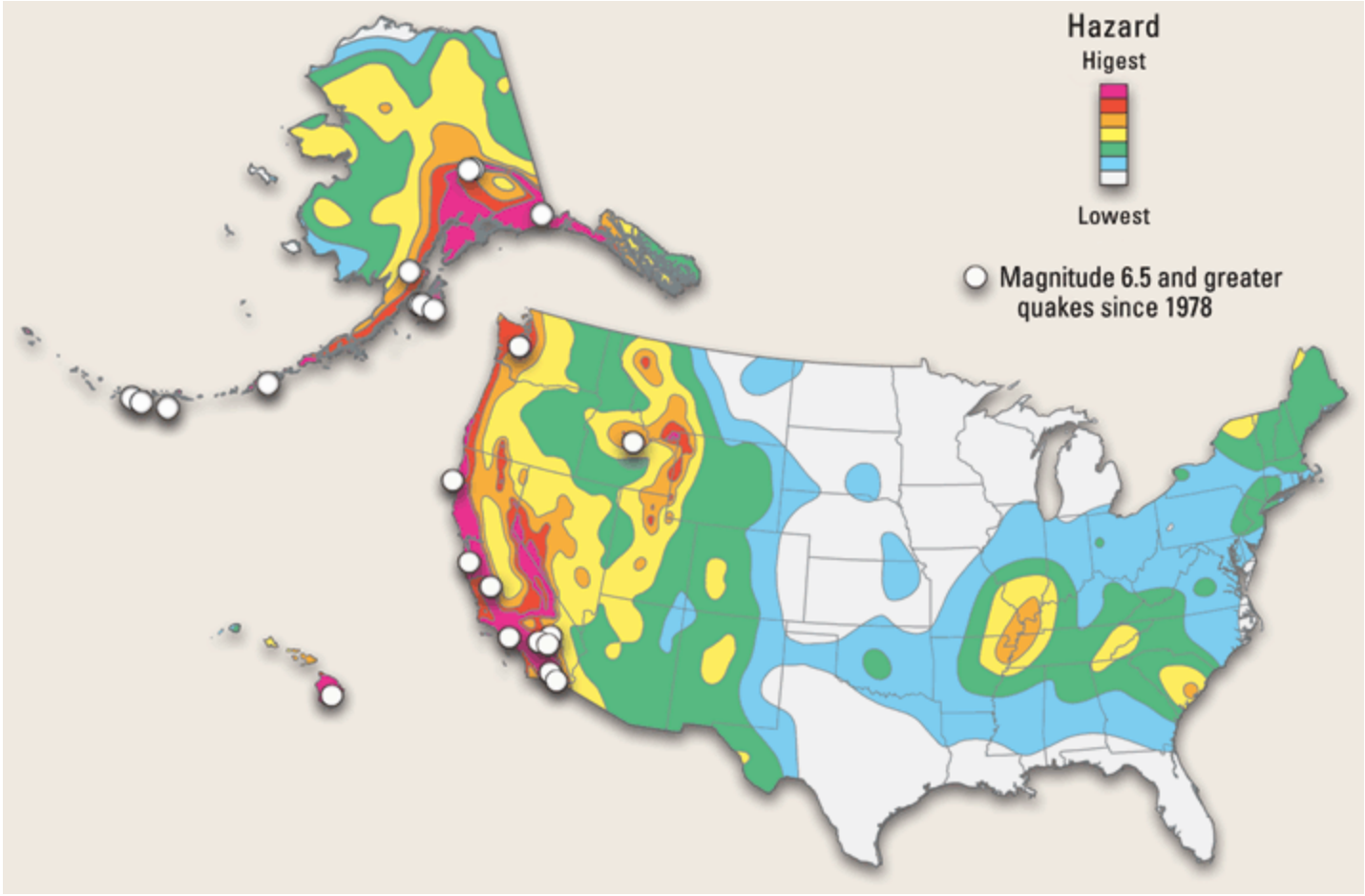

Earthquakes
Causes
Seismic waves
Seismographs
Seismic monitoring
http://www.pep.bc.ca/hazard_preparedness/Earthquake_photos.html

Earthquake Hazard Map



http://pubs.usgs.gov/fs/2003/fs017-03/

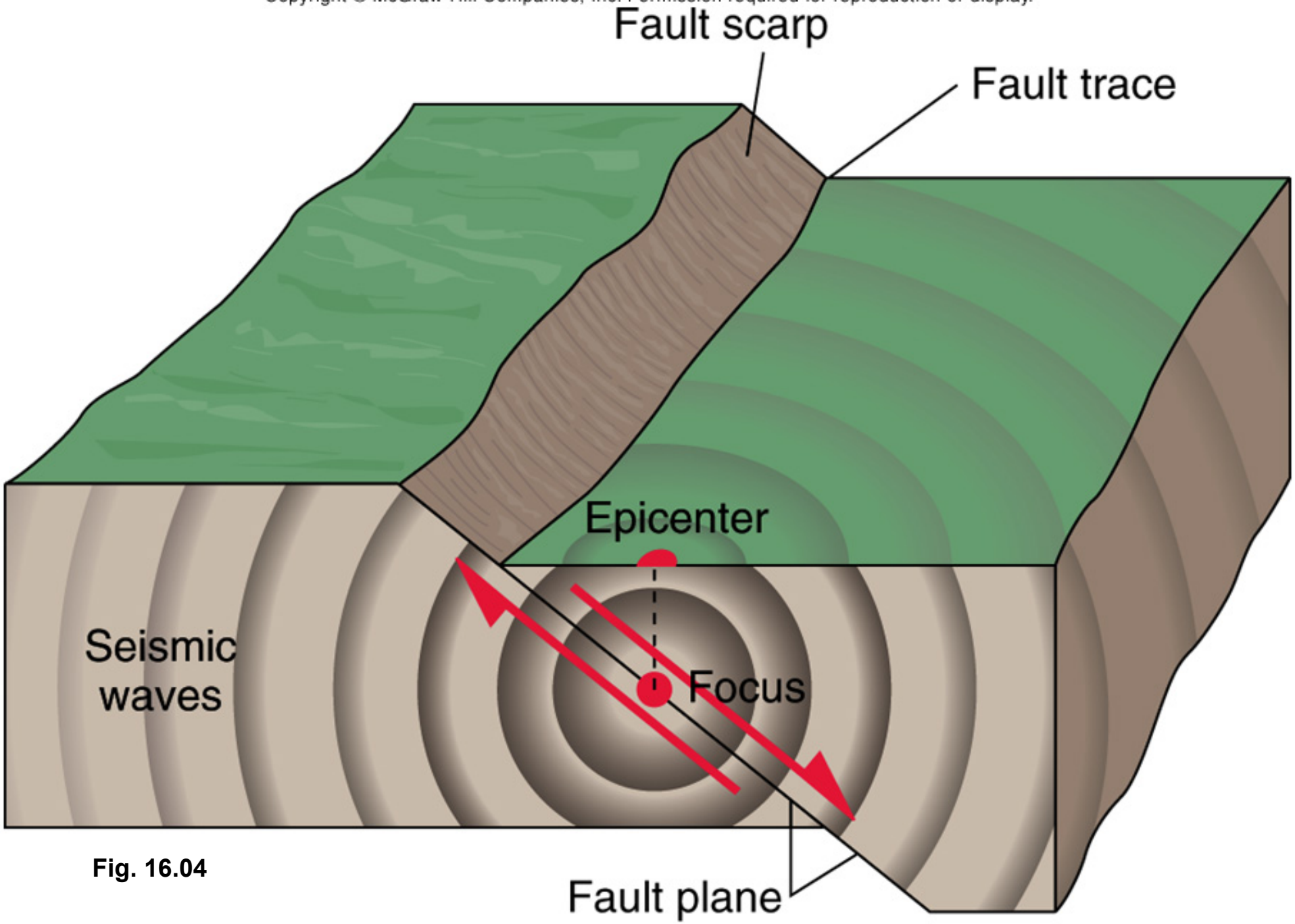


Fig. 16.04

B

Photo by National Geophysical Data Center

Photo by Univ. of Colorado; courtesy National Geophysical Data Center, Boulder, CO

Earthquake-induced ground movement sometimes leave traces on the surface

http://www.scoop.co.nz/stories/images/0601/e98b6785f8c3230d28b4.jpeg

http://sar.informatik.hu-berlin.de/research/projects/2006-EWS/ews.htm

http://www.lib.washington.edu/fish/earthquake2.jpg

Table 16.2 Comparison of Earthquake Magnitude, Description, Intensity, and Expected Annual World Occurrence

Richter Magnitude	Description	Maximum Expected Mercalli Intensity at Epicenter	Annual Expected Number
2.0	Very Minor	I Usually detected only by instruments	600,000
2.0–2.9	Very Minor	I–II Felt by some indoors; especially on upper floors	300,000
3.0–3.9	Minor	III Felt indoors	49,000
4.0–4.9	Light	IV–V Felt by most; slight damage	6,200
5.0–5.9	Moderate	VI–VII Felt by all; damage minor to moderate	800
6.0–6.9	Strong	VII–VIII Everyone runs outdoors; moderate to major damage	266
7.0–7.9	Major	IX–X Major damage	18
8.0 or higher	Great	X–XII Major and total damage	1 or 2

Source: U.S. Geological Survey

The Richter Scale is a logarithmic scale that measures the magnitude of an earthquake. A magnitude 5.0 quake has Earth movements ten times greater than a 4.0 magnitude quake (= ~32x the energy released).

In theory, the local crust melts in a magnitude 10 or greater quake. The most energetic quake recorded to date had a magnitude of approximately 9.0.

Largest Earthquakes in History

Japan – March 11, 2011
Magnitude: 9.0
Confirmed deaths: 15,883 (with tsunami)

Year	Epicenter	Mag.	Deaths
1960	Chile	9.5	1,650
1964	Prince William Sound, AK	9.2	128 (with tsunami)
2004	Sumatra	9.1	227,000 (with tsunami)
1952	Kamchatka, Russia	9.0	none
1906	Ecuador (off coast)	8.8	~1,000 (with tsunami)
2010	Chile	8.8	~1,000 (with tsunami)
1965	Rat Islands, AK	8.7	none
2005	Northern Sumatra	8.6	~1,000 (small tsunami, no deaths)
1950	Assam, Tibet	8.6	~780 (+536 killed in dam-break flood)
1957	Andreanof Islands, AK	8.6	none (with major tsunami and eruption)

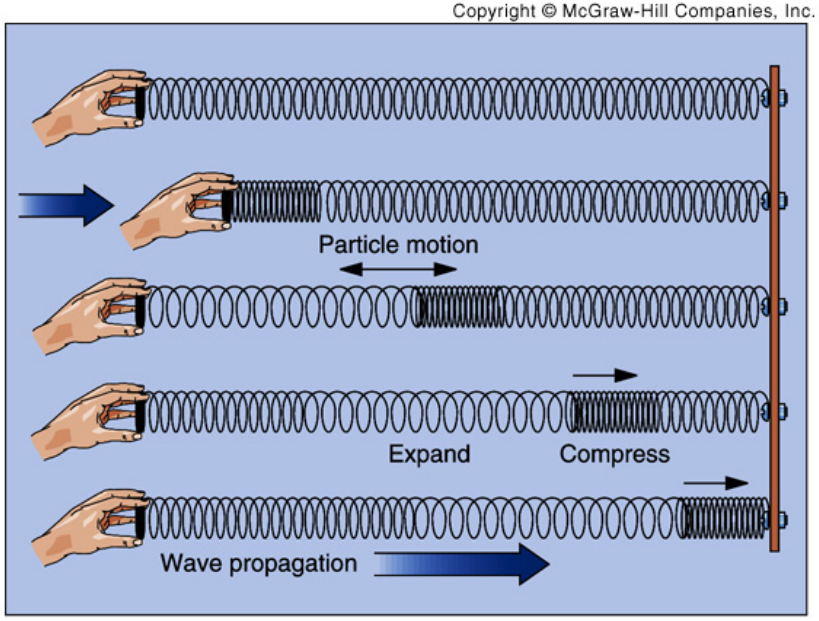
http://earthquake.usgs.gov/regional/world/most_destructive.php

Deadliest Earthquakes in History

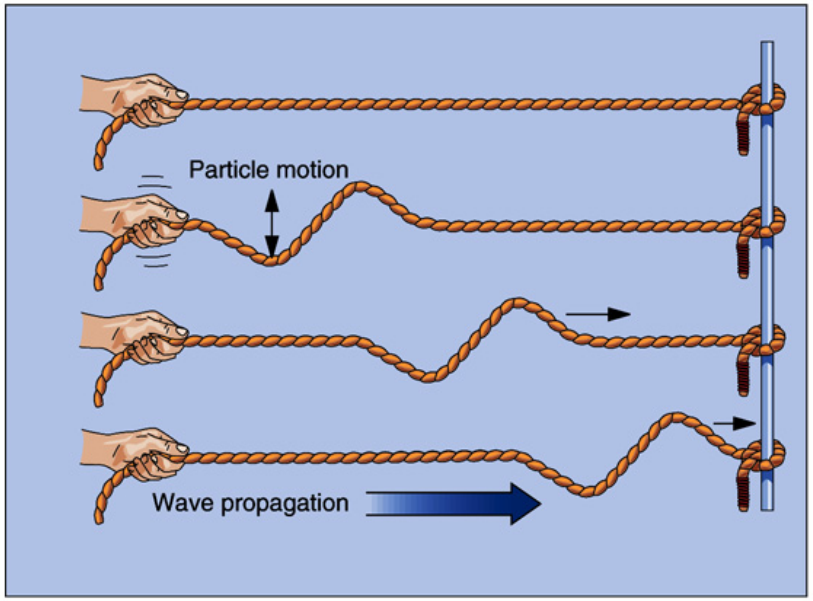
Year	Epicenter	Mag.	Deaths	
1556	Shensei, China	~8	830,000	Ming Dynasty
1976	Tangshan, China	7.5	255,000	(actual death toll ~500,000)
2010	Port of Prince, Haiti	7.0	230,000	
1138	Aleppo, Syria	n/a	230,000	
2004	Sumatra	9.1	227,000	(Christmas Tsunami)
856	Iran	n/a	200,000	
1920	Ning-hsia, China	7.8	200,000	
893	Iran	na	150,000	
1923	Kanto, Japan	7.9	142,000	(Great Tokyo Fire)
1948	Turkmenistan	7.3	110,000	
1929	Chihli, China	n/a	100,000	
2005	Pakistan	7.6	86,000	

http://earthquake.usgs.gov/regional/world/most_destructive.php

Body Waves

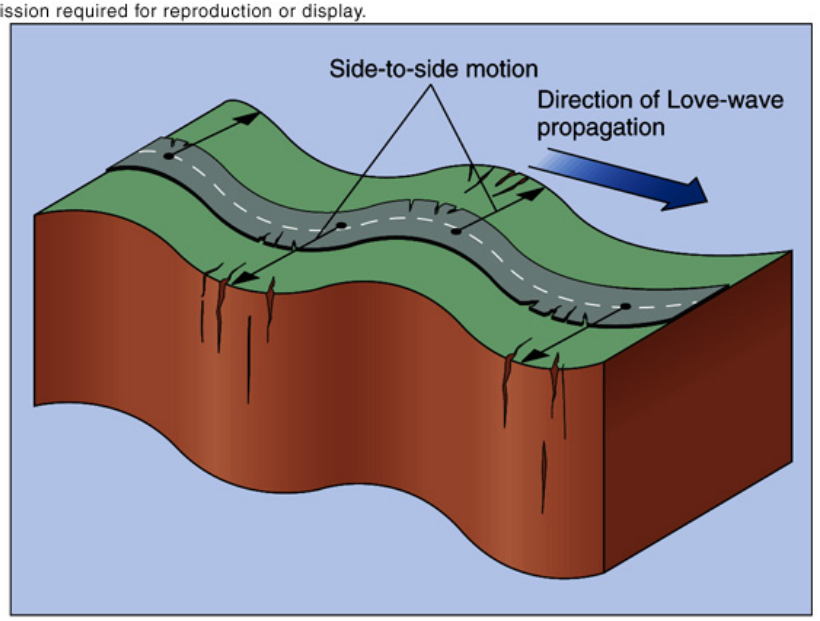


A Primary wave

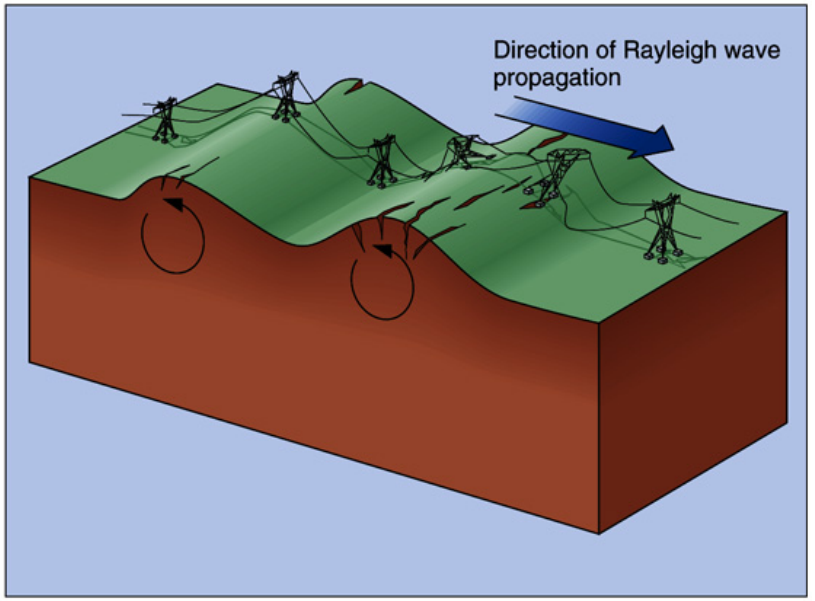


B Secondary wave

Surface Waves



C Love wave

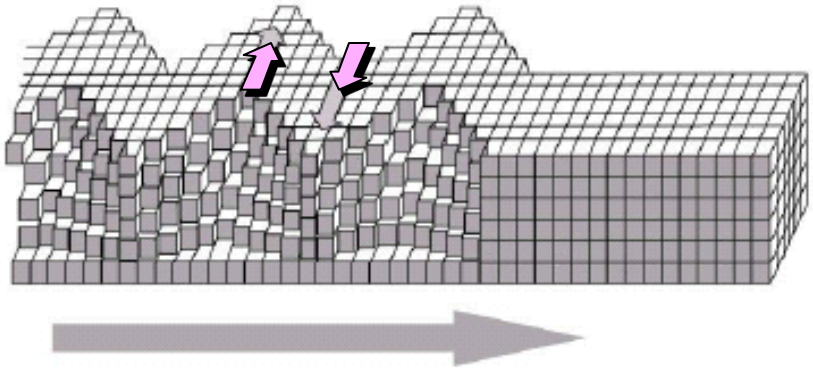


D Rayleigh wave

Fig. 16.05

Seismic Waves - Surface

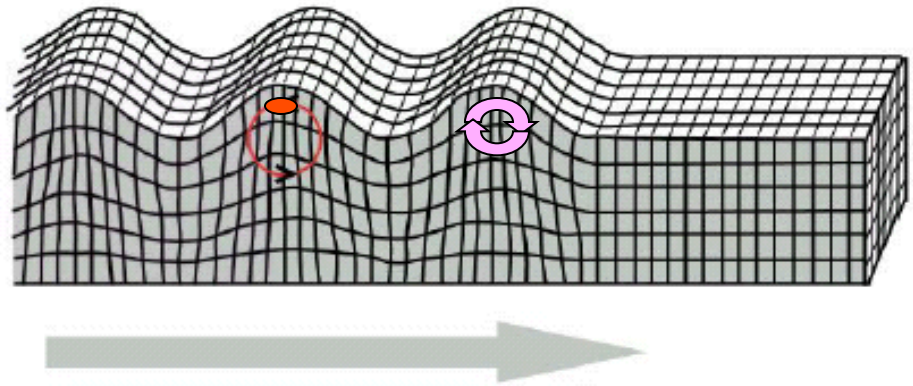
Love Wave



Love waves are shearing horizontal waves. The motion of a Love wave is similar to the motion of a secondary wave except that Love wave only travel along the surface of the Earth.

Love waves do not propagate in water.

Rayleigh Wave



Rayleigh waves travel along the surface of the Earth.

Rayleigh waves produce retrograde elliptical motion. The ground motion is thus both horizontal and vertical. The motion of Rayleigh waves is similar to the motion of ocean waves except that ocean waves are prograde.

(Irving 2001)

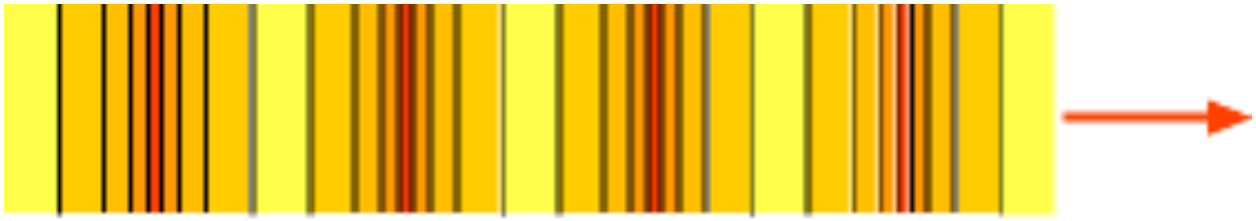
C

Fig. 16.18

Photo by I. J. Witkind, U.S. Geological Survey

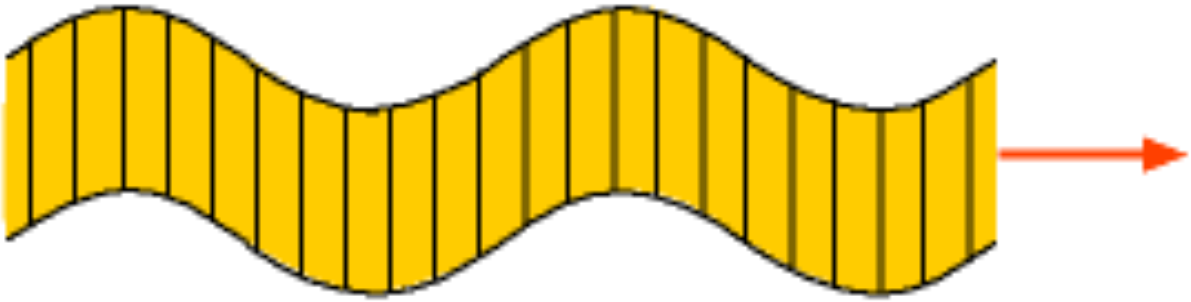
Body Waves

P-waves



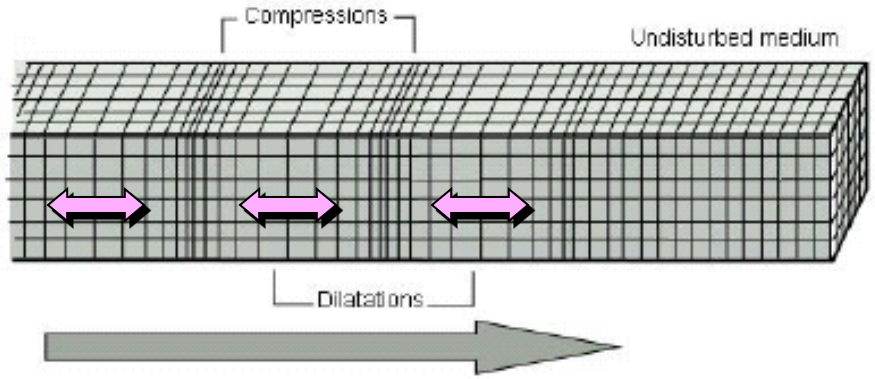
P wave (``push-pull'') travels through liquid and solid.

S-waves



S wave (``shakes'') travels slower and only through solid.

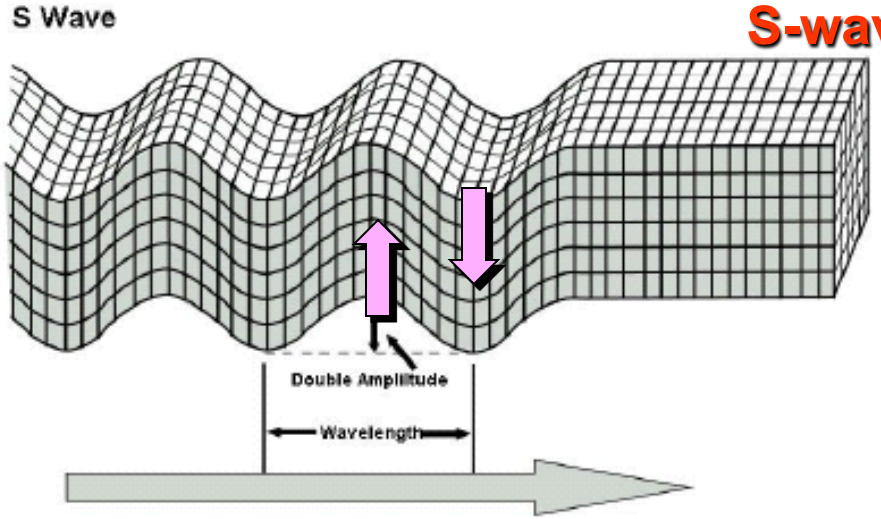
Seismic Waves – Body Waves



P-waves

The primary wave, or P-wave, is a body wave that can propagate through the Earth's core. This wave can also travel through water.

The P-wave is also a sound wave. It thus has longitudinal motion. Note that the P-wave is the fastest of the four waveforms.



S-waves

The secondary wave, or S-wave, is a shear wave. It is a type of body wave.

The S- wave produces an amplitude disturbance that is at right angles to the direction of propagation.

Note that water cannot withstand a shear force. S-waves thus do not propagate in water.

(Irving 2001)

132 C.E. Chinese invent first earthquake recorder

1875 C.E Invention of first accurate seismograph

1906 C.E San Francisco earthquake recorded by first wide-spread seismic network

http://www.fathom.com/feature/122149

http://www.central.k12.ca.us/akers/inventions.html

http://www.mssc.edu/seg-vm/pict0688.html

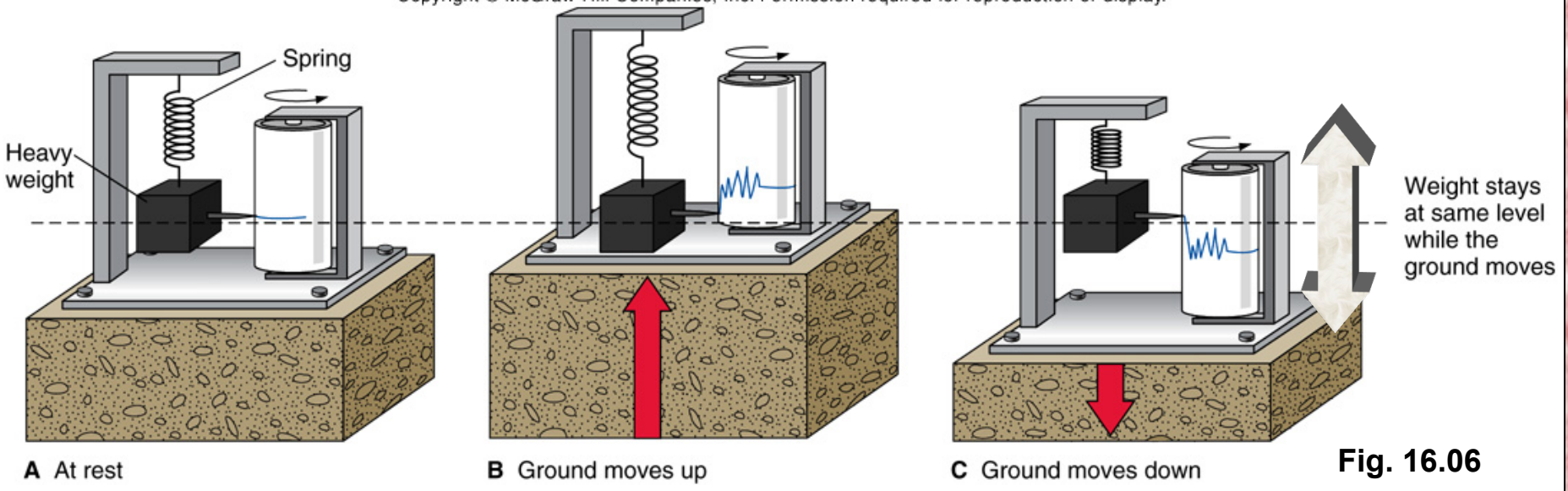


Fig. 16.06

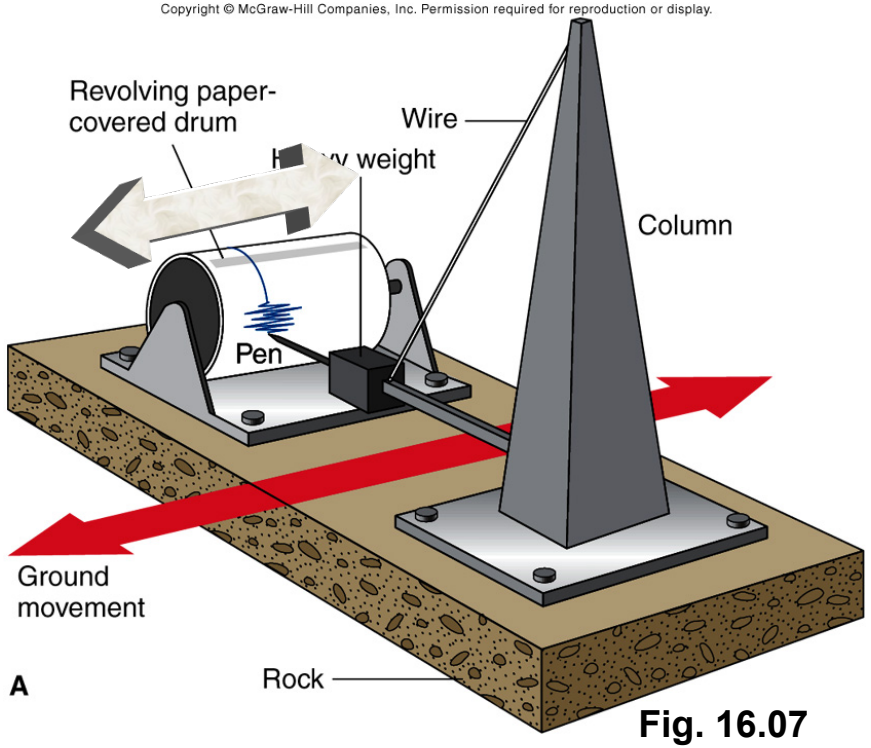
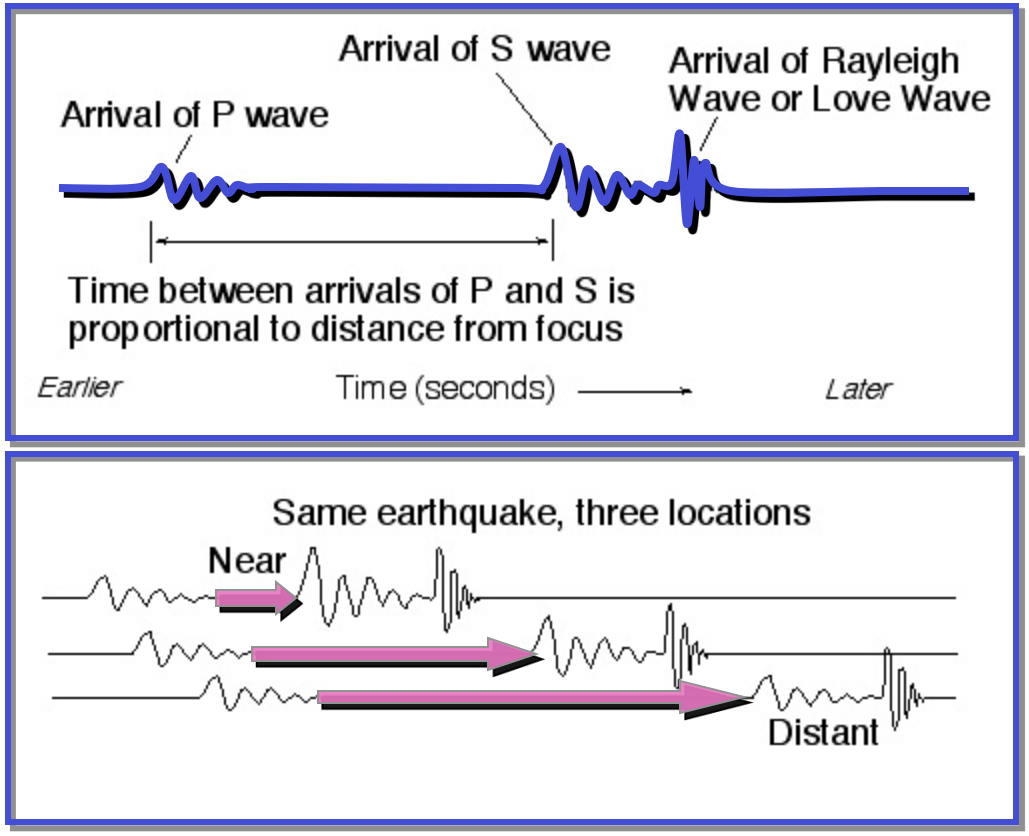


Fig. 16.07

A **seismograph** measures relative movement of the ground to a stationary pen.

Seismograms



Seismogram – record of ground movement produced by a seismograph

P-wave velocity will always be higher than S-wave velocity, no matter what the waves travel through.

P-waves arrive at the station first, followed by S-waves and later by surface waves.

Because S-waves travel more slowly than P-waves, the farther the waves have traveled, the farther behind the S-waves will be and the longer the time gap until they arrive.

http://www.gly.uga.edu/railsback/GeologicalDiagrams1.html

Earthquake in Pacific Northwest

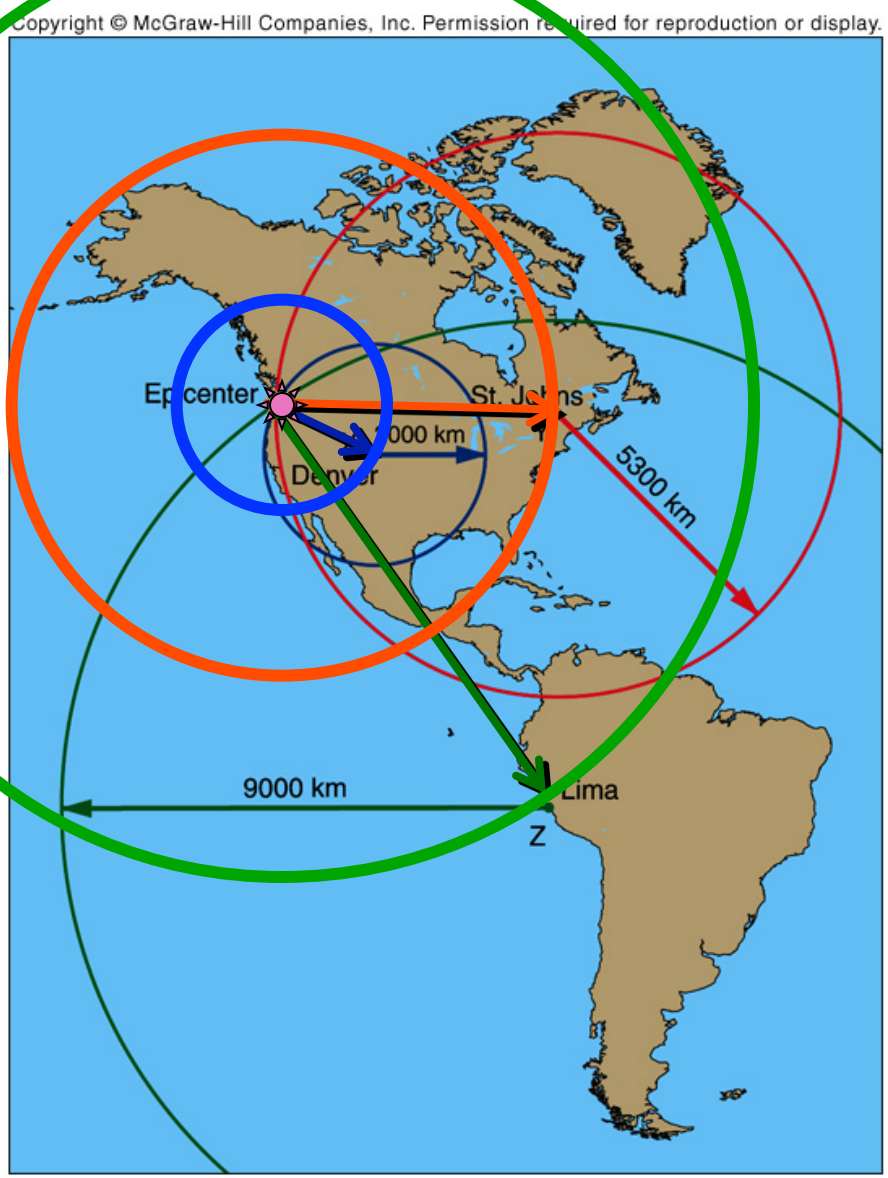


Fig. 16.10

Waves arrive in Denver

distance: 2000 km

Waves arrive in St. John's

distance: 5300 km

Waves arrive in Lima

distance: 9000 km

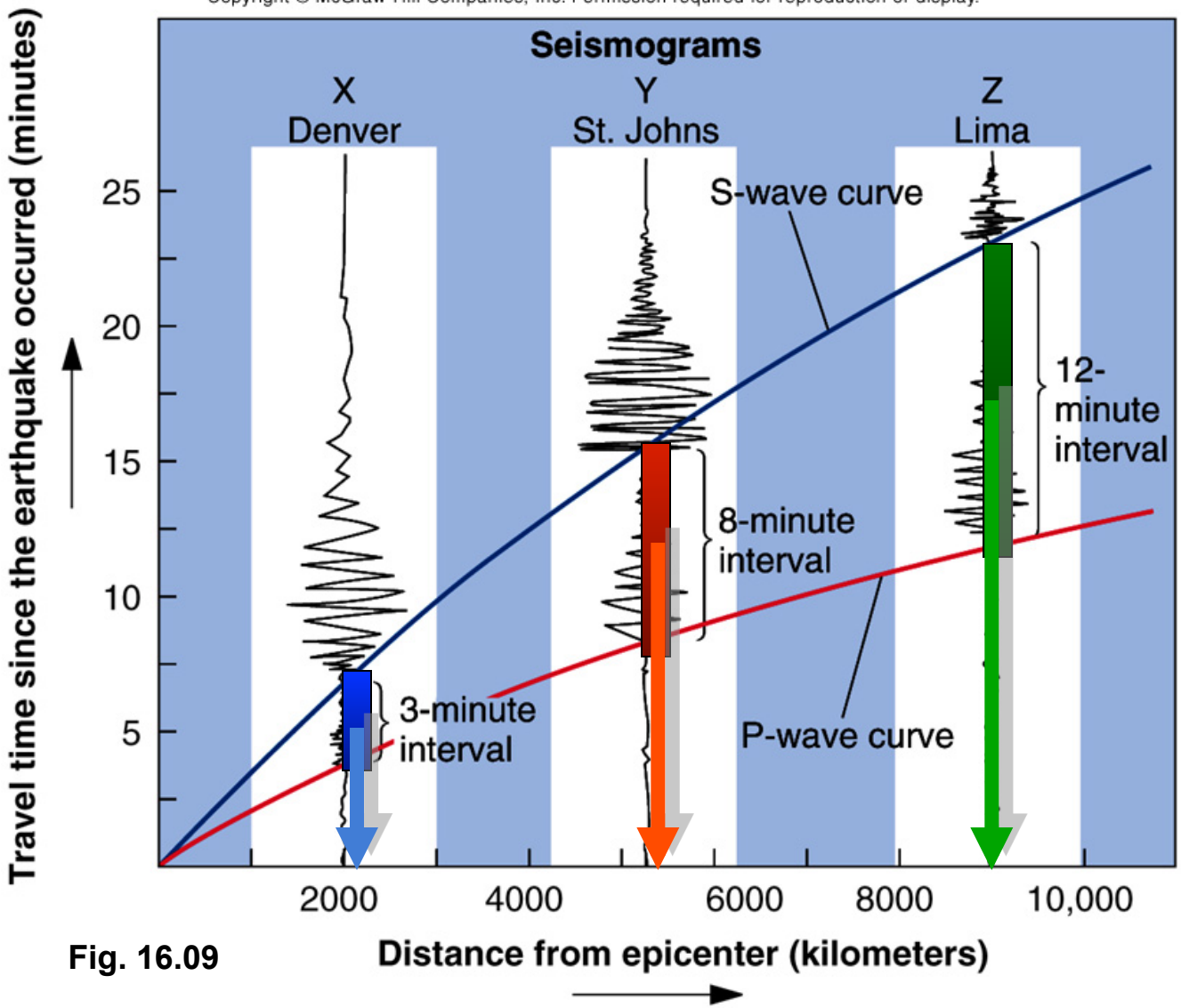


Fig. 16.09

The difference between the arrival times for P-waves and S-waves can be used to determine the distance to the earthquake's epicenter

Nuclear Non-Proliferation

Partial Test Ban Treaty, 1963 - banned testing in atmosphere, oceans, and space

Non-proliferation Treaty, 1968 - banned non-nuclear powers from developing nuclear weapons

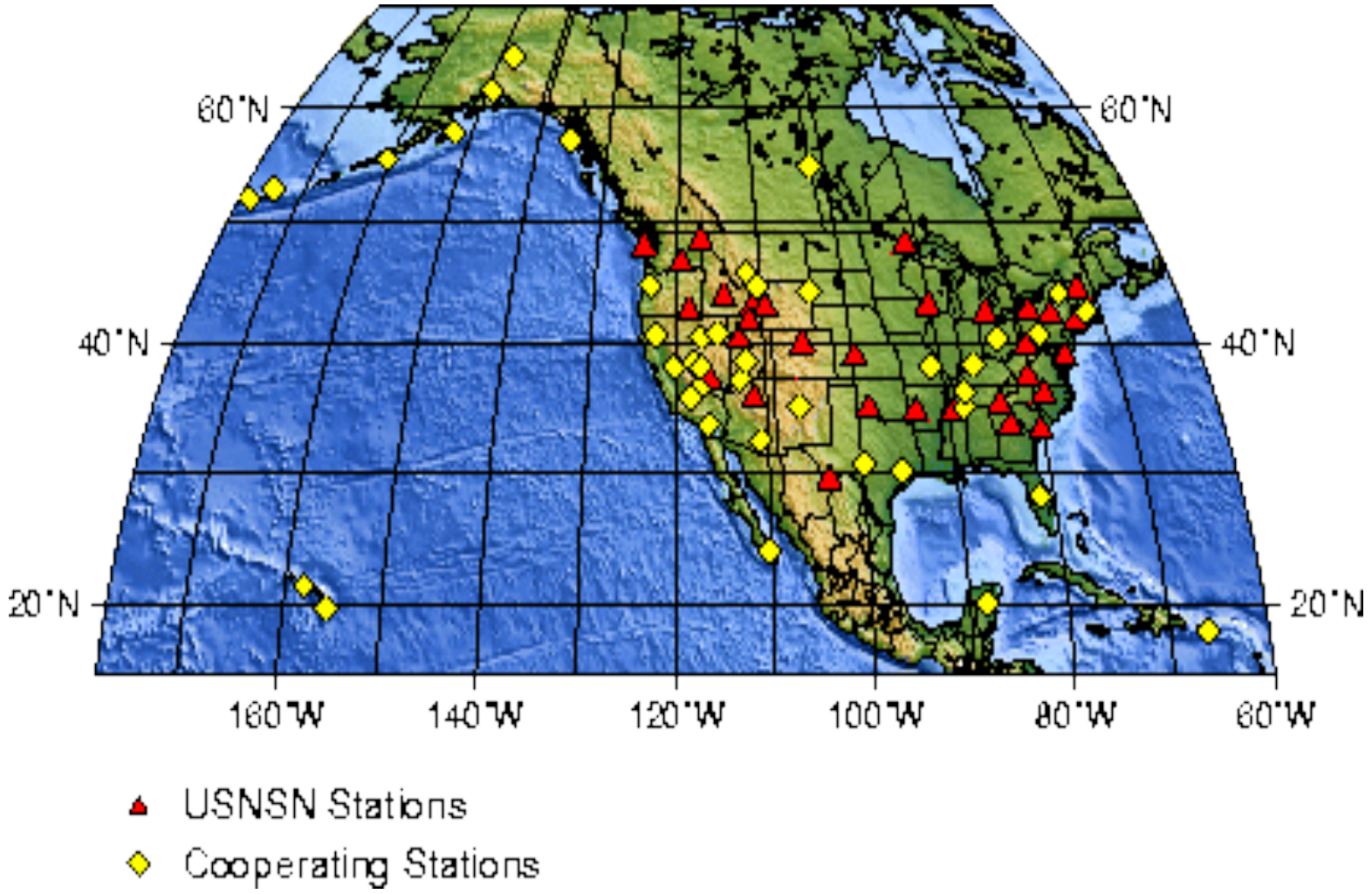
Comprehensive Test Ban Treaty, 1996 - banned all nuclear testing

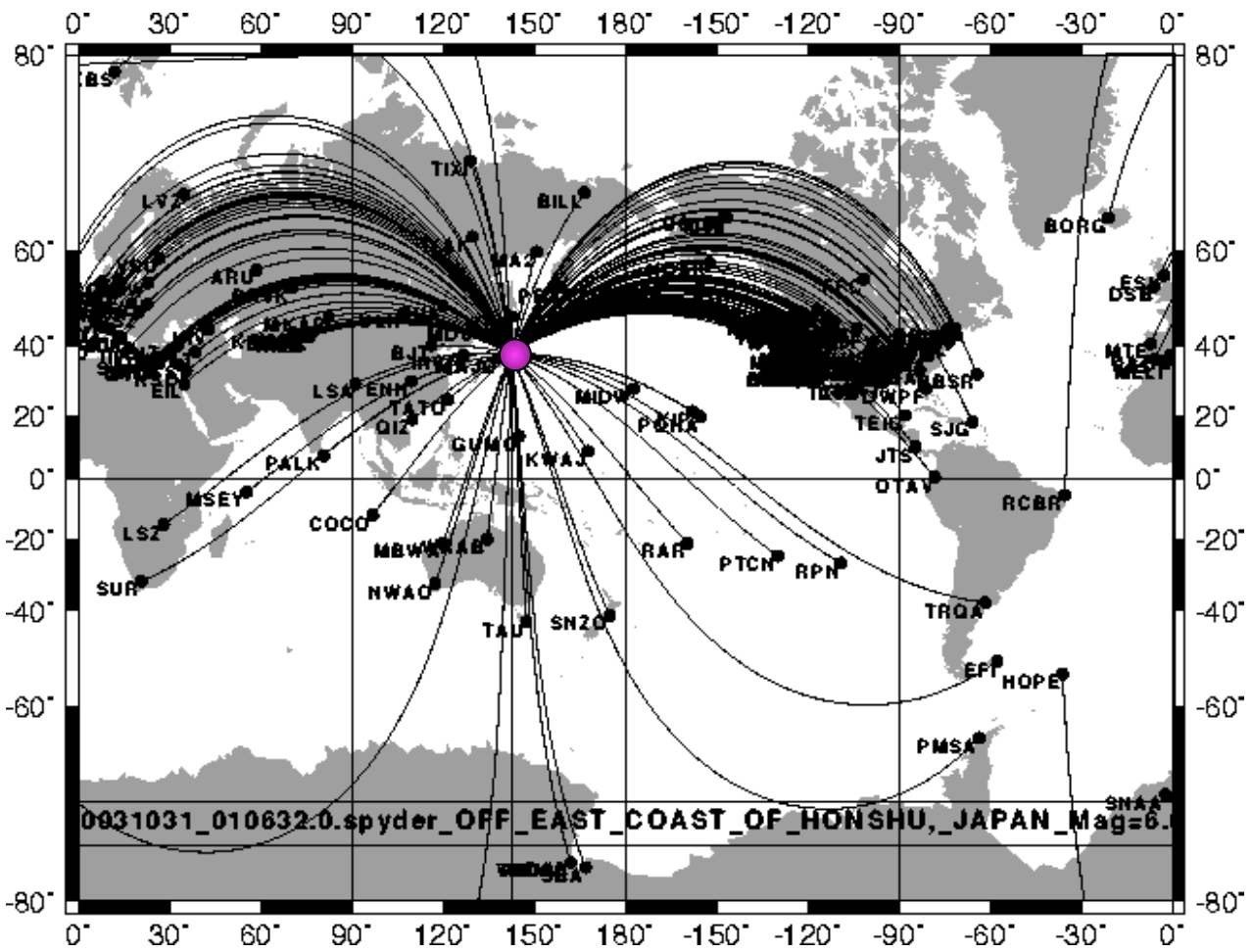
Threshold Test Ban Treaty, 1974.
Seabed Treaty, 1971.
Outer Space Treaty, 1967.
Antarctic Treaty, 1959.

A nuclear explosion will cause seismic waves, and many seismic stations participate in test-ban monitoring.

http://nuketesting.enviroweb.org/hew/

North American seismic stations participating in Nuclear Test Ban Treaty monitoring





Responding stations - October 31, 2003

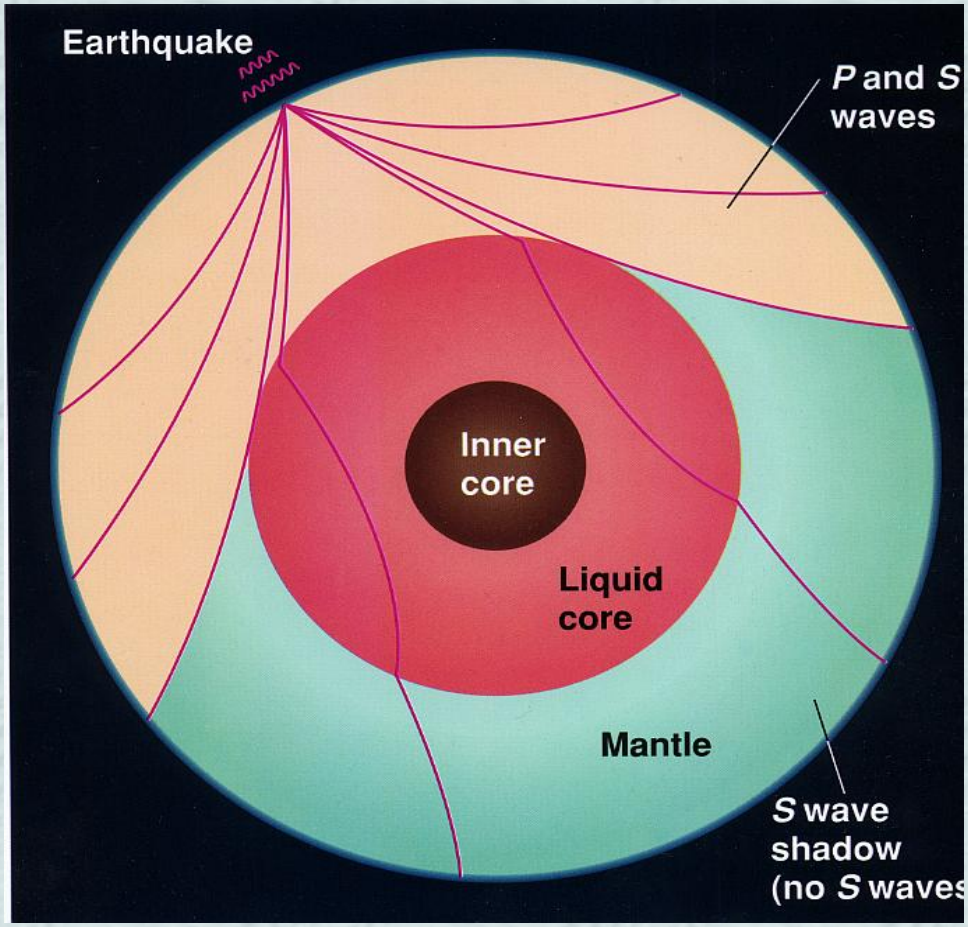
Earthquake near Honshu, Japan **- *Magnitude 6.6***

http://www.iris.edu/

Body Waves

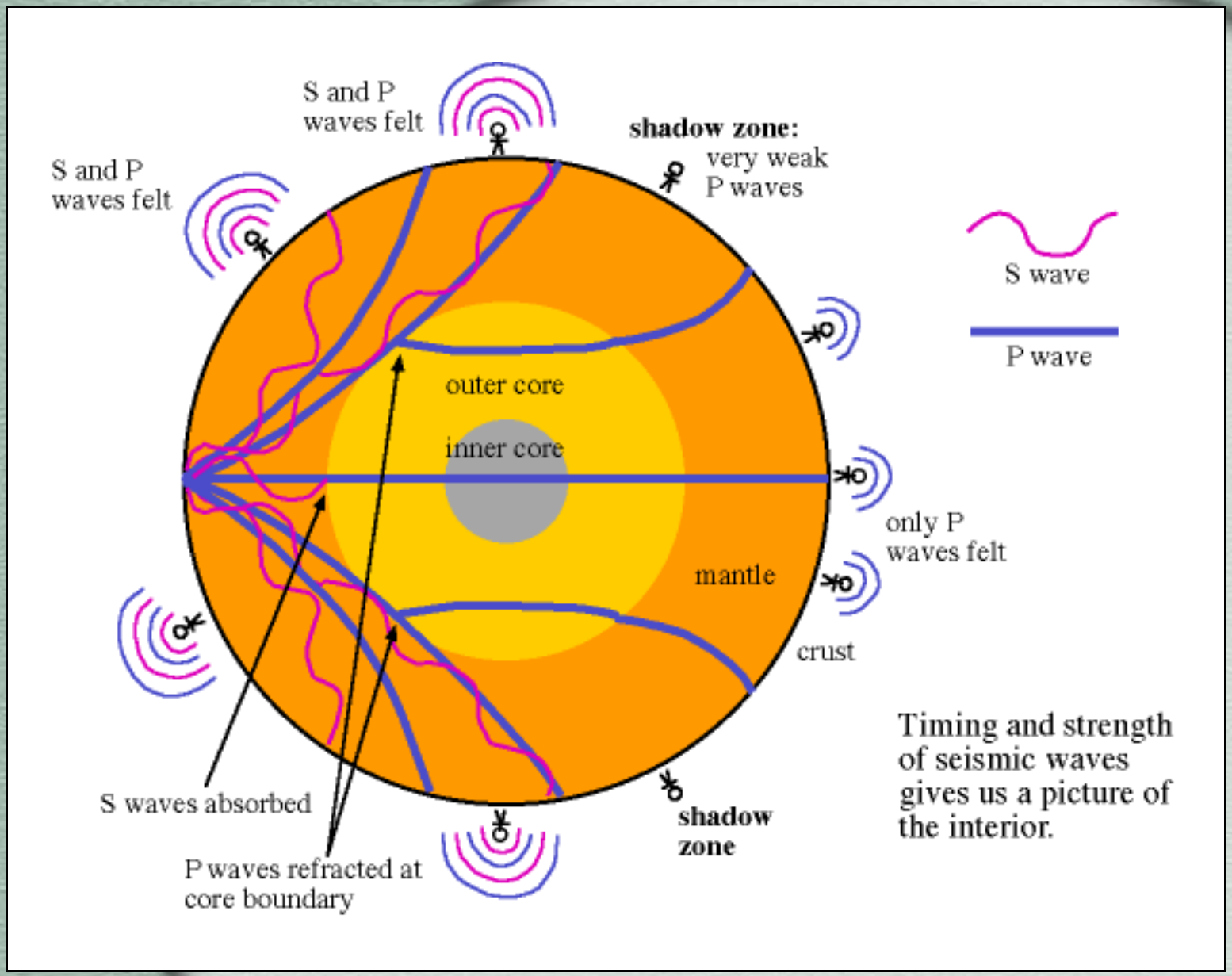
Unlike surface waves, body waves move through the bulk of the Earth.

By understanding the properties of different kinds of body waves, we can gather data about the structure of the Earth's interior.

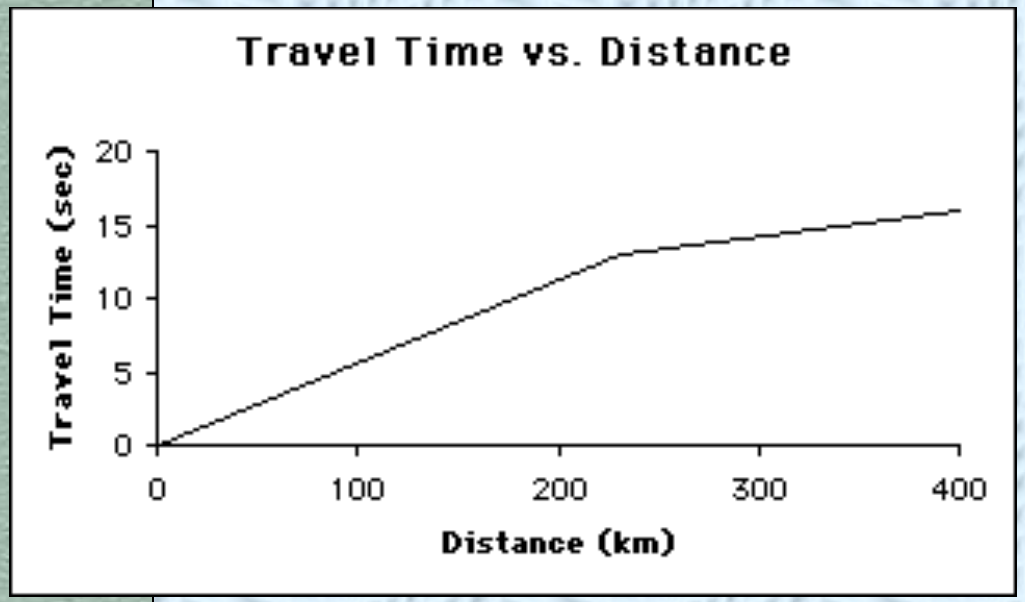


S-Waves versus P-Waves

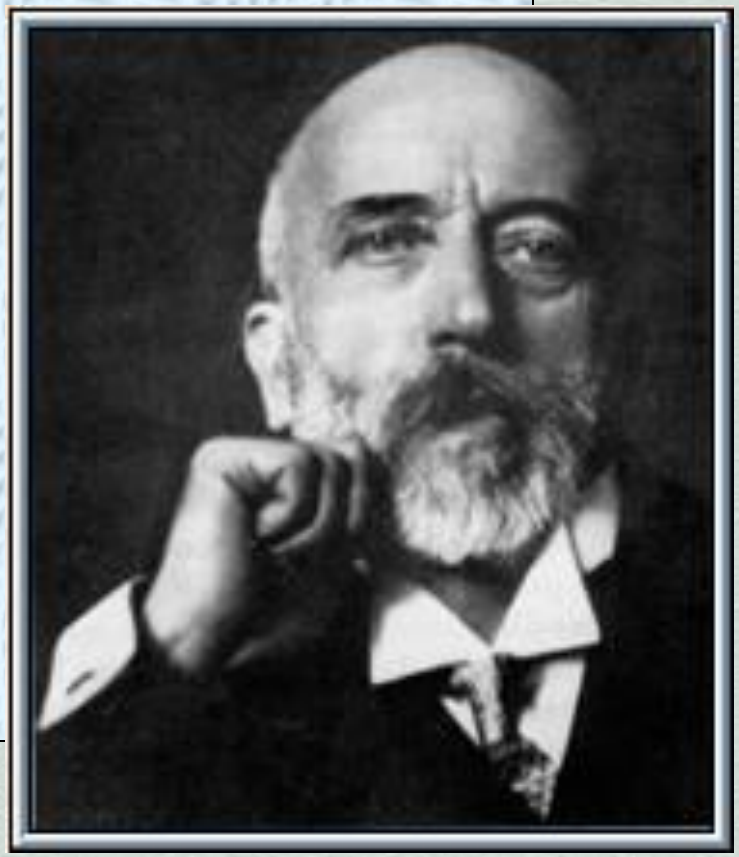
P-Waves	***S-Waves***
pressure wave forms, equivalent to sound waves	shear wave forms
faster	***slower***
Moves through: *solid, liquid, gas*	Moves through: *solid only*

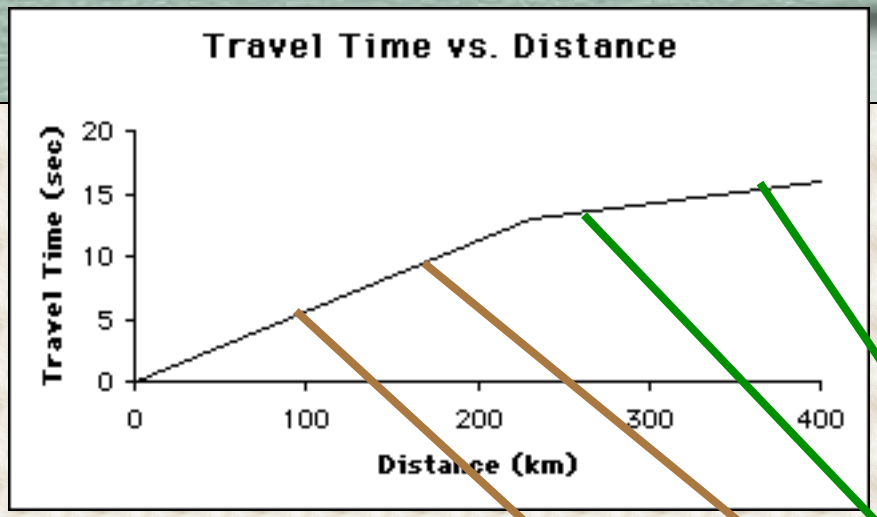

S and P
waves felt
shadow zone:
very weak
P waves
S and P
waves felt
S wave
P wave
outer core
inner core
only P
waves felt
mantle
crust
S waves absorbed
shadow
zone
P waves refracted at
core boundary
Timing and strength
of seismic waves
gives us a picture of
the interior.

Velocity Discontinuities

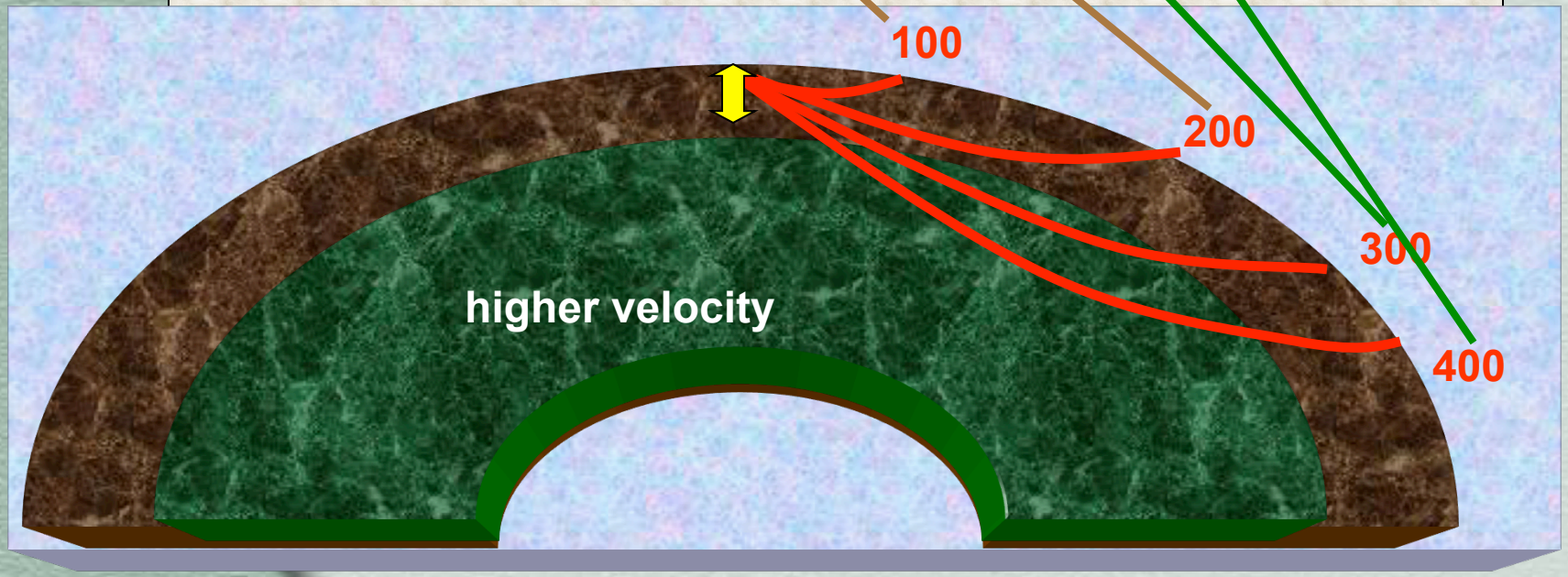


Andrija Mohorovicic´





Discontinuities

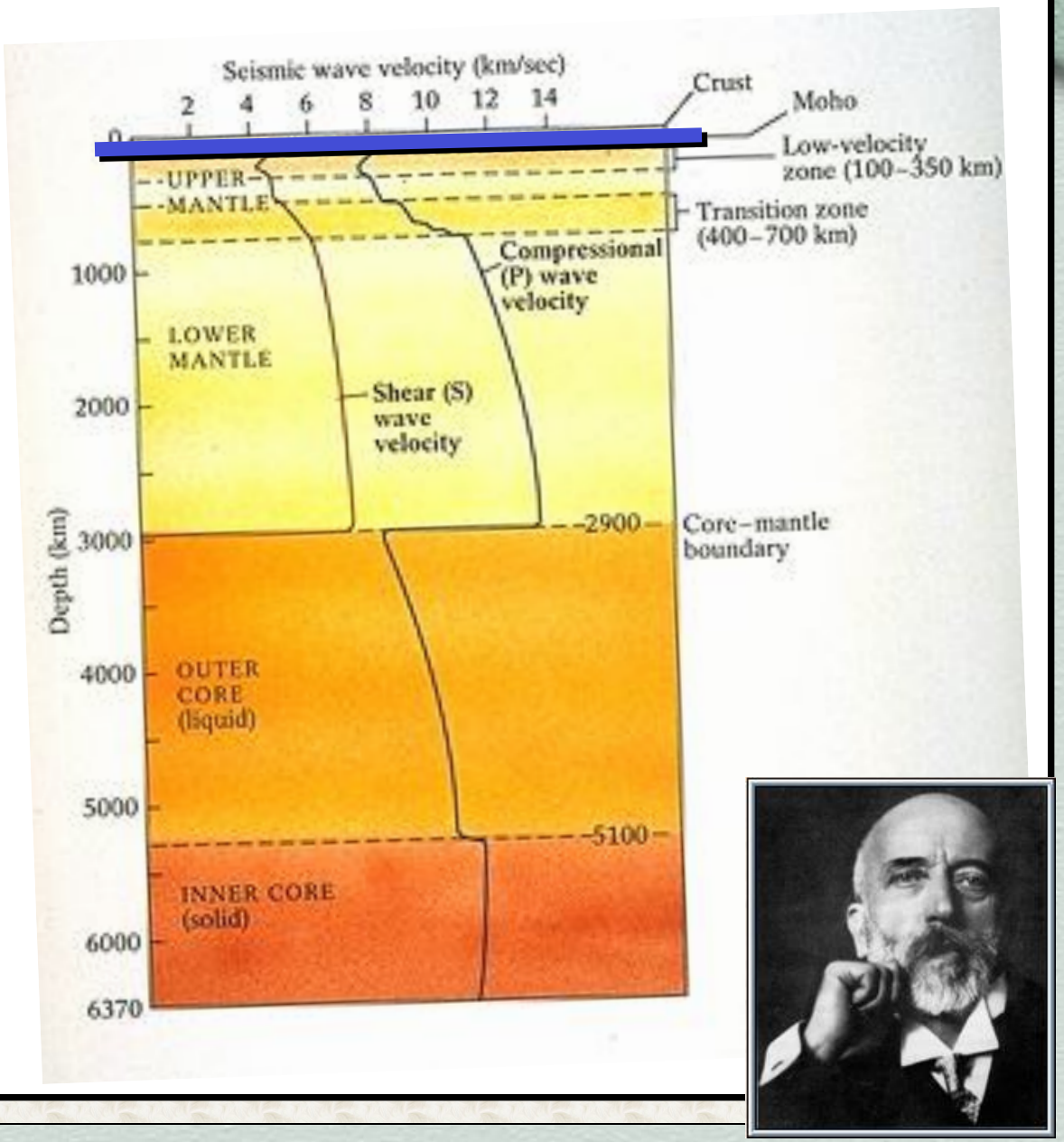


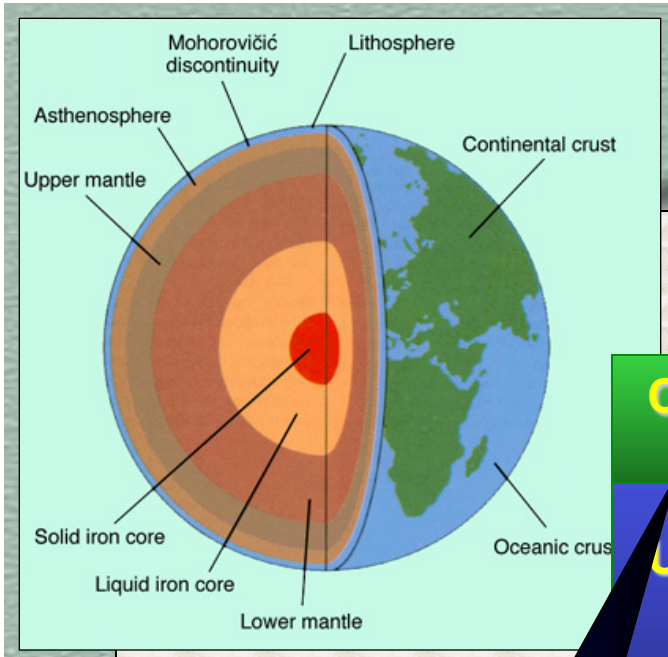
Apologies for this not being indicative of the Earth's actual curvature

Mohorovicic´ Discontinuity

The boundary between the Earth's crust and mantle is marked by a velocity discontinuity.

It is called the Moho for short. Similar discontinuities mark the boundaries between the other layers of the Earth.





http://www.glossary.oilfield.slb.com

Moho Discontinuity

	Thickness (km)	Density (g/cm^3)	Typical Rocks
Crust	30	2.2 2.9	silica rocks andesite, basalt at base
Upper Mantle	720	3.4	peridodite, eclogite, olivine, spinel, garnet, pryoxene
Lower Mantle	2,171	4.4	magnesium and silicon oxides
Outer Core	2,259	9.9	iron+oxygen, sulfur, nickel alloy (liquid)
Inner Core	1,221	12.8	iron+oxygen, sulfur, nickel alloy (solid)
Center		13.1	

zone including uppermost mantle and lowermost crust is called the aethenosphere

http://pubs.usgs.gov/gip/interior/