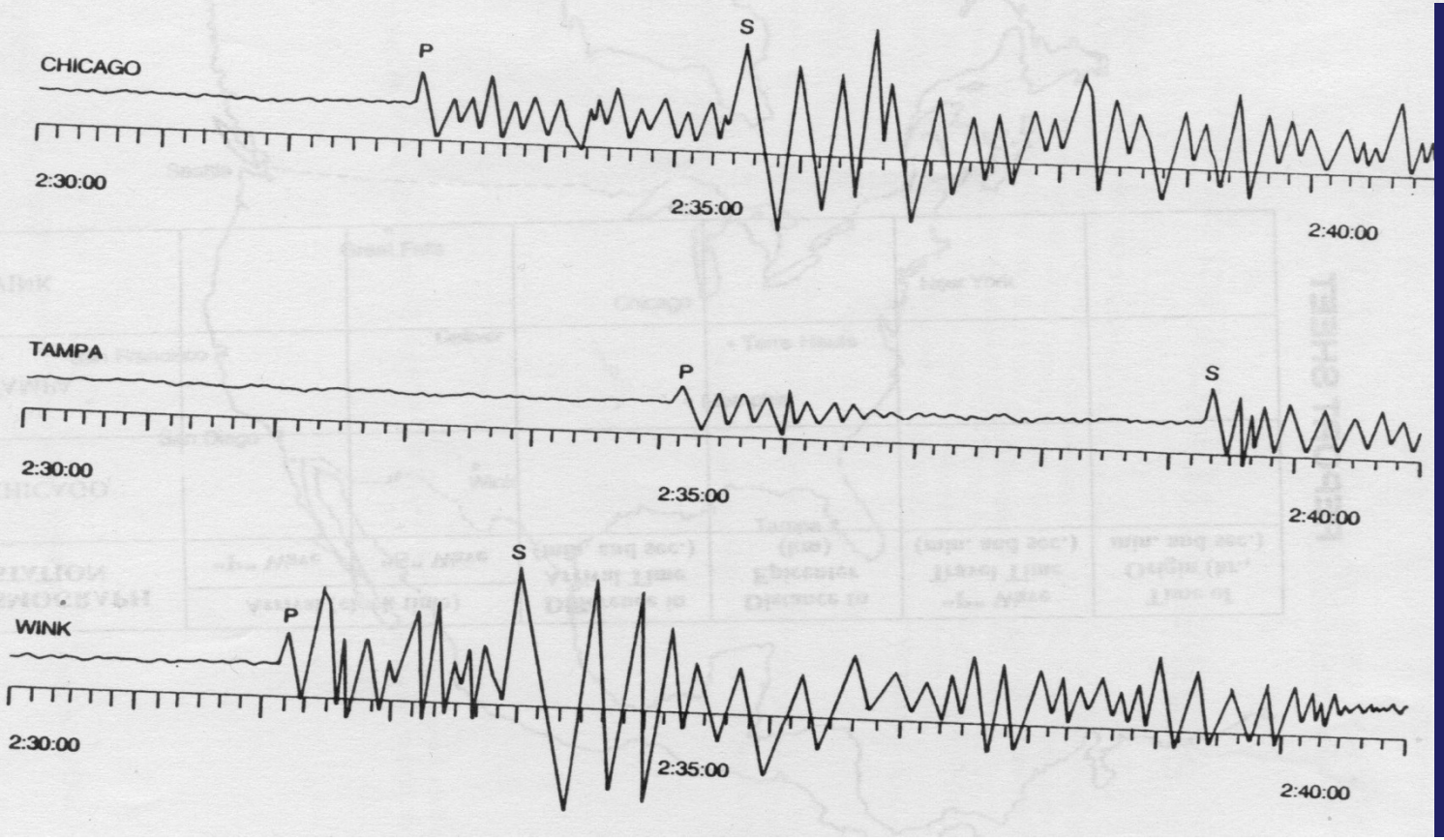
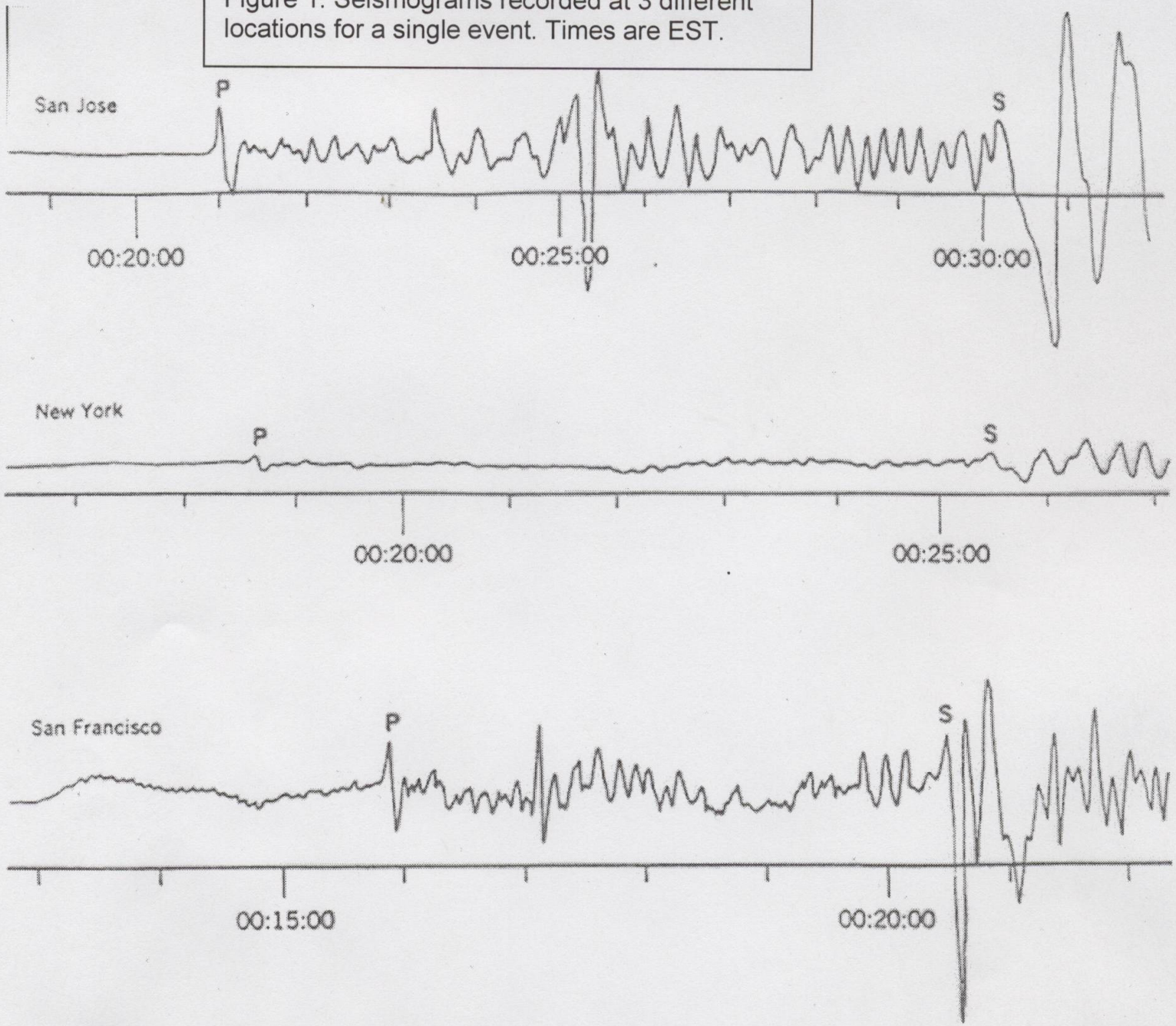


Figure 1. Seismograms recorded at 3 different locations for a single event. Times are EST.



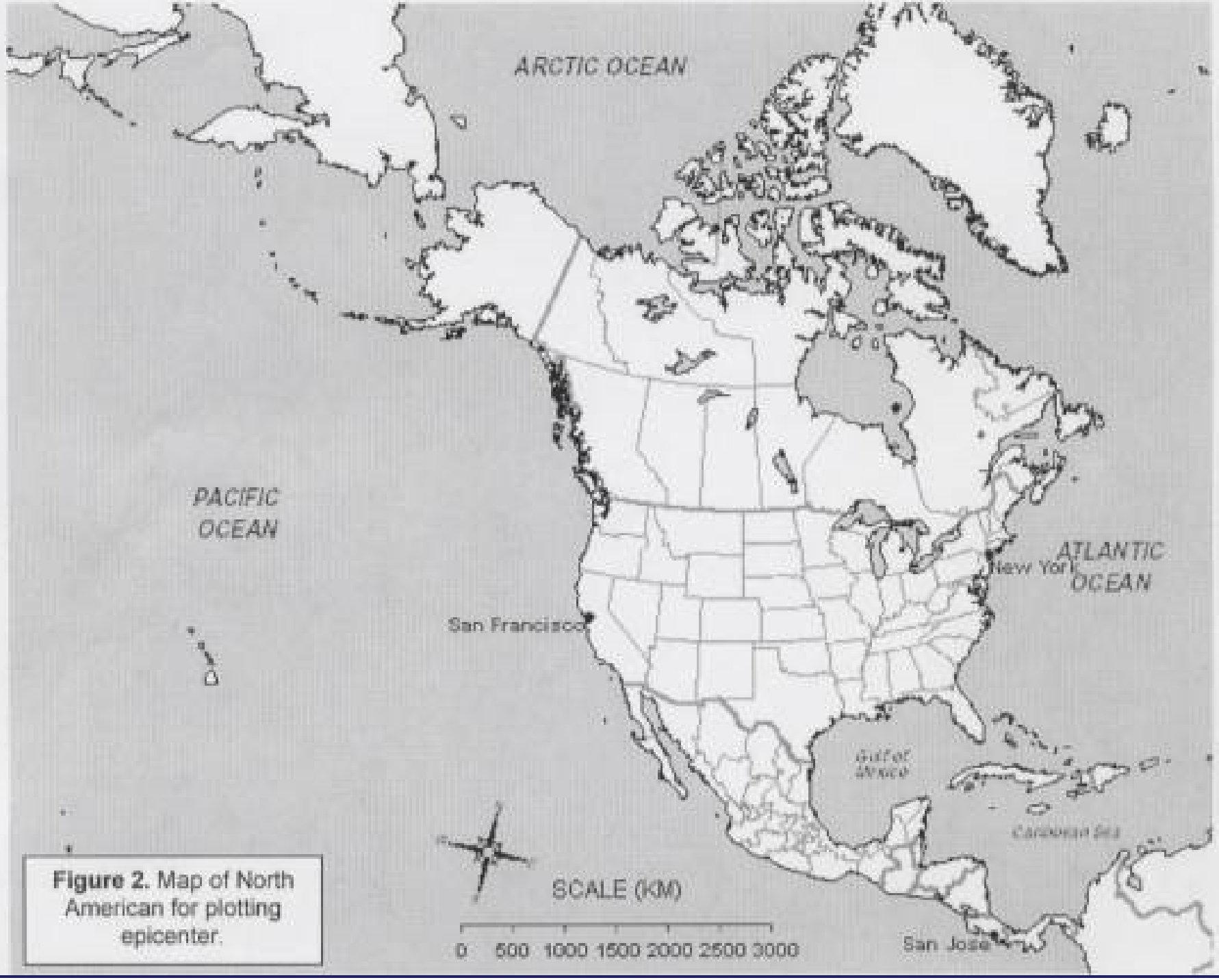
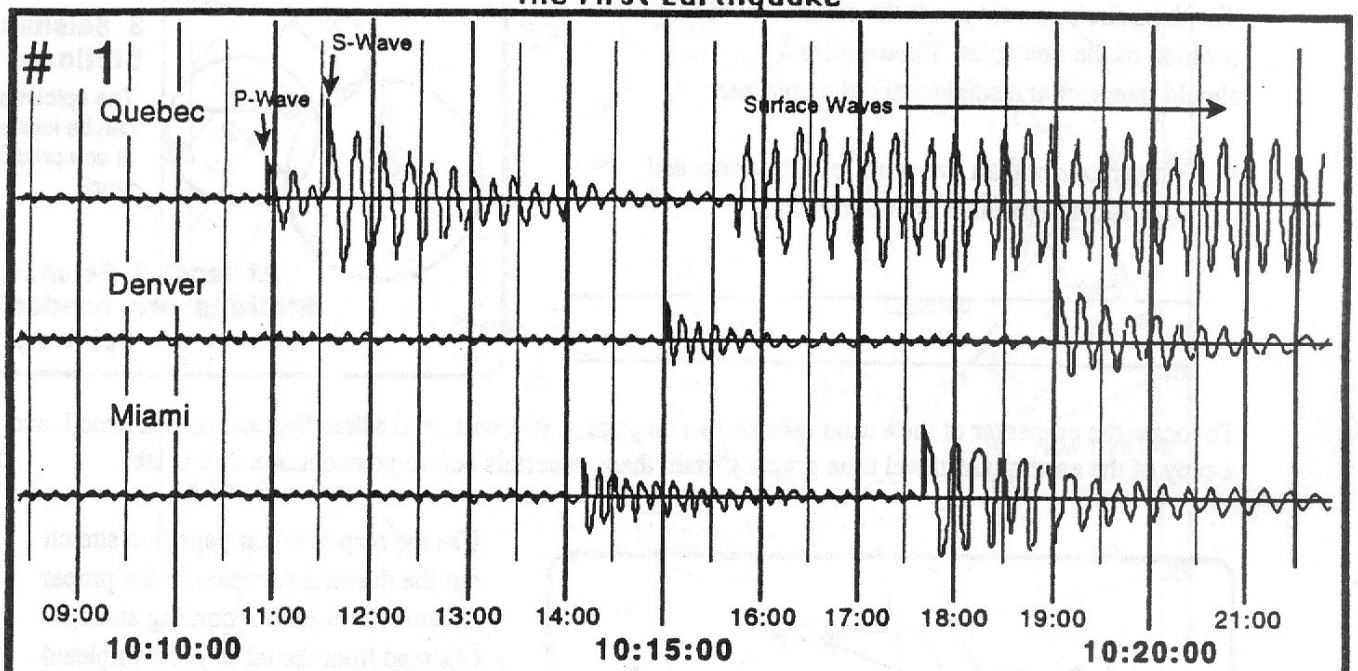


Figure 2. Map of North American for plotting epicenter.

1. In the box below, what is the time separation between the vertical lines?
(Please note that the times on this chart are shown; HOURS : MINUTES : SECONDS) _____

The First Earthquake



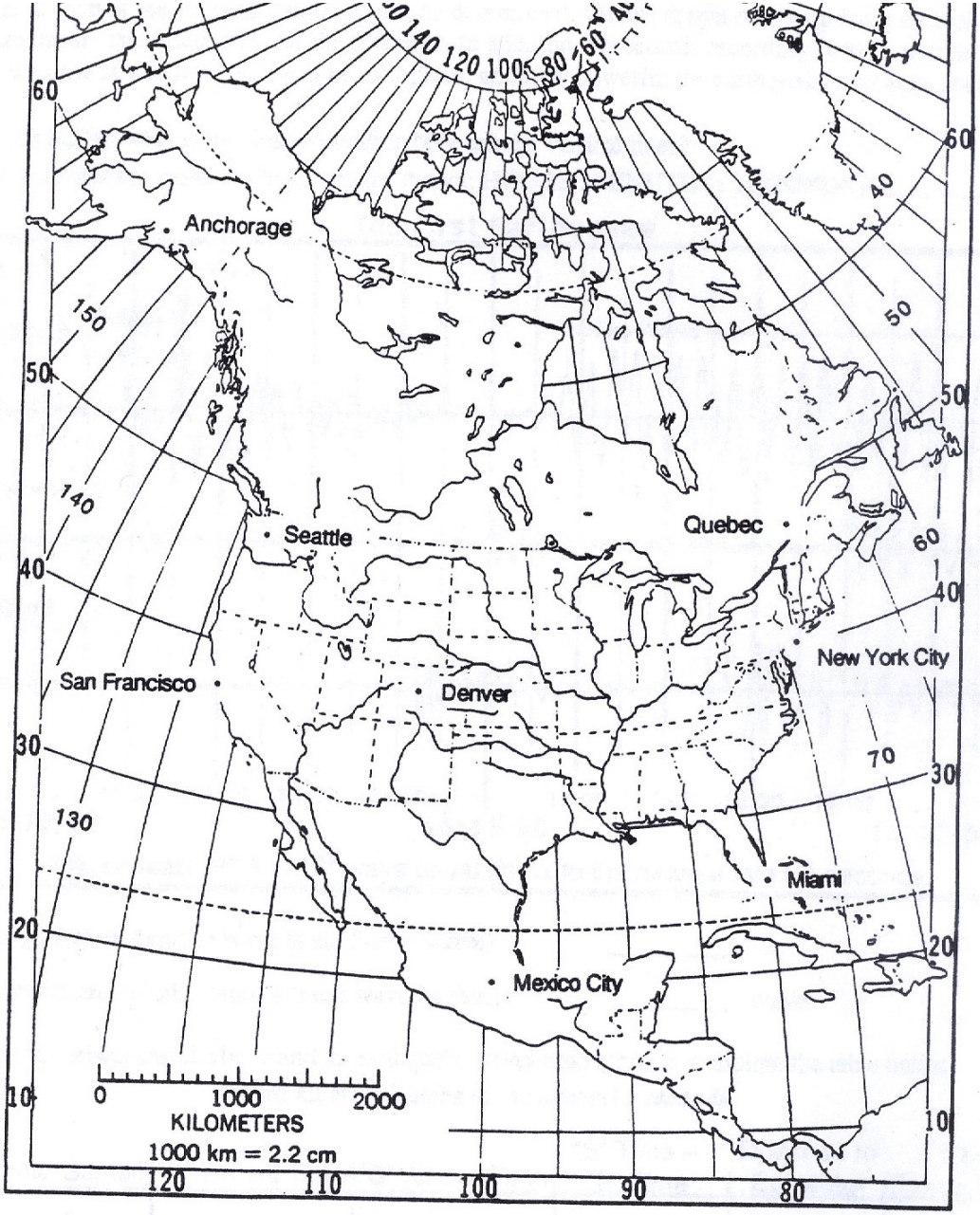
Please read "P" and "S" wave arival times to the nearest five (5) seconds.

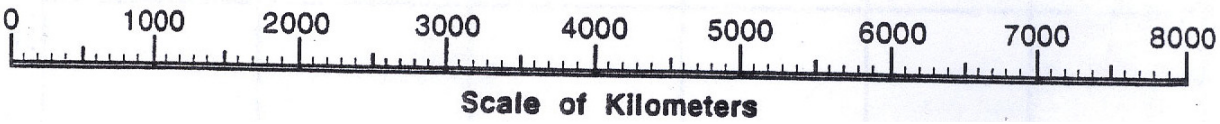
2. Which type of earthquake wave is the first to arrive? _____

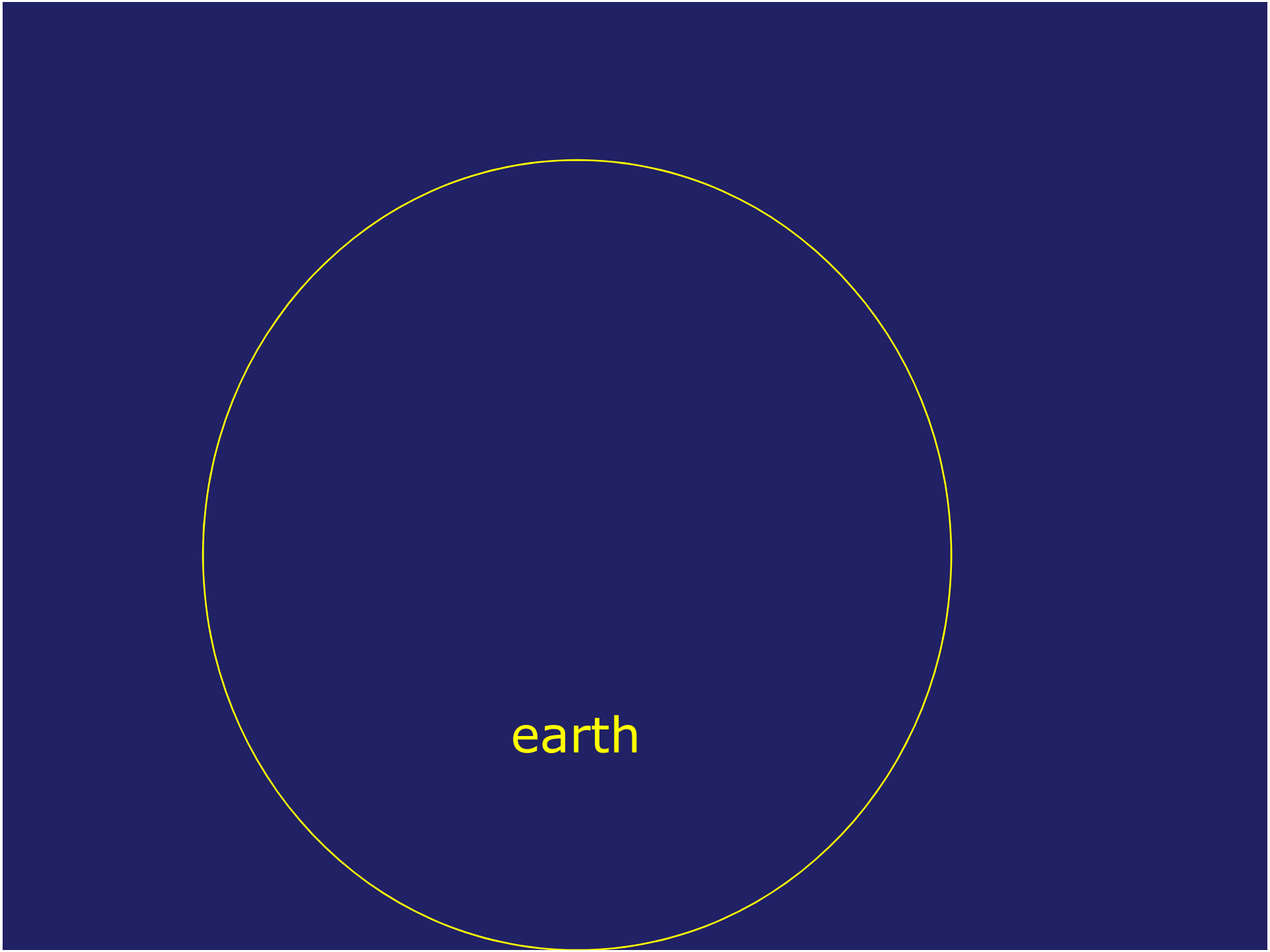
3. The second, and usually more intense wave, is the... _____ wave.

Use the seismograms above and an earthquake travel time graph to complete the table below.
Record all arrival times to the ***nearest 5 seconds***.

	Seismic Station	"P" Arrival Time	"S" Arrival Time	"S" Time – "P" Time	Distance to Epicenter	P-Wave Travel Time
	Quebec					
# 1						

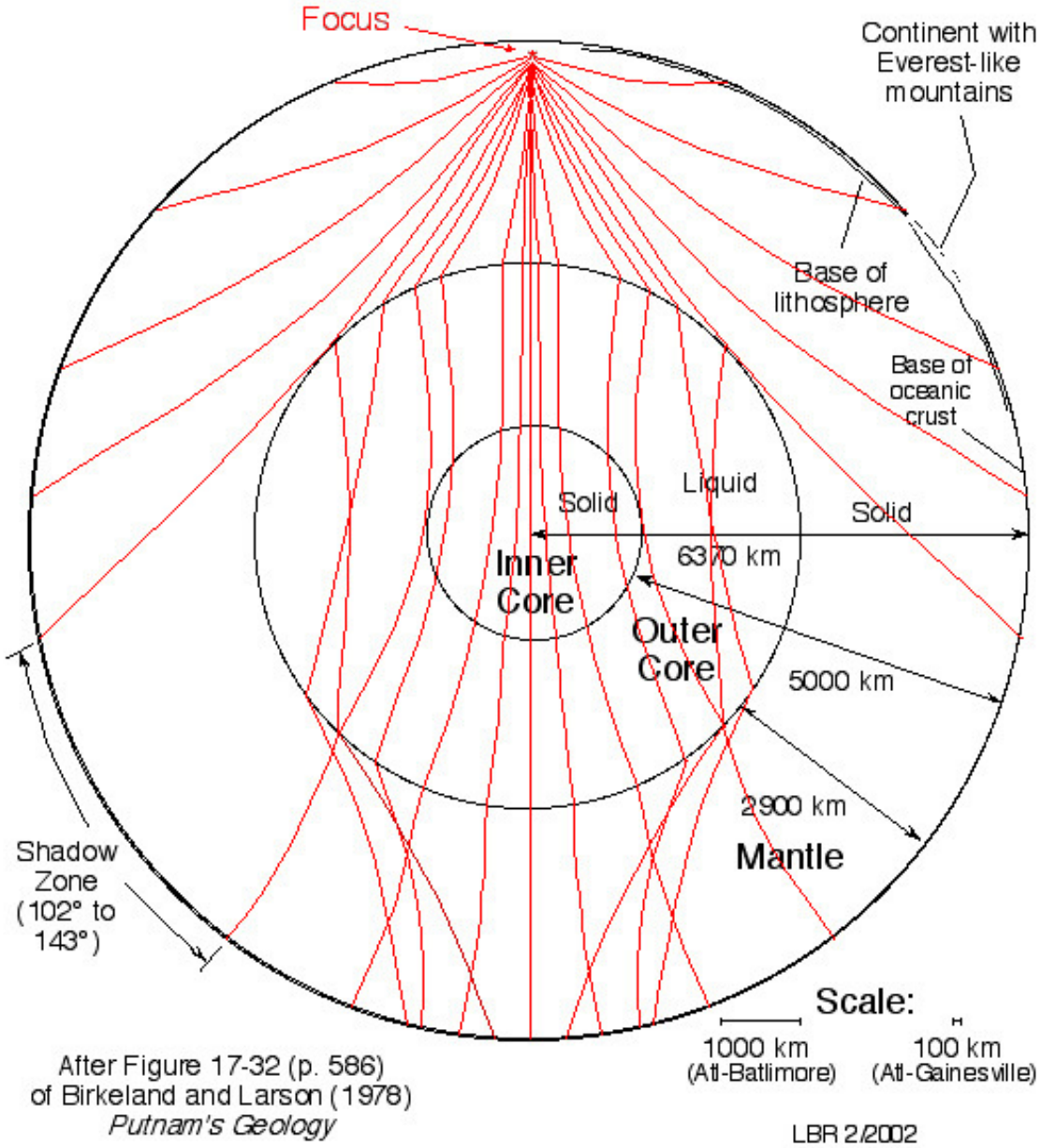

Anchorage
Seattle
Quebec
New York City
San Francisco
Denver
Miami
Mexico City
0
1000
2000
KILOMETERS
1000 km = 2.2 cm


0
1000
2000
3000
4000
5000
6000
7000
8000
Scale of Kilometers


earth

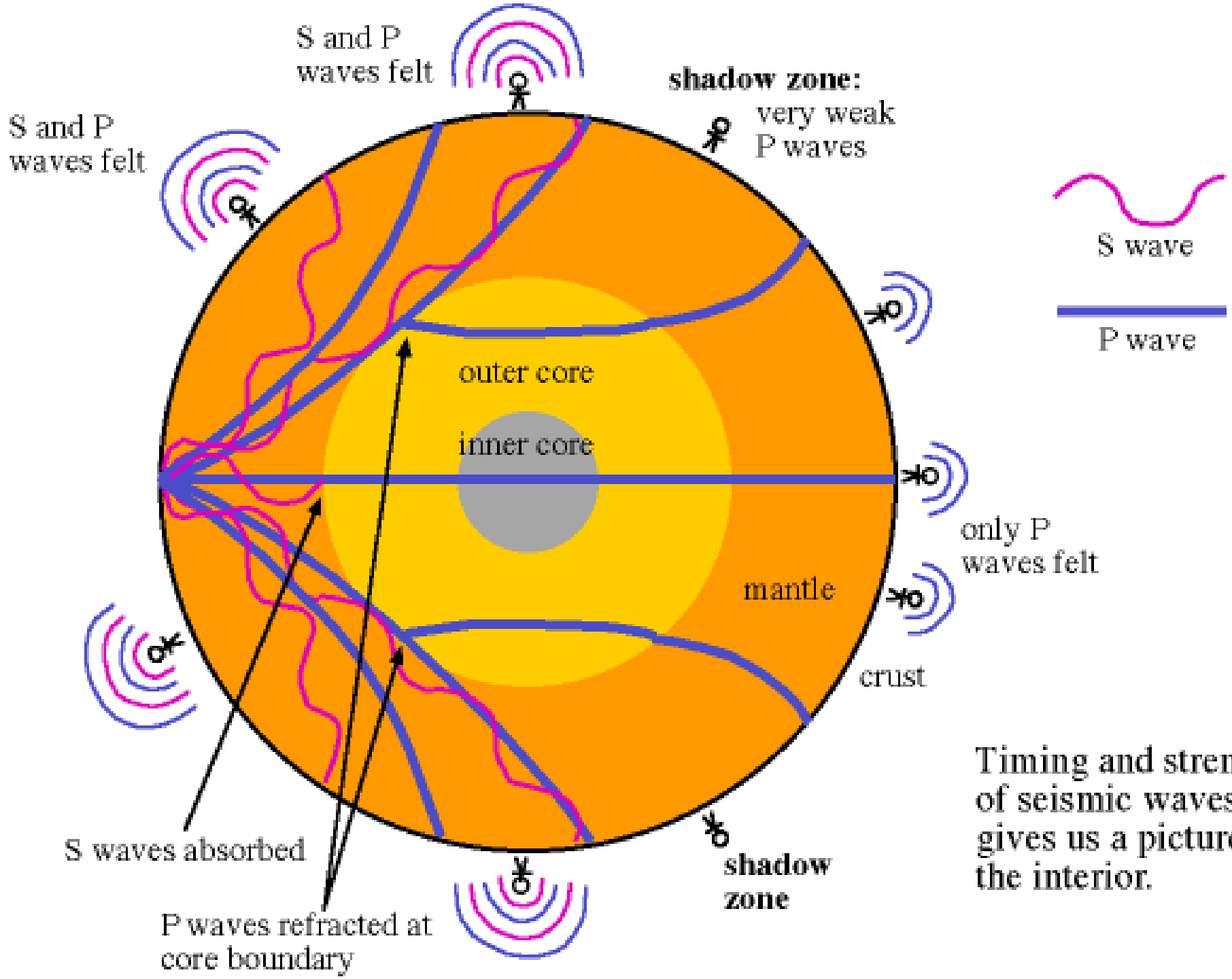
P & S Wave Animation

Passage of P waves through the Earth



After Figure 17-32 (p. 586) of Birkeland and Larson (1978) *Putnam's Geology*

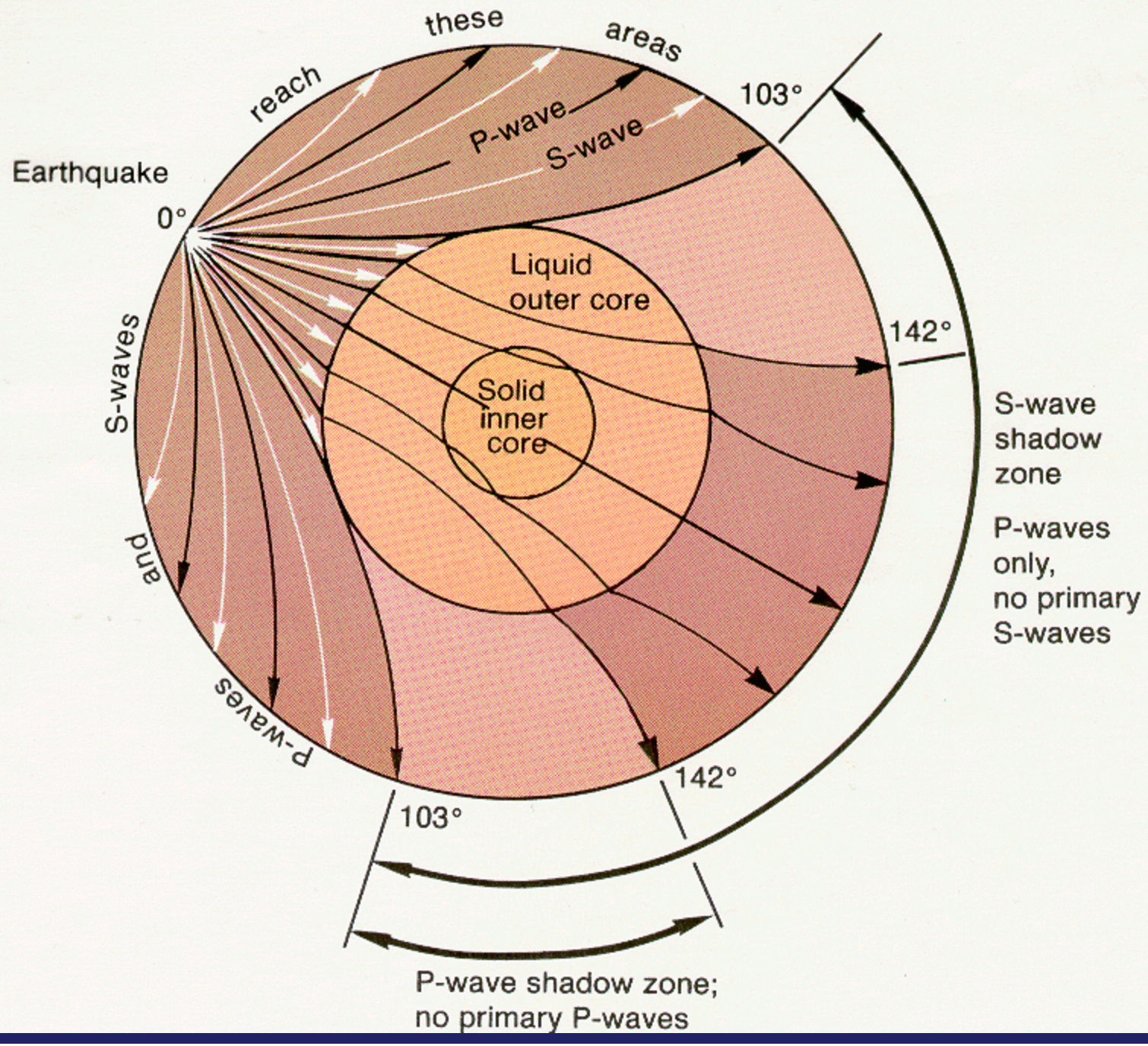
LBR 2/2002



Timing and strength of seismic waves gives us a picture of the interior.

Shadow zone:

Between 102º and 143º away from the epicenter, neither P or S waves are recorded


these
areas
reach
103°
P-wave
S-wave
Earthquake
0°
Liquid
outer core
142°
S-waves
Solid
inner
core
S-wave
shadow
zone
and
P-waves
only,
no primary
S-waves
P-waves
142°
103°
P-wave shadow zone;
no primary P-waves

How do measure how strong an earthquake is?

Two ways:

1) Richter Scale
   - a magnitude scale
   - ranges from 0 to 9
   - less than 2.5 are usually not felt by people
   - Each increase in Richter magnitude is an increase by 30 times in energy

Live Seismogram Lamont-Doherty

http://www.ldeo.columbia.edu/cgi-bin/LCSN/WebSeis/24hr_heli.pl?id=

How do measure how strong an earthquake is?

Two ways:

2) Mercalli Scale

-an intensity scale

-based on damage reports

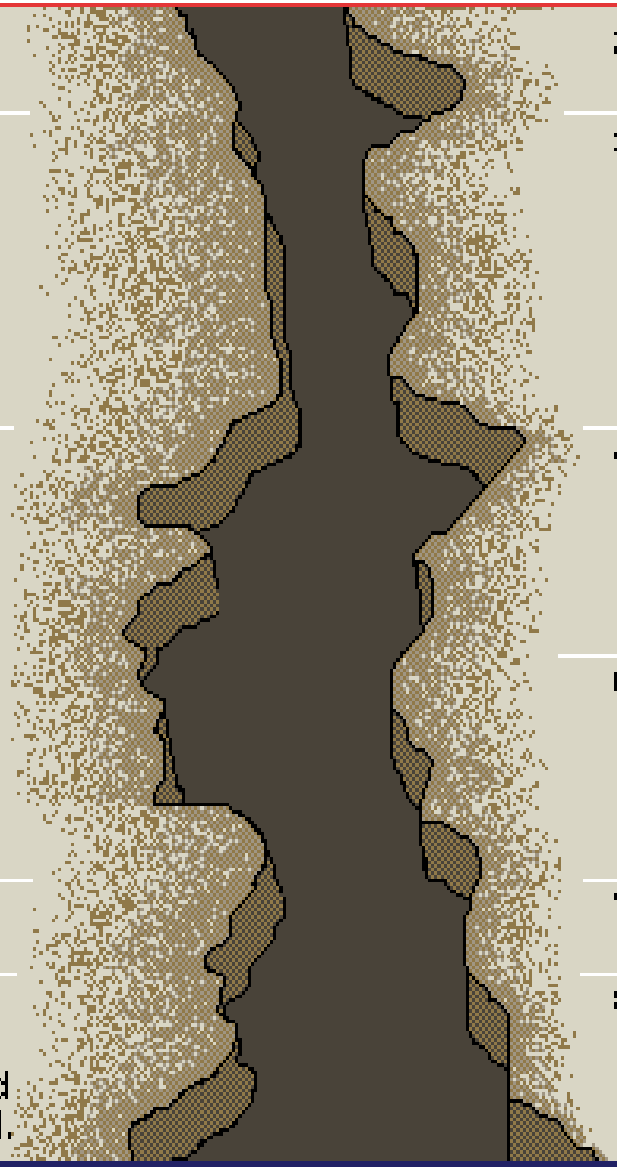
-range from I to XII

-I is usually felt by few people

-XII results in total devastation

Earth science rules

Modified Mercalli Scale		Richter Scale	
I.	Felt by almost no one.	2.5	Generally not felt, but recorded on seismometers.
II.	Felt by very few people.		
III.	Tremor noticed by many, but they often do not realize it is an earthquake.	3.5	Felt by many people.
IV.	Felt indoors by many. Feels like a truck has struck the building.		
V.	Felt by nearly everyone; many people awakened. Swaying trees and poles may be observed.		
VI.	Felt by all; many people run outdoors. Furniture moved, slight damage occurs.	4.5	Some local damage may occur.
VII.	Everyone runs outdoors. Poorly built structures considerably damaged; slight damage elsewhere.		
VIII.	Specially designed structures damaged slightly, others collapse.	6.0	A destructive earthquake.
IX.	All buildings considerably damaged, many shift off foundations. Noticeable cracks in ground.		
X.	Many structures destroyed. Ground is badly cracked.	7.0	A major earthquake.
XI.	Almost all structures fall. Bridges wrecked. Very wide cracks in ground.	8.0 and up	Great earthquakes.
XII.	Total destruction. Waves seen on ground surfaces, objects are tumbled and tossed.		



USGS

http://earthquake.usgs.gov/recenteqsww/Quakes/quakes_all.html

- Mercalli maps
- Recent earthquakes

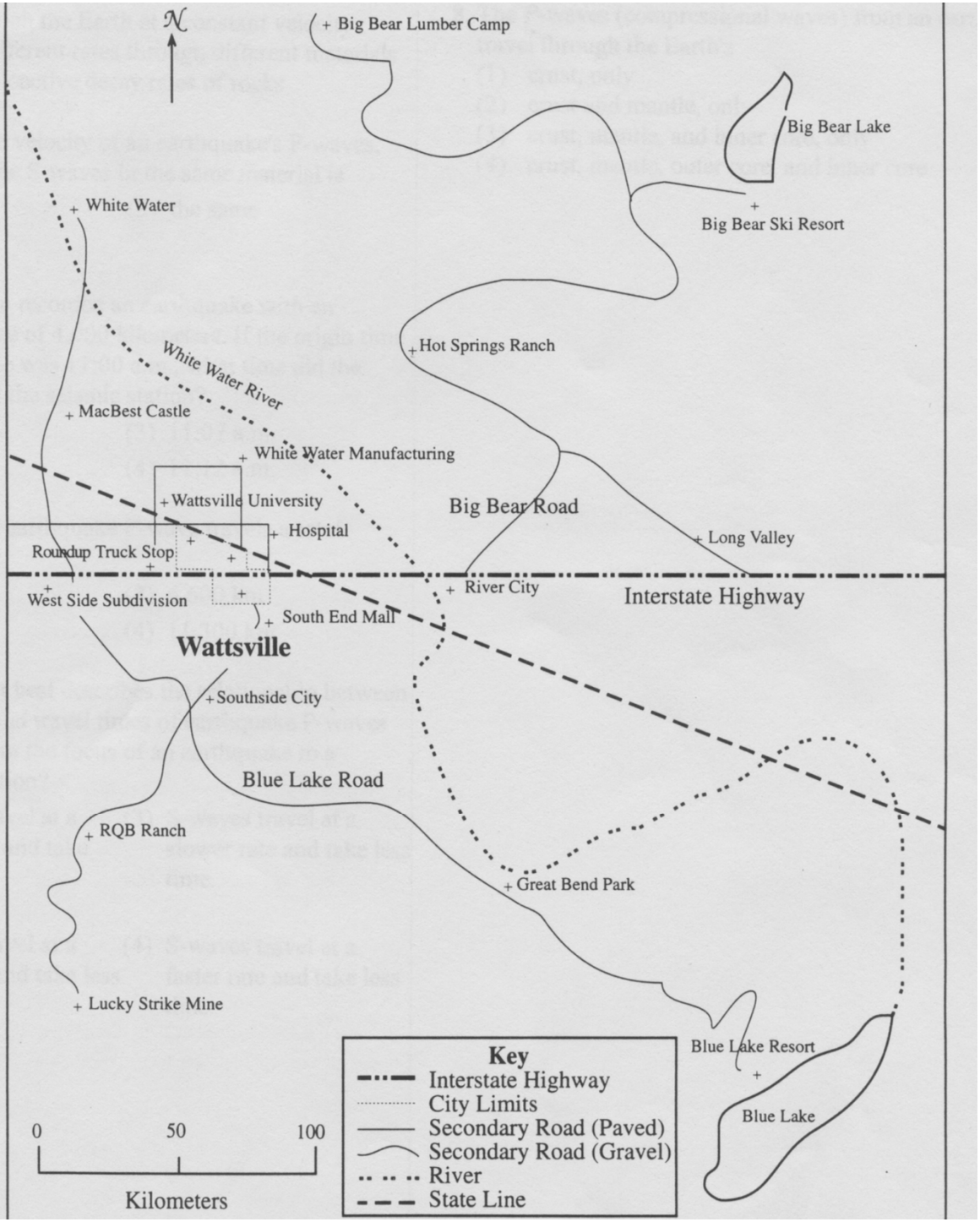
Other results of earthquakes include:

1) fires (gas and water lines rupture)

2) Buildings –especially those built on loose sediment (earthquakes don't kill people; buildings do)

3) Tsunamis (giant tidal waves)

I = 1
II = 2
III = 3
IV = 4
V = 5
VI = 6
VII = 7
VIII = 8
IX = 9
X = 10
XI = 11
XII = 12



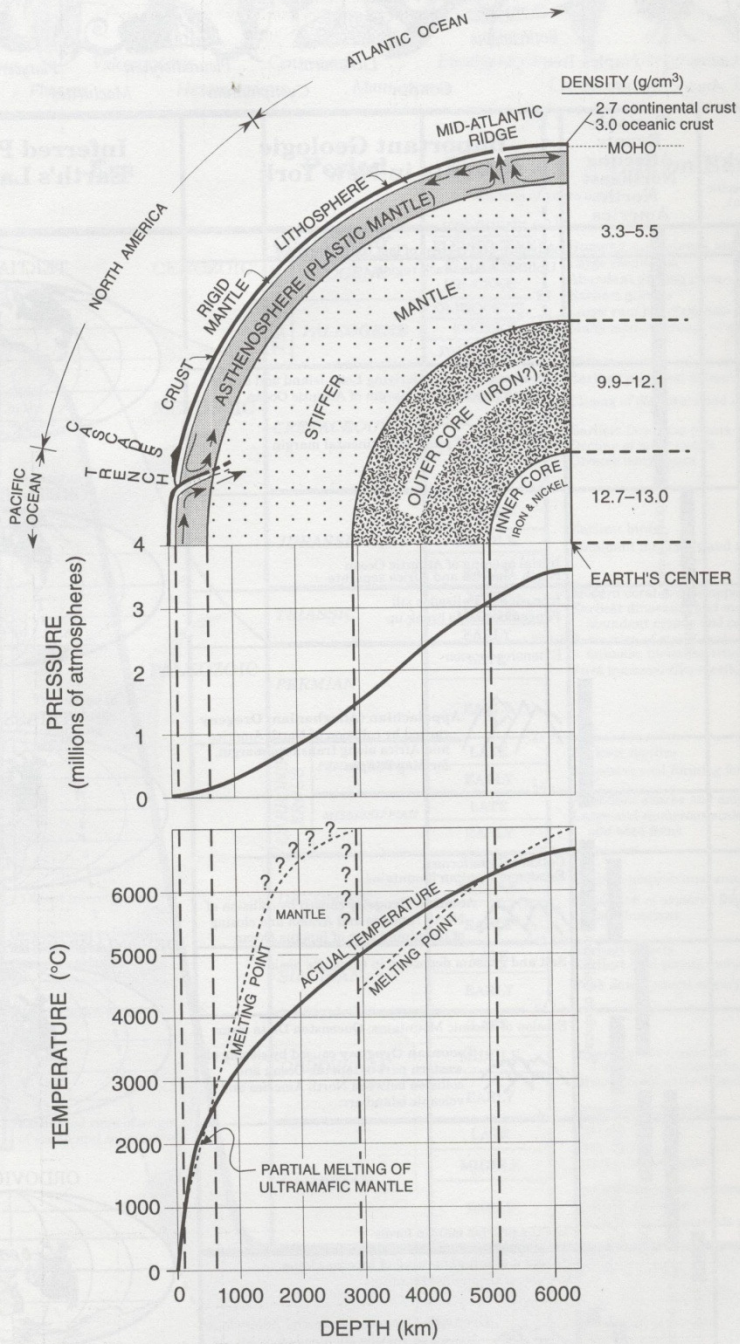
Because of seismic waves (P and S), we know that the earth is divided into four major layers:

1)The crust

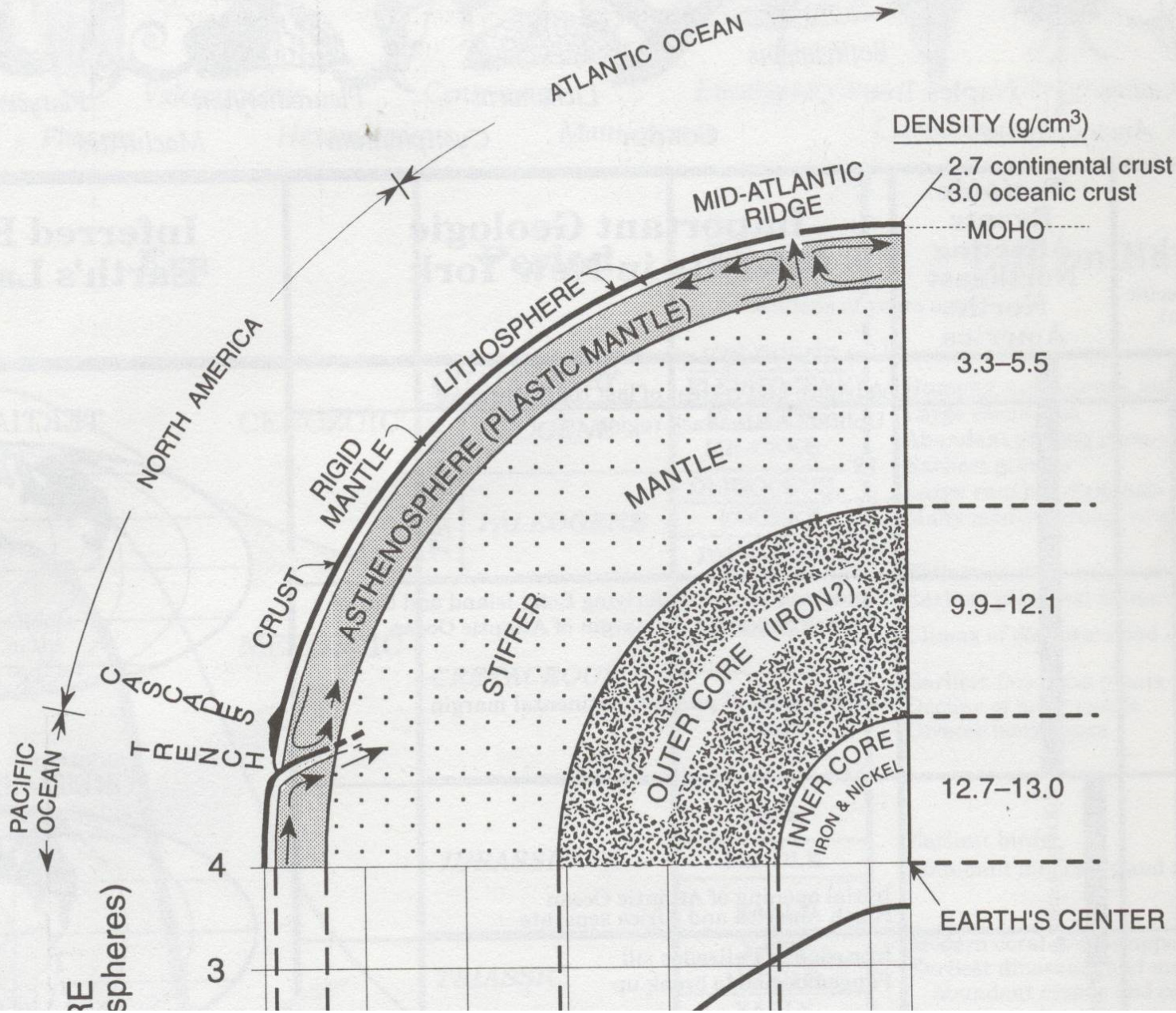
-continental crust = thicker and made of mostly granite

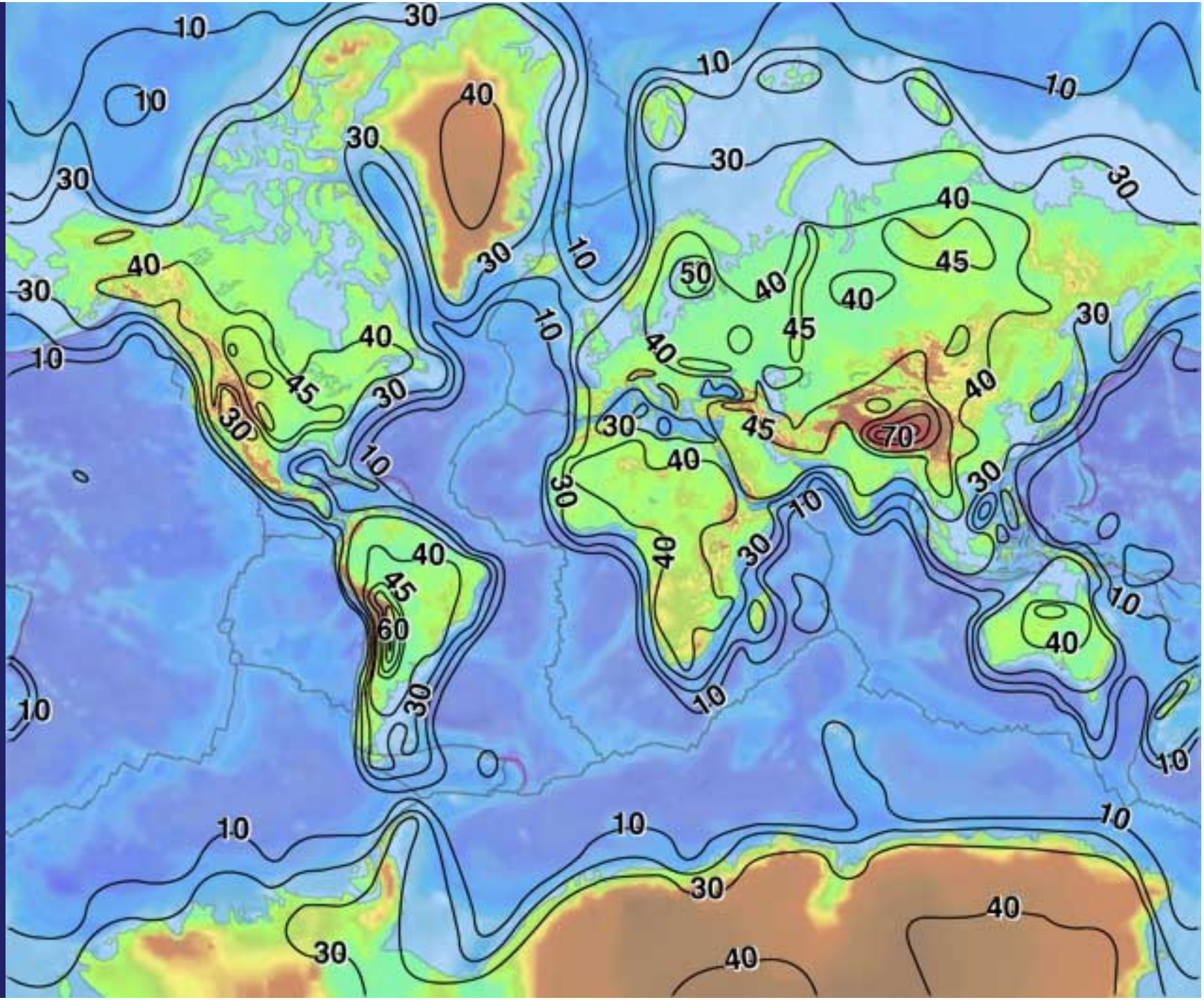
-oceanic crust=thinner and made of mostly basalt

Inferred Properties of Earth's Interior



Inferred Properties of Earth's Interior



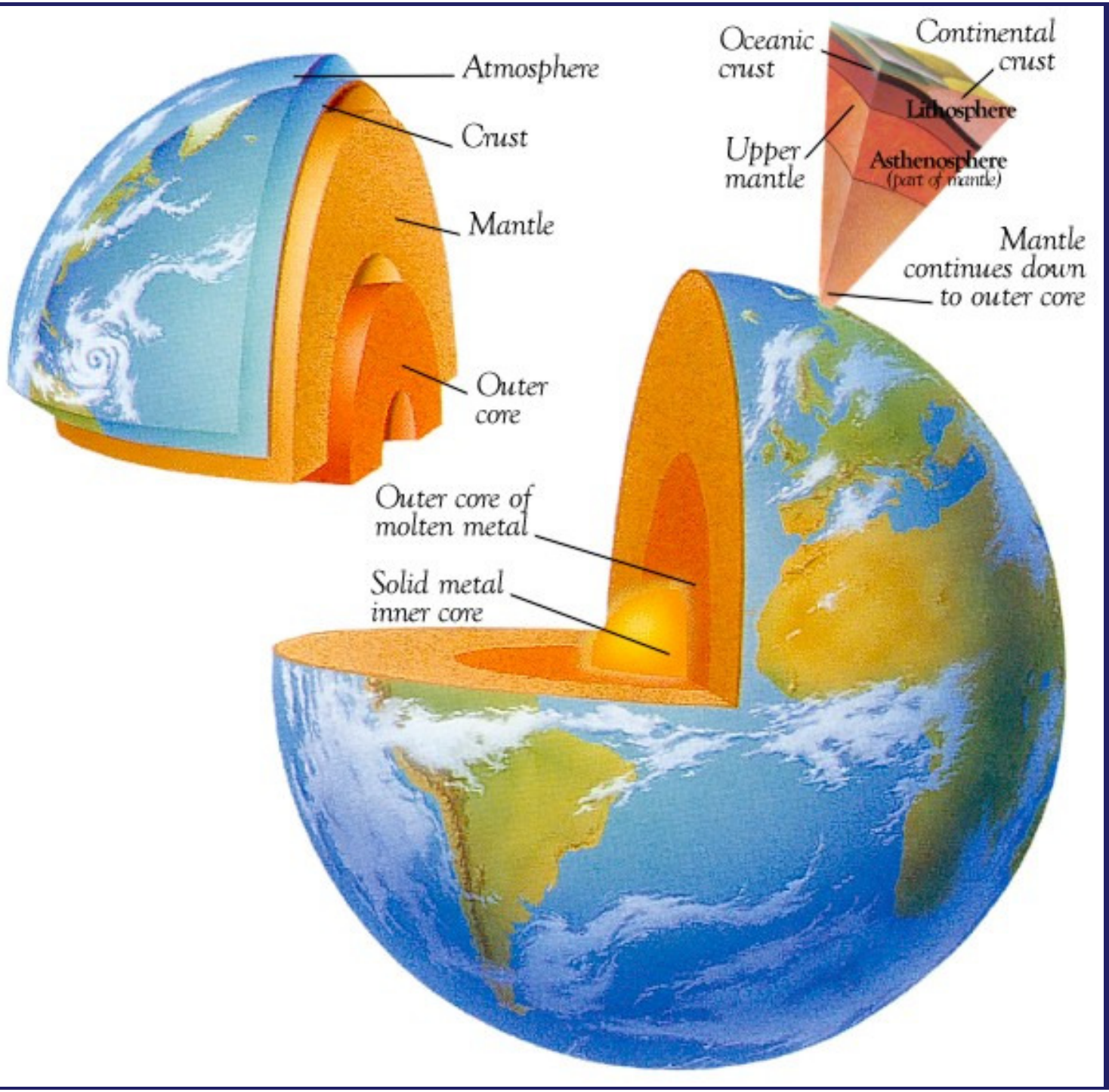

10
30
40
45
50
60
70

Because of seismic waves (P and S), we know that the earth is divided into four major layers:

2) The mantle

-solid layer

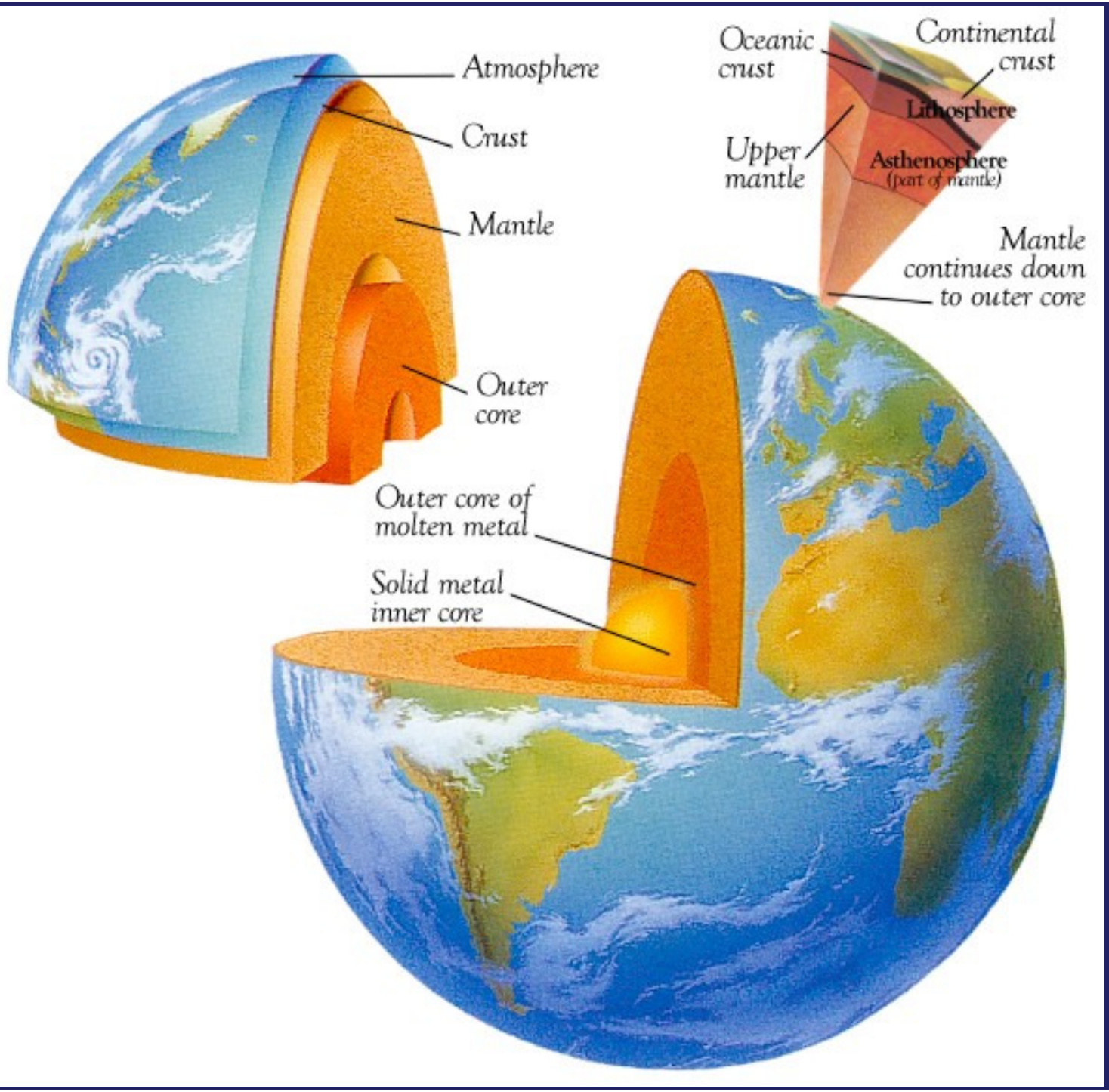
-thickest layer (2900 km)


Atmosphere
Crust
Mantle
Outer core
Oceanic crust
Continental crust
Lithosphere
Upper mantle
Asthenosphere
(part of mantle)
Mantle continues down to outer core
Outer core of molten metal
Solid metal inner core

Because of seismic waves (P and S), we know that the earth is divided into four major layers:

3) The outer core

- the only true liquid layer
- made of liquid iron and nickel
- 2200 km thick


Atmosphere
Crust
Mantle
Outer core
Oceanic crust
Continental crust
Lithosphere
Upper mantle
Asthenosphere
(part of mantle)
Mantle continues down to outer core
Outer core of molten metal
Solid metal inner core

Because of seismic waves (P and S), we know that the earth is divided into four major layers:

4) The inner core

- solid metal ball in the center of earth
- made of iron and nickel
- similar to the composition of meteorites

Wattsville Mercalli Map:

Less than IV = purple

IV-V = blue

V-VI = green

VI-VII = yellow

VII-VIII = orange

>VIII = red