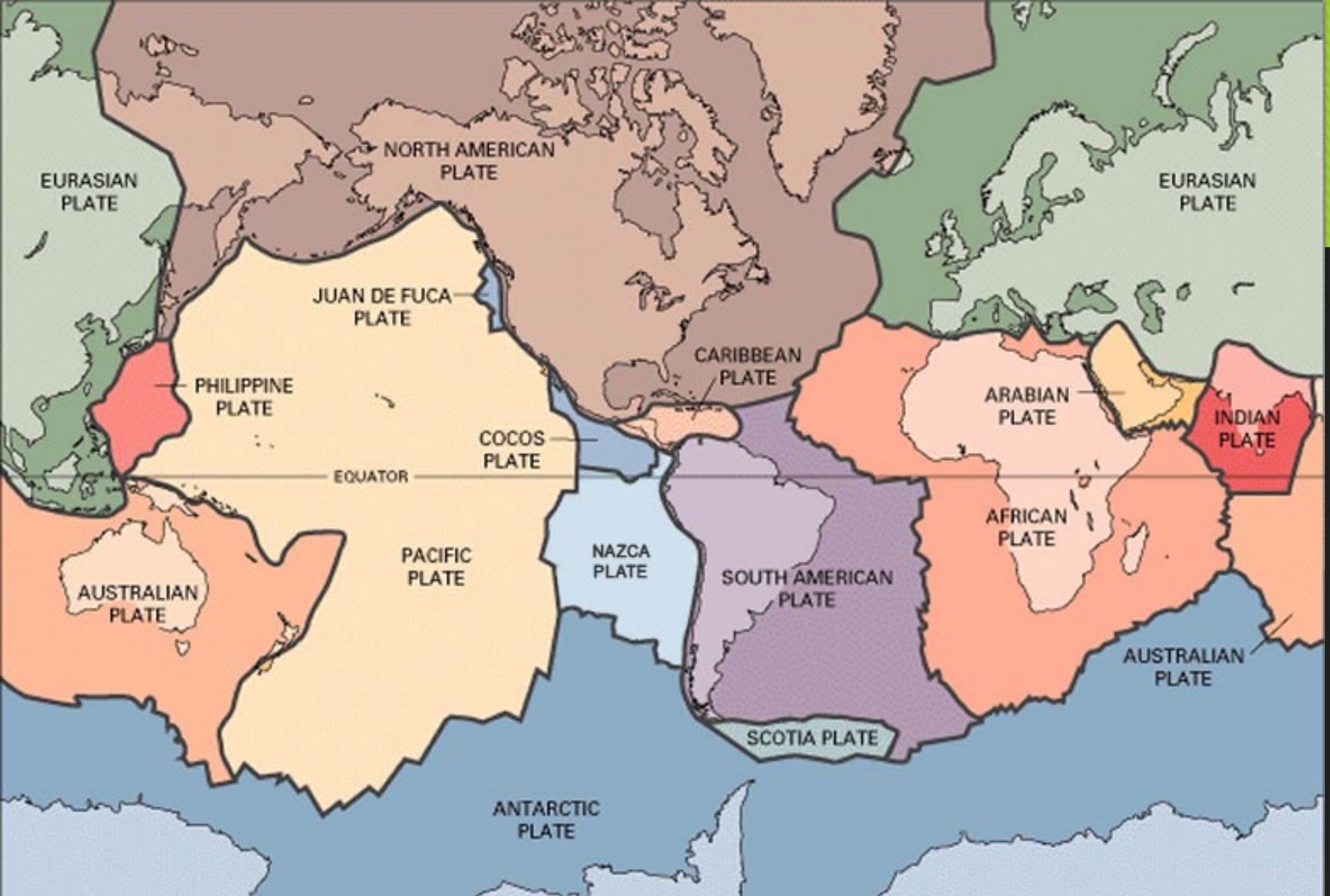
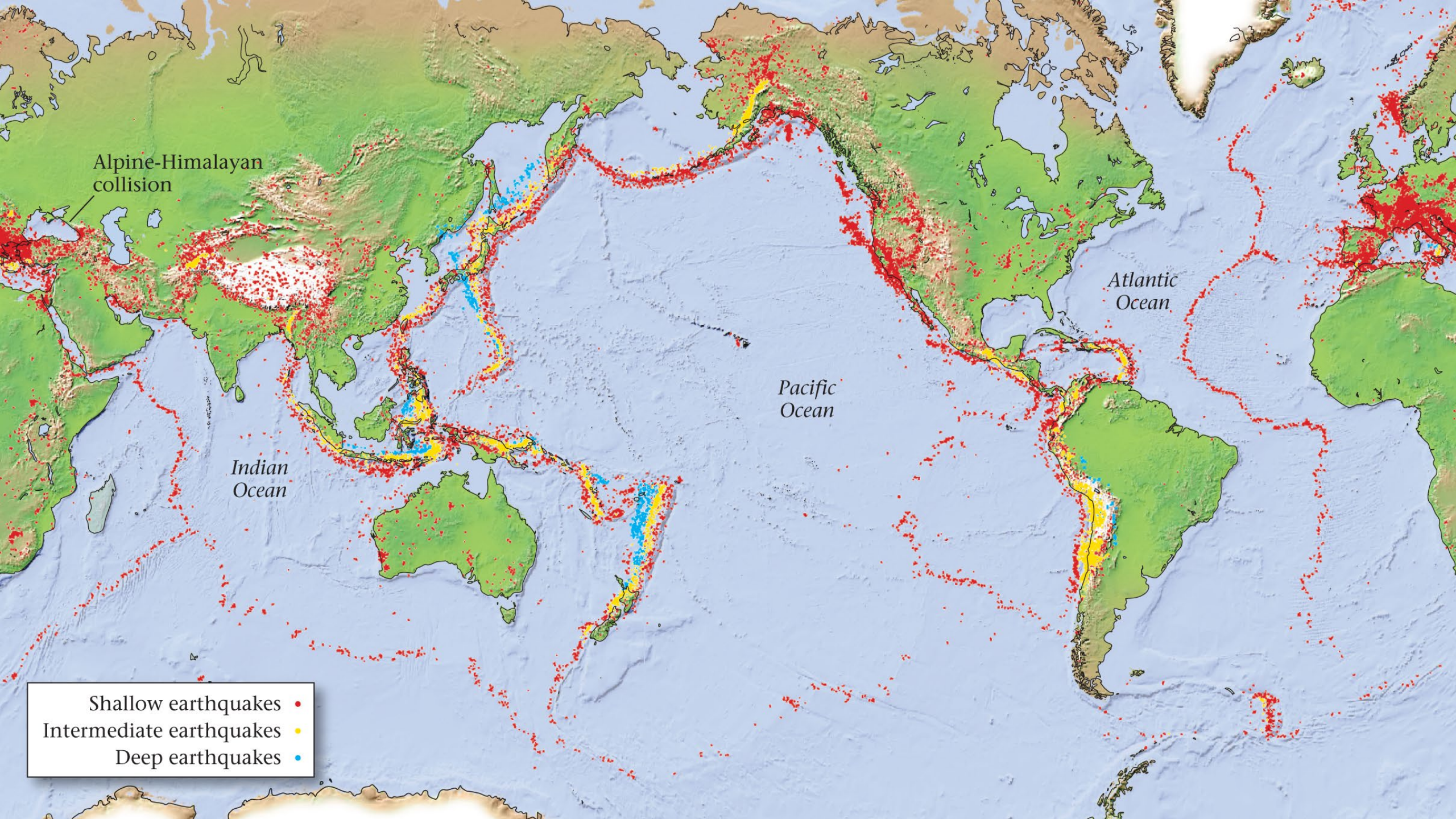
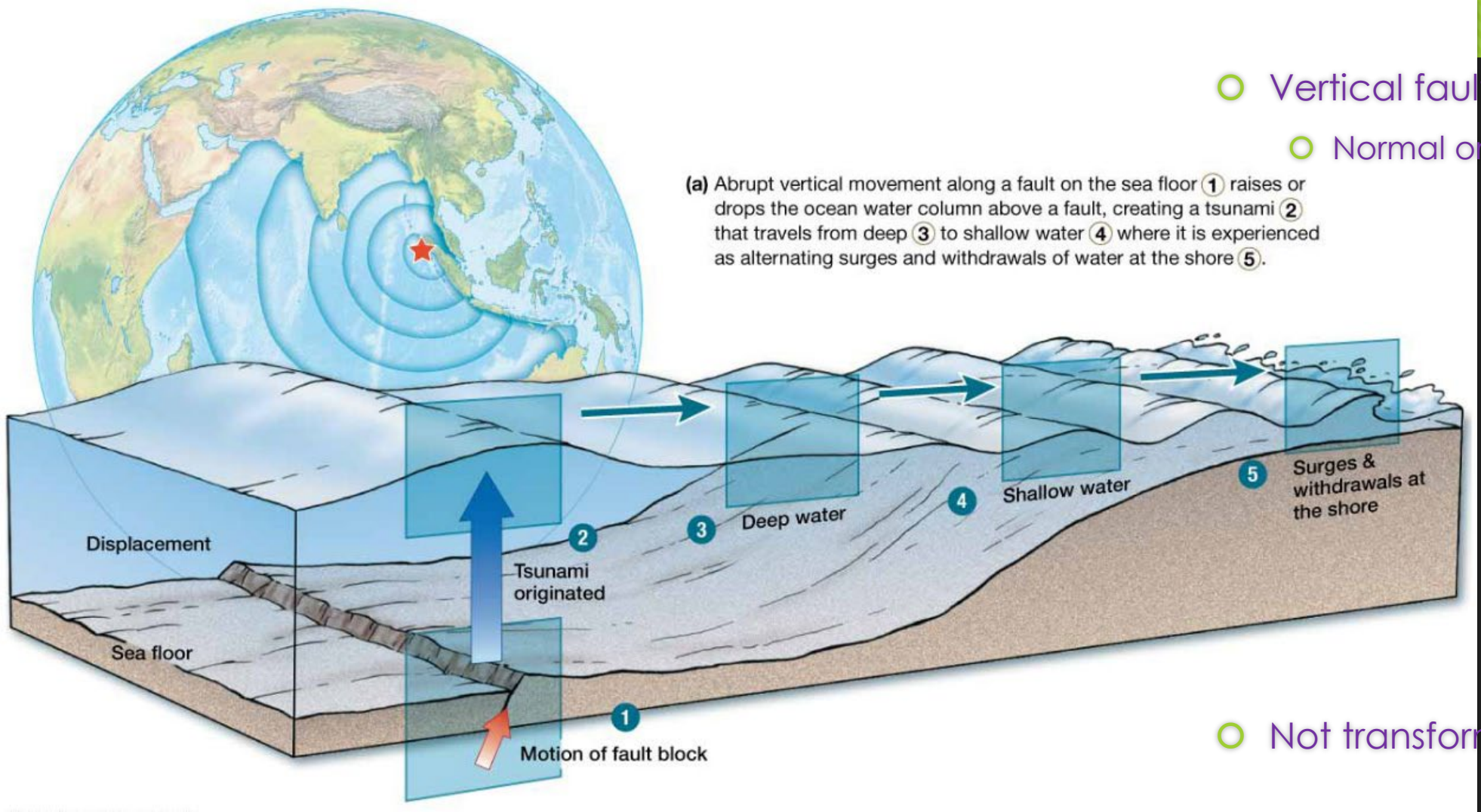
Earthquakes

University of Northern Iowa – Department of Earth and Environmental Sciences

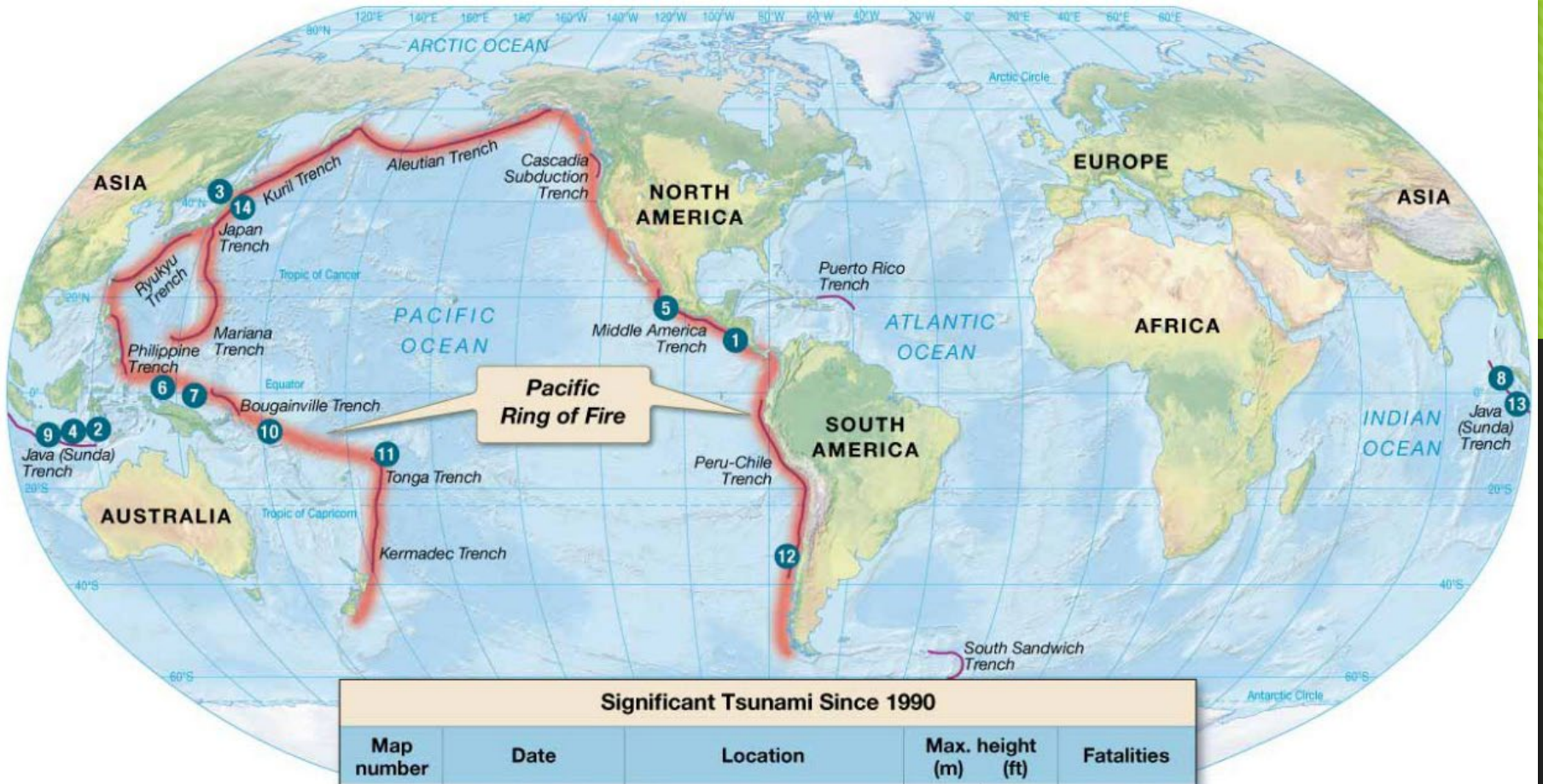

NORTH AMERICAN PLATE
EURASIAN PLATE
EURASIAN PLATE
JUAN DE FUCA PLATE
CARIBBEAN PLATE
PHILIPPINE PLATE
ARABIAN PLATE
INDIAN PLATE
COCOS PLATE
EQUATOR
AFRICAN PLATE
PACIFIC PLATE
NAZCA PLATE
SOUTH AMERICAN PLATE
AUSTRALIAN PLATE
AUSTRALIAN PLATE
SCOTIA PLATE
ANTARCTIC PLATE


Alpine-Himalayan collision
Indian Ocean
Pacific Ocean
Atlantic Ocean
Shallow earthquakes
Intermediate earthquakes
Deep earthquakes

Fault movement / earthquakes – Seismic Tsunami

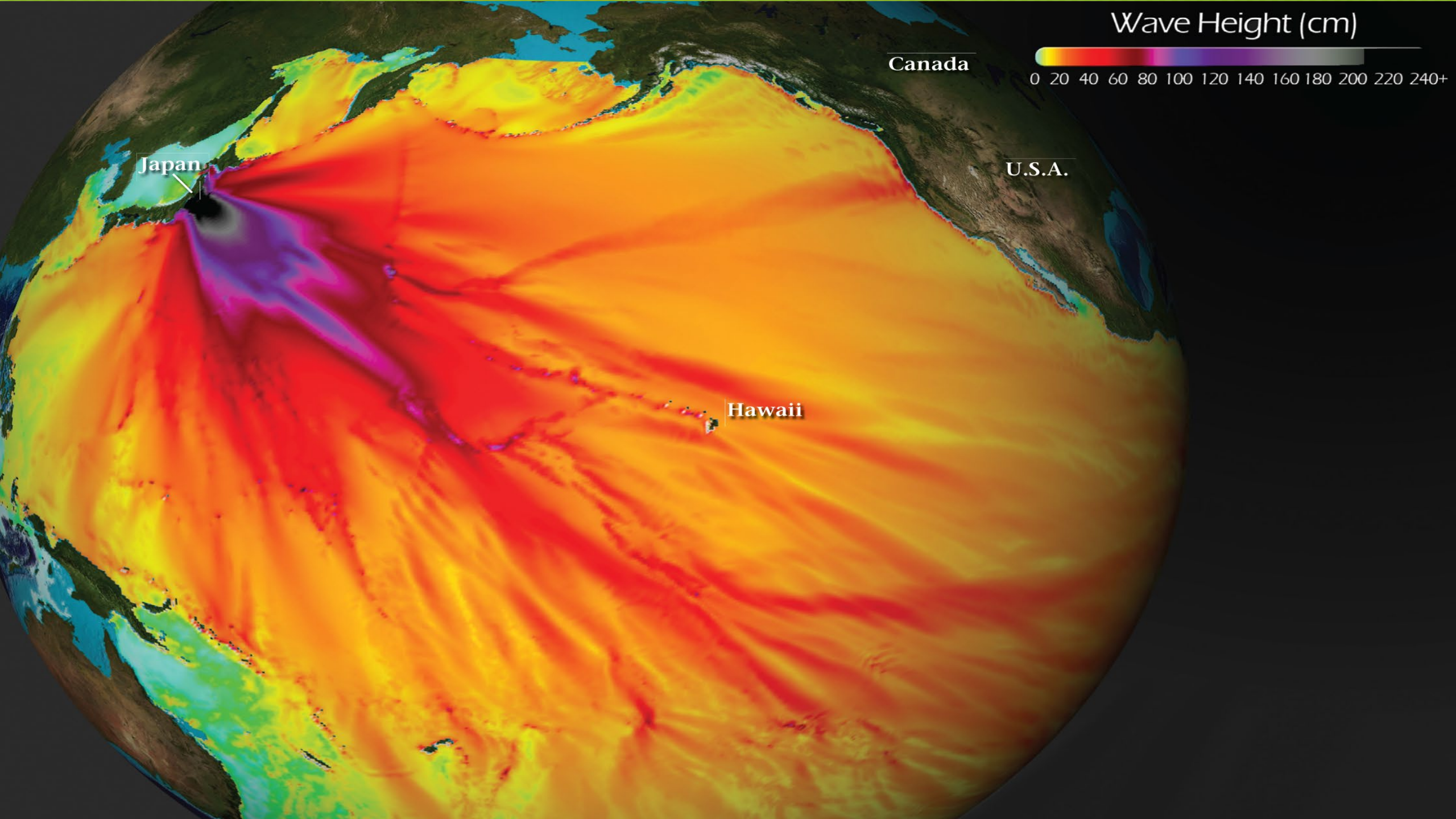


- Vertical faulting
  - Normal or reverse faulting
- Not transform faulting



Significant Tsunami Since 1990

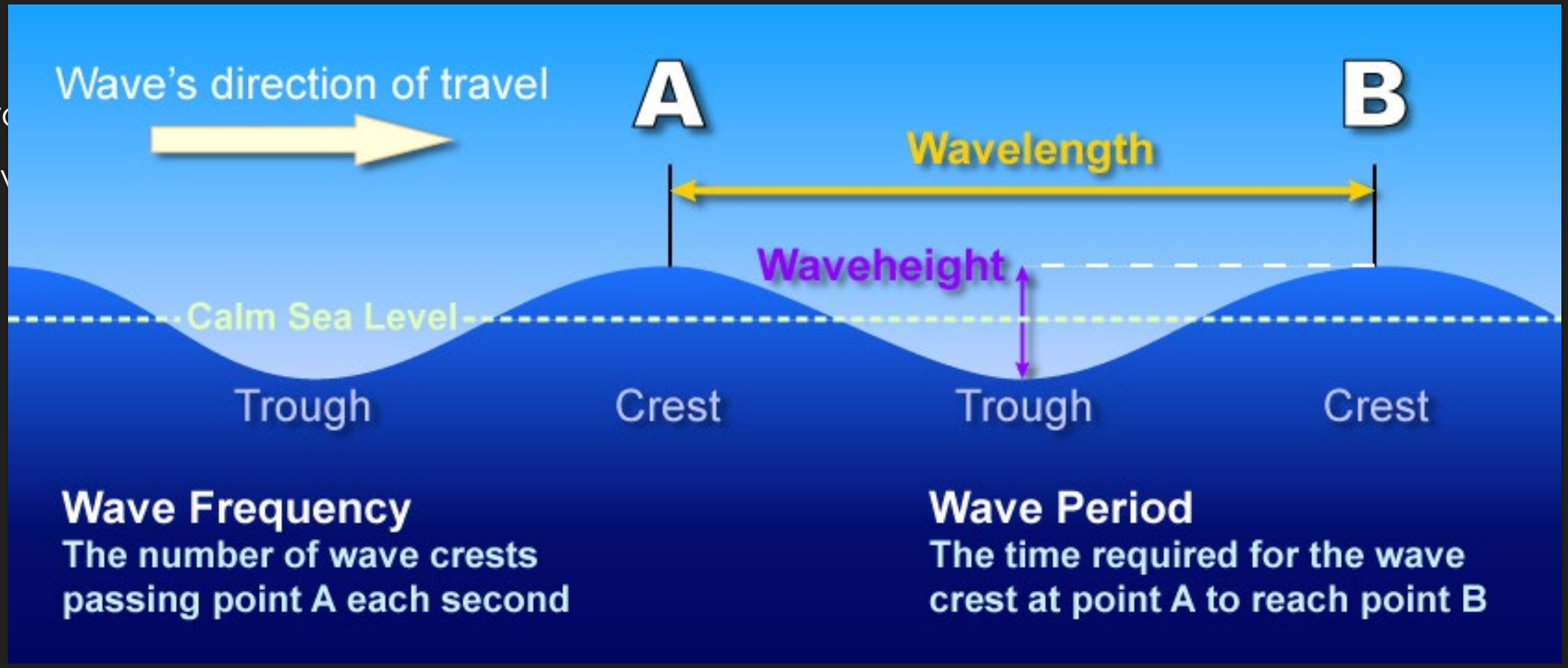
Map number	Date	Location	Max. height (m)	Max. height (ft)	Fatalities
1	Sep. 2, 1992	Nicaragua	10	33	170
2	Dec. 12, 1992	Flores Island, Indonesia	26	85	>1,000
3	Jul. 12, 1993	Okushiri, Japan	31	102	239
4	Jun. 2, 1994	East Java, Indonesia	14	46	238
5	Oct. 9, 1995	Jalisco, Mexico	11	36	1
6	Feb. 17, 1996	Irian Jaya, Indonesia	8	26	161
7	Jul. 17, 1998	Papua New Guinea	15	49	>2,200
8	Dec. 26, 2004	Sumatra, Indonesia	35	115	300,000
9	Jul. 17, 2006	Central Java, Indonesia	3	10	668
10	Apr. 1, 2007	Solomon Islands	5	16	52
11	Sep. 29, 2009	Samoa	14	46	189
12	Feb. 27, 2010	Chile	3	10	550
13	Oct. 25, 2010	Pagai Island, Indonesia	3	10	435
14	Mar. 11, 2011	Tohoku, Japan	40	131	19,508


Wave Height (cm)
0 20 40 60 80 100 120 140 160 180 200 220 240+
Canada
U.S.A.
Japan
Hawaii

Tsunami Waves

Enormous wa

Extremely lo

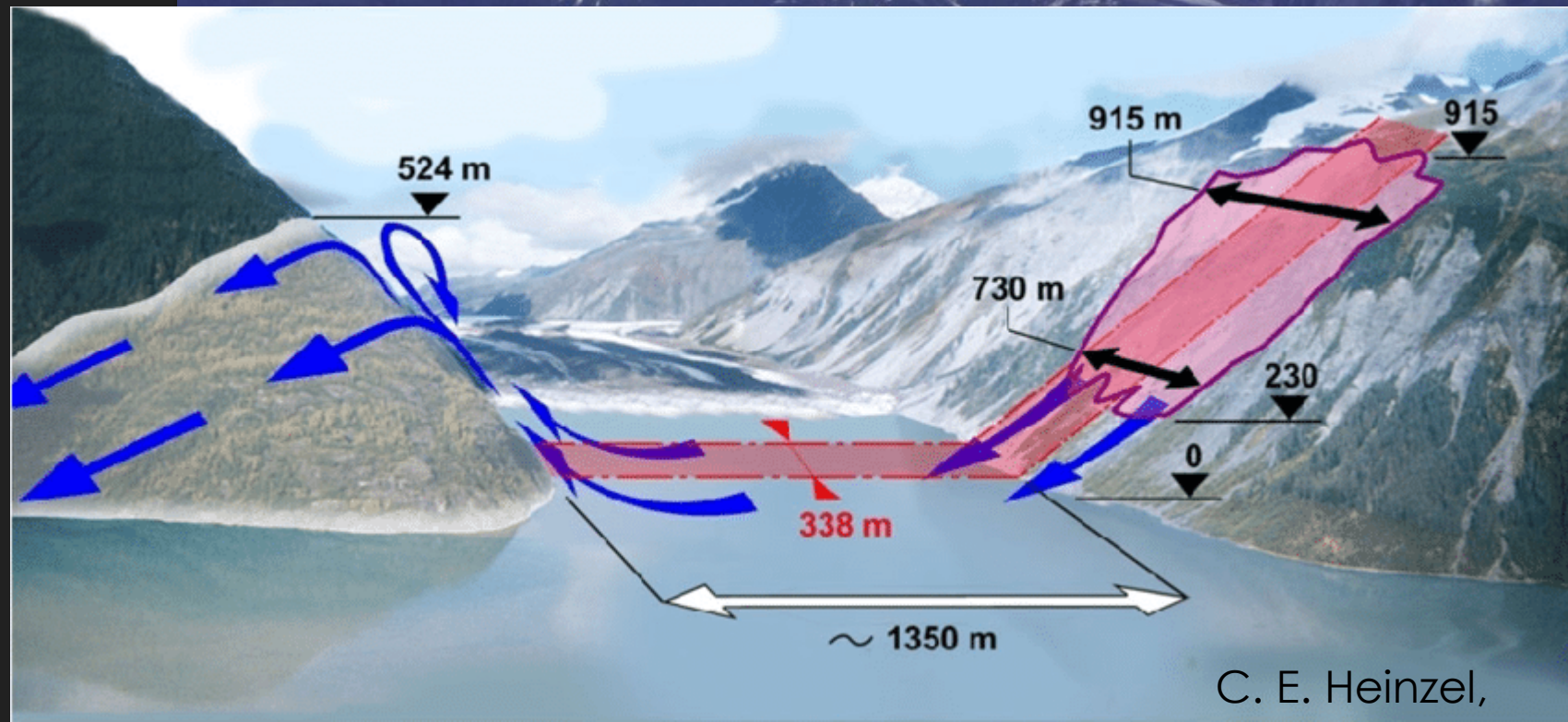


Deep vs Shallow water

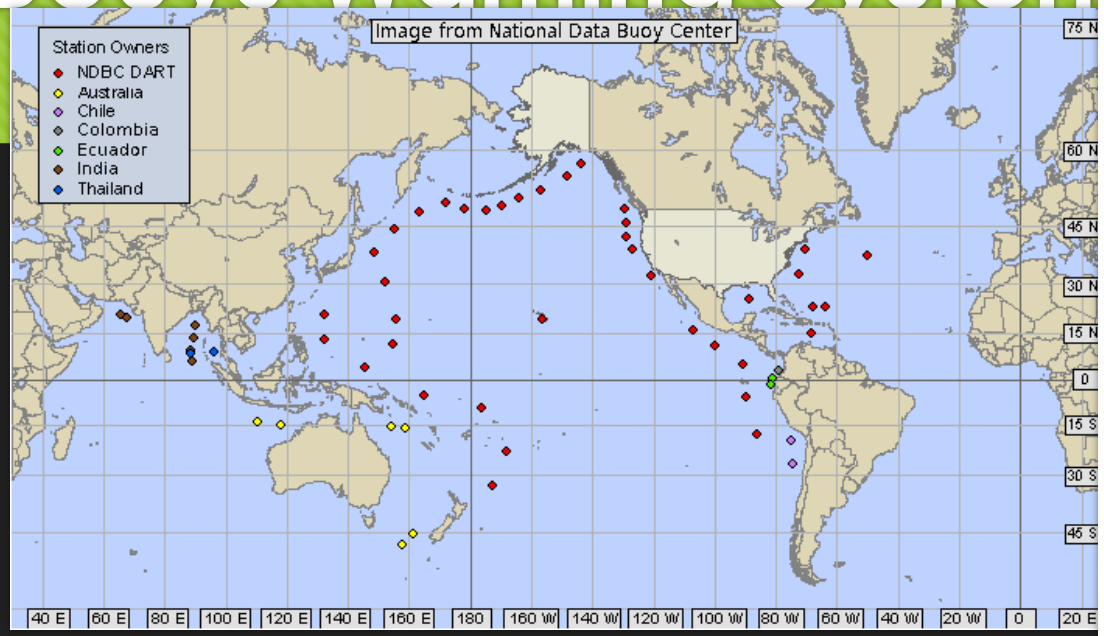
- **Deep water**
  - In the deep ocean the waves may go by unnoticed (low wave height)
  - Wave speed?
    - 800 km/hr (480mph)!!!!!
- **Shallow water**
  - Wave height grows exponentially
  - From 1 to 525 meters
    - or 1740 feet!

Lituya Bay Alaska

- 1959
- Tsunami Wave



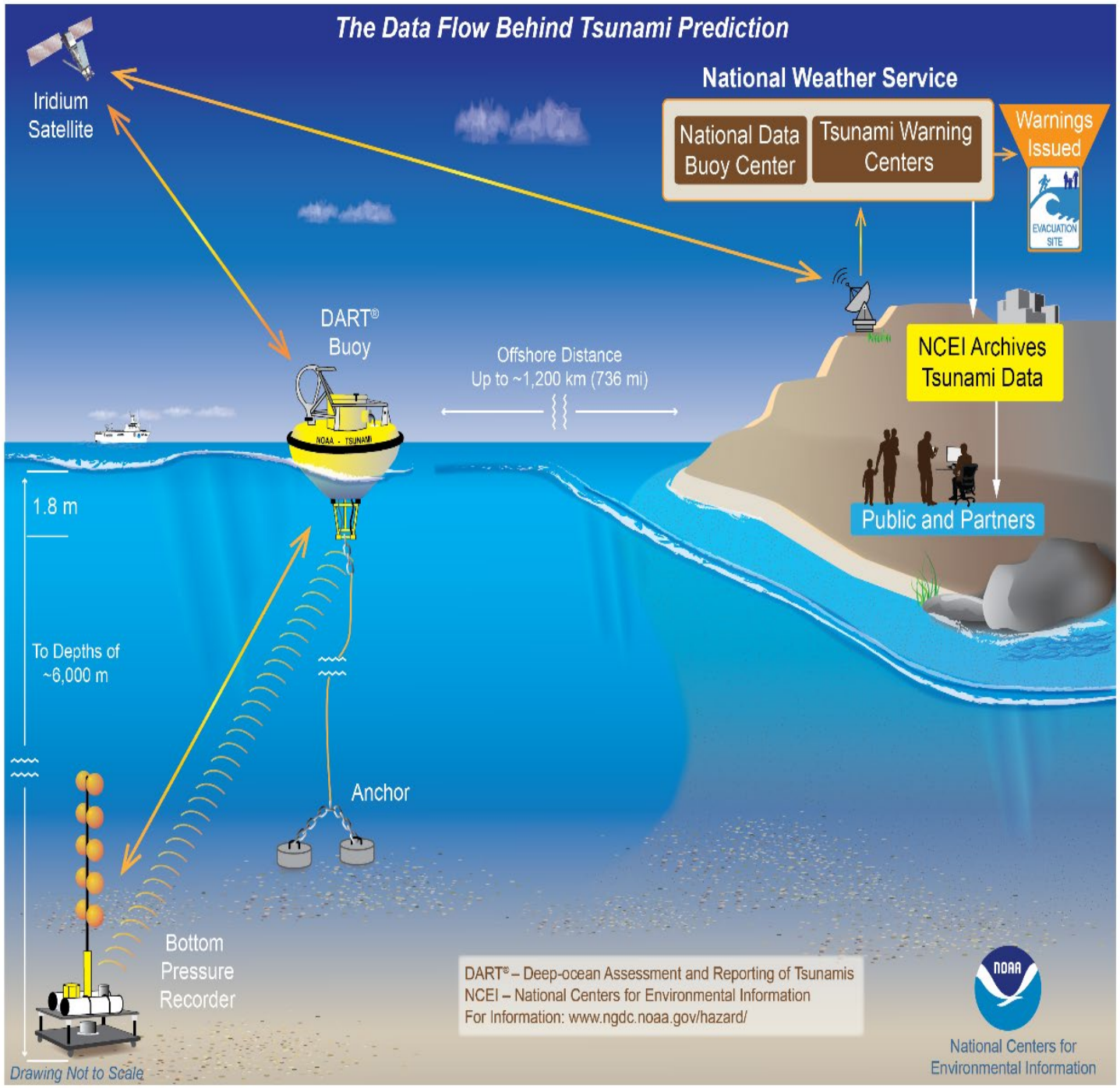
Bouys Warning System



Pacific Tsunami Warning System (PTWC)

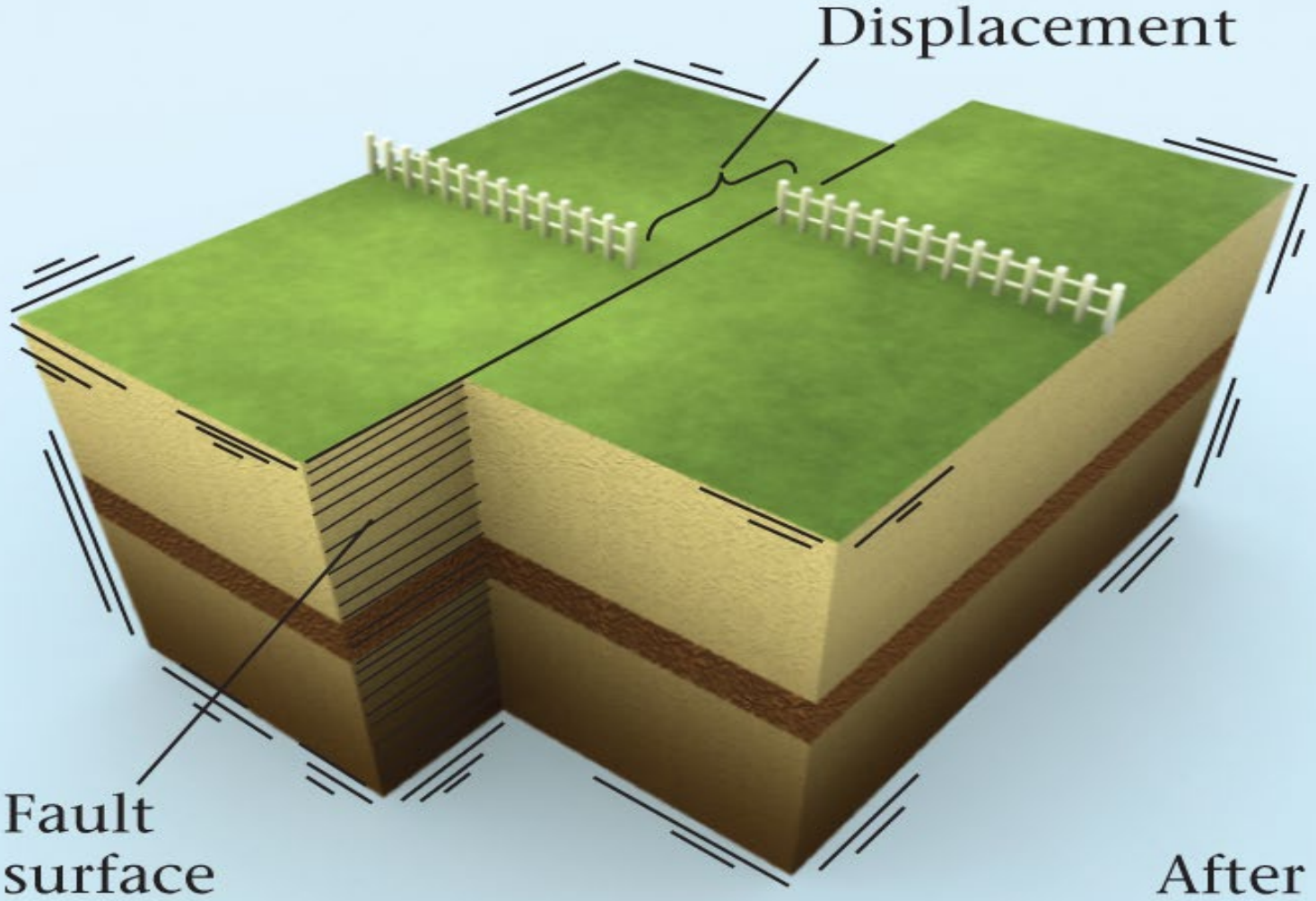
Deep-ocean Assessment Reporting of Tsunamis (DART)

https://nctr.pmel.noaa.gov/animate.html

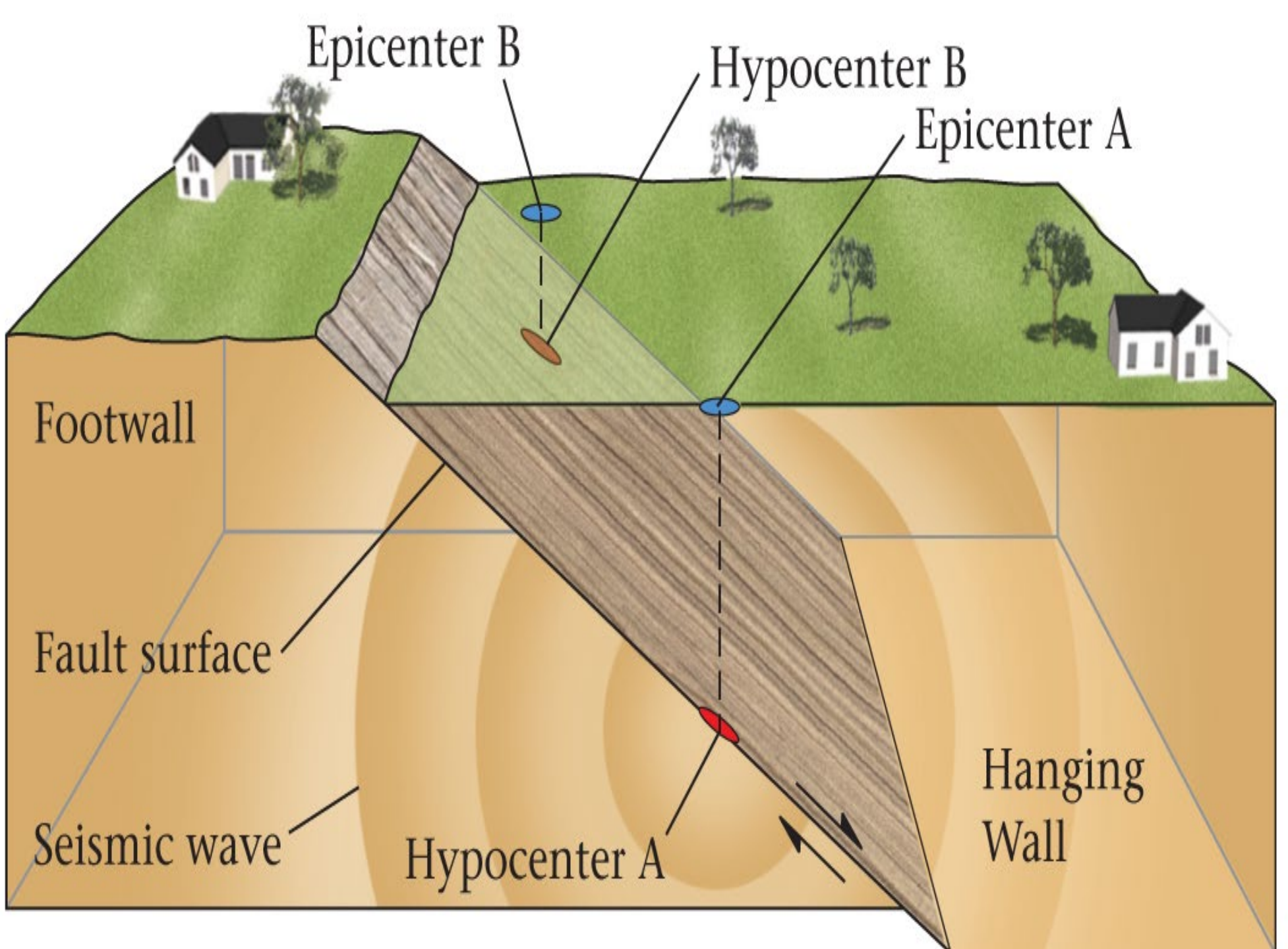


Year	Location	Number of Deaths
2011	Tohoku, Japan (tsunami)	20,000
2011	Christchurch, New Zealand	180
2010	Haiti	230,000
2010	Concepcion, Chile	1,000
2008	Sichuan, China	70,000
2005	Pakistan	80,000
2004	Sumatra (tsunami)	230,000
2003	Bam, Iran	41,000
2001	Bhuj, India	20,000
1999	Calaraca/Armenia, Colombia	2,000
1999	Izmit, Turkey	17,000
1995	Kobe, Japan	5,500
1994	Northridge, California	51
1990	Western Iran	50,000
1989	Loma Prieta, California	65
1988	Spitak, Armenia	24,000
1985	Mexico City	9,500
1983	Turkey	1,300
1978	Iran	15,000
1976	T'ang-shan, China	255,000
1976	Caldiran, Turkey	8,000
1976	Guatemala	23,000
1972	Nicaragua	12,000
1971	San Fernando, California	65
1970	Peru	66,000
1968	Iran	12,000
1964	Anchorage, Alaska	131
1963	Skopje, Yugoslavia	1,000
1962	Iran	12,000
1960	Agadir, Morocco	12,000
1960	Southern Chile	6,000
1948	Turkmenistan, USSR	110,000
1939	Erzincan, Turkey	40,000
1939	Chillan, Chile	30,000
1935	Quetta, Pakistan	60,000
1932	Gansu, China	70,000
1927	Tsinghai, China	200,000
1923	Tokyo, Japan	143,000
1920	Gansu, China	180,000
1915	Avezzano, Italy	30,000
1908	Messina, Italy	160,000
1906	San Francisco	500
1896	Japan	22,000
1886	Charleston, South Carolina	60
1866	Peru and Ecuador	25,000
1811–12	New Madrid, Missouri (3 events)	few
1783	Calabria, Italy	50,000
1755	Lisbon, Portugal	70,000
1556	Shen-shu, China	830,000

Displacement

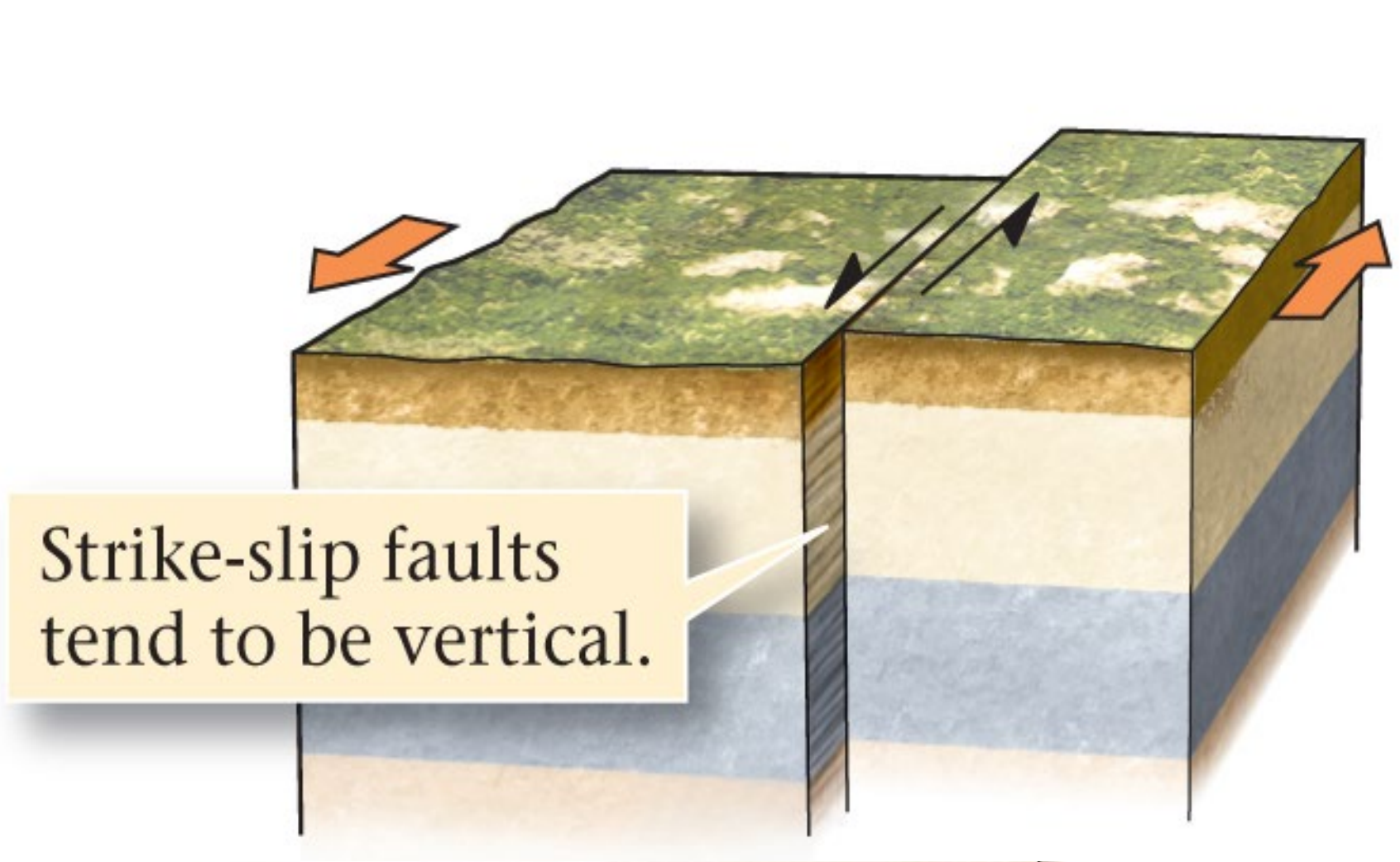


Earthquake terms

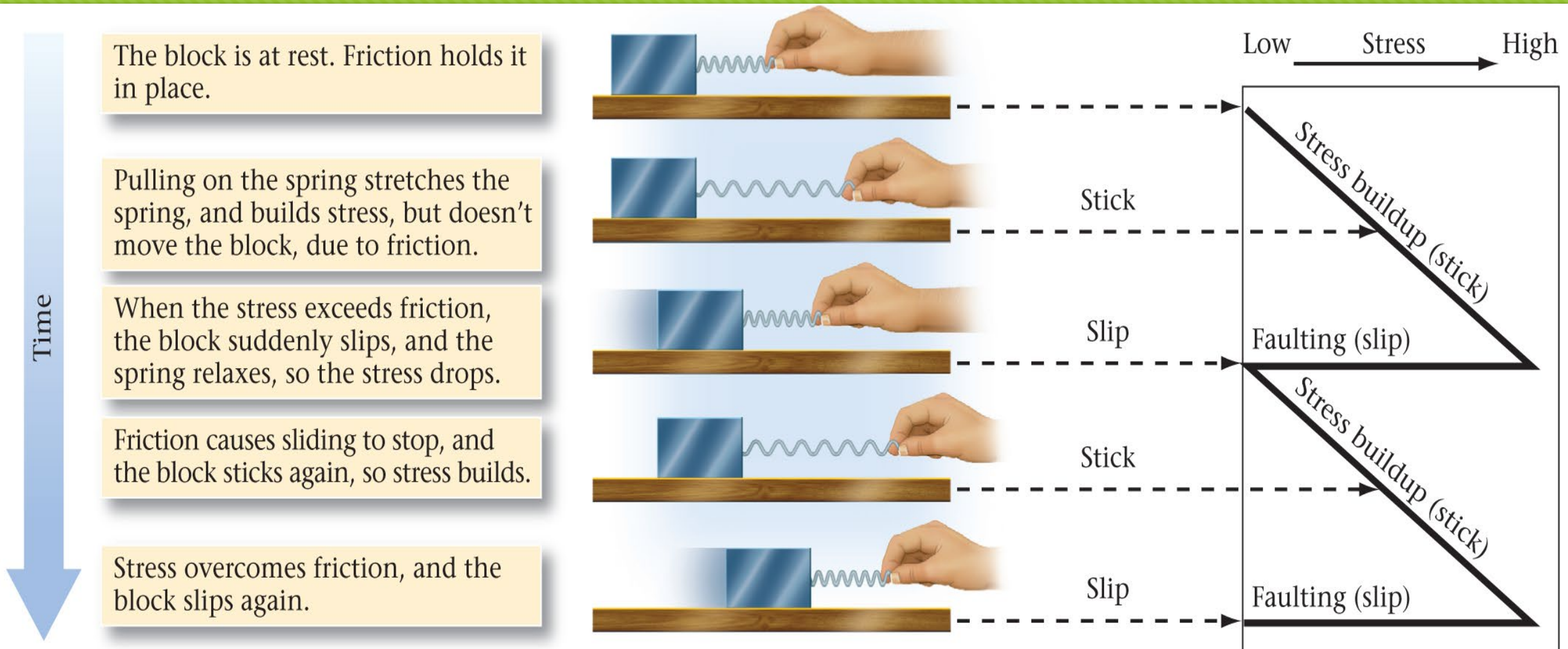


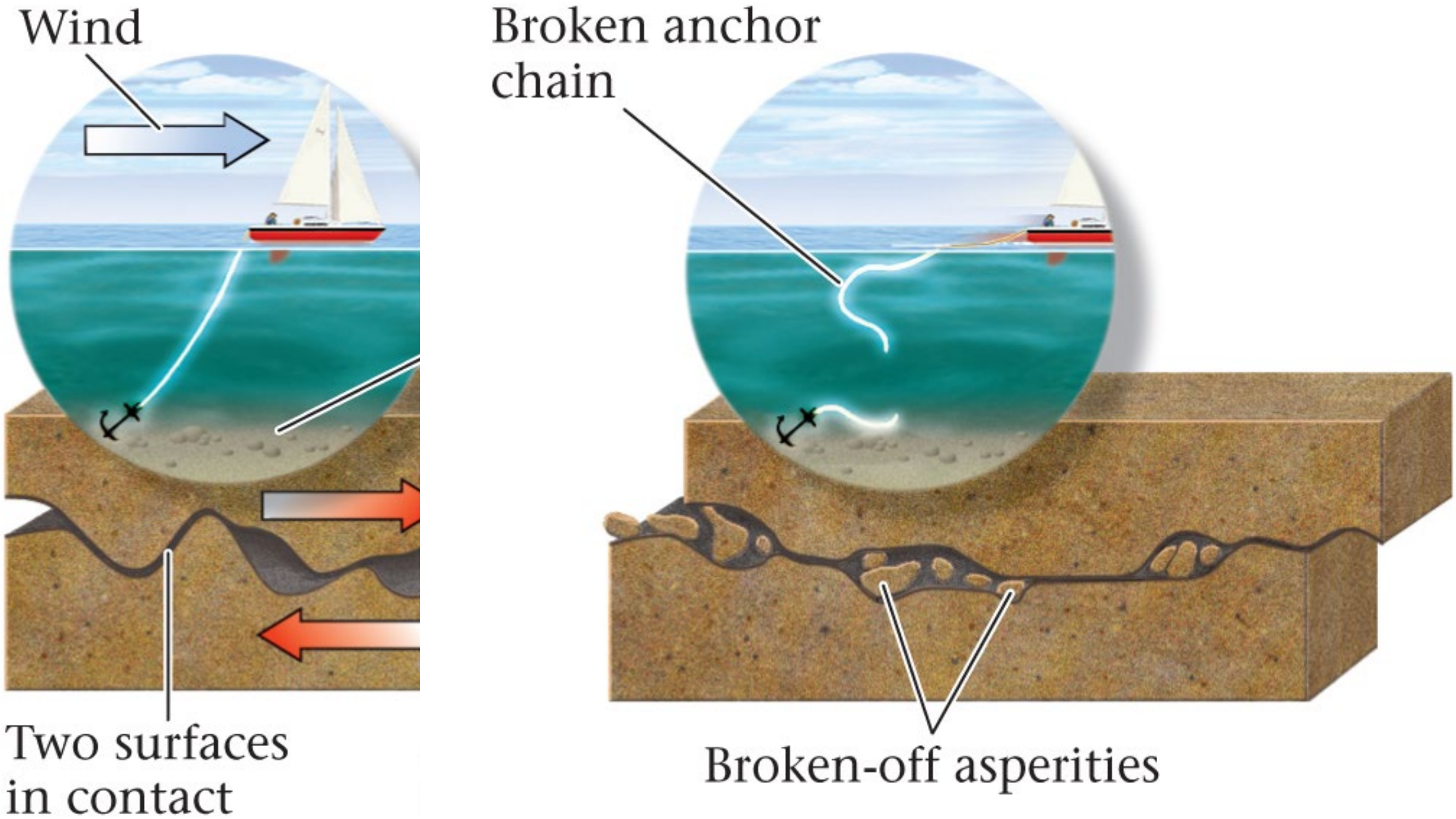
Fault types

Strike-slip



Friction, time, and critical thresholds

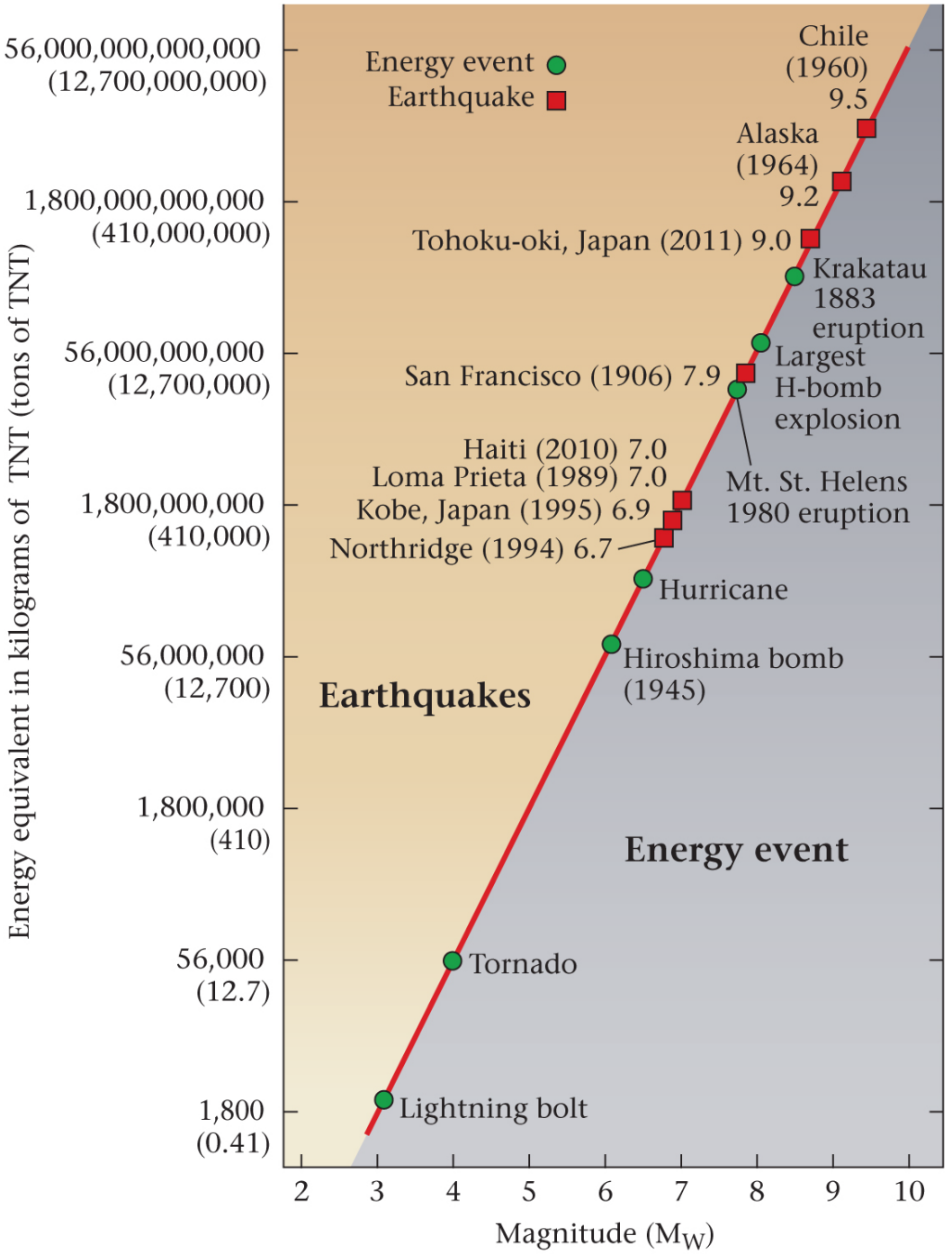



Wind
Broken anchor chain
Two surfaces in contact
Broken-off asperities

Scale

Modified Mercalli Scale (Intensity)

Richter Magnitude Scale



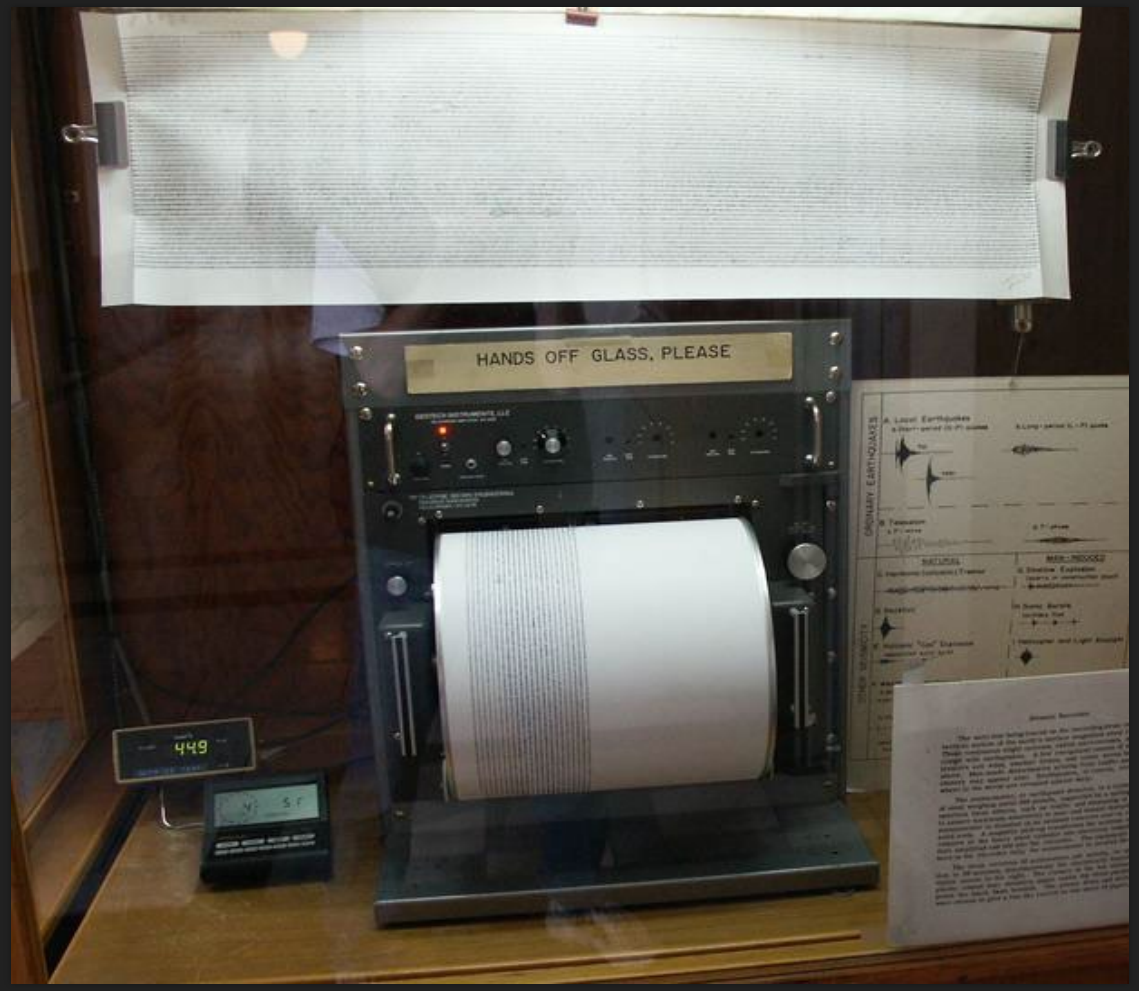
Measuring the Energy of an Earthquake

- Modified Mercalli Scale (Intensity)
- Richter Magnitude Scale

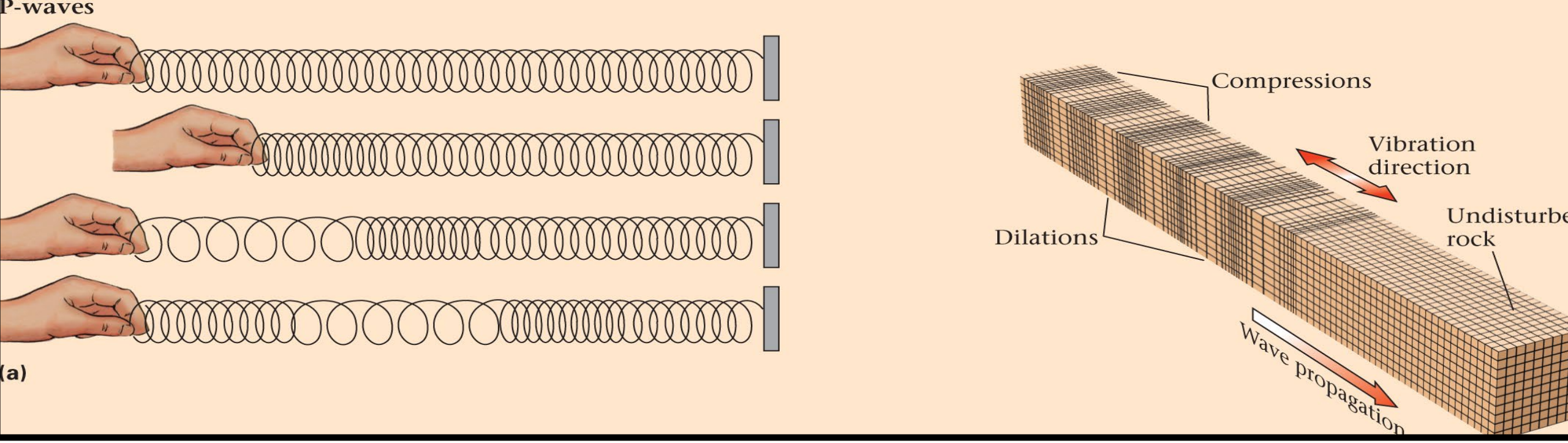
MMI	Destructiveness (Perceptions of the Extent of Shaking and Damage)
I	Detected only by seismic instruments; causes no damage.
II	Felt by a few stationary people, especially in upper floors of buildings; suspended objects, such as lamps, may swing.
III	Felt indoors; standing automobiles sway on their suspensions; it seems as though a heavy truck is passing.
IV	Shaking awakens some sleepers; dishes and windows rattle.
V	Most people awaken; some dishes and windows break, unstable objects tip over; trees and poles sway.
VI	Shaking frightens some people; plaster walls crack, heavy furniture moves slightly, and a few chimneys crack, but overall little damage occurs.
VII	Most people are frightened and run outside; a lot of plaster cracks, windows break, some chimneys topple, and unstable furniture overturns; poorly built buildings sustain considerable damage.
VIII	Many chimneys and factory smokestacks topple; heavy furniture overturns; substantial buildings sustain some damage, and poorly built buildings suffer severe damage.
IX	Frame buildings separate from their foundations; most buildings sustain damage, and some buildings collapse; the ground cracks, underground pipes break, and rails bend; some landslides occur.
X	Most masonry structures and some well-built wooden structures are destroyed; the ground severely cracks in places; many landslides occur along steep slopes; some bridges collapse; some sediment liquifies; concrete dams may crack; facades on many buildings collapse; railways and roads suffer severe damage.
XI	Few masonry buildings remain standing; many bridges collapse; broad fissures form in the ground; most pipelines break; severe liquefaction of sediment occurs; some dams collapse; facades on most buildings collapse or are severely damaged.
XII	Earthquake waves cause visible undulations of the ground surface; objects are thrown up off the ground; there is complete destruction of buildings and bridges of all types.

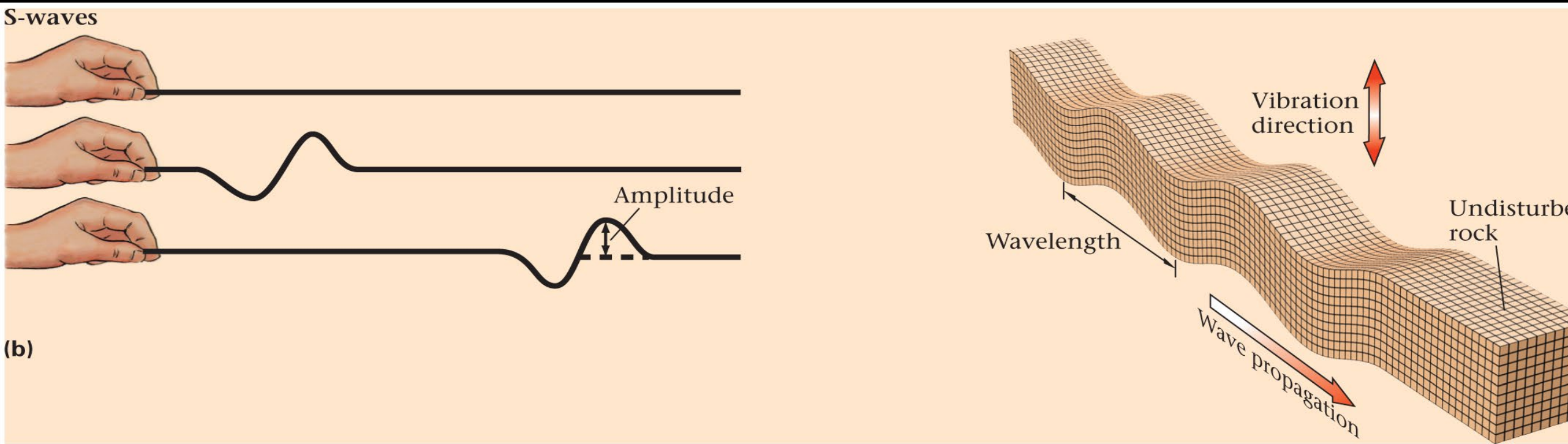
Richter Scale

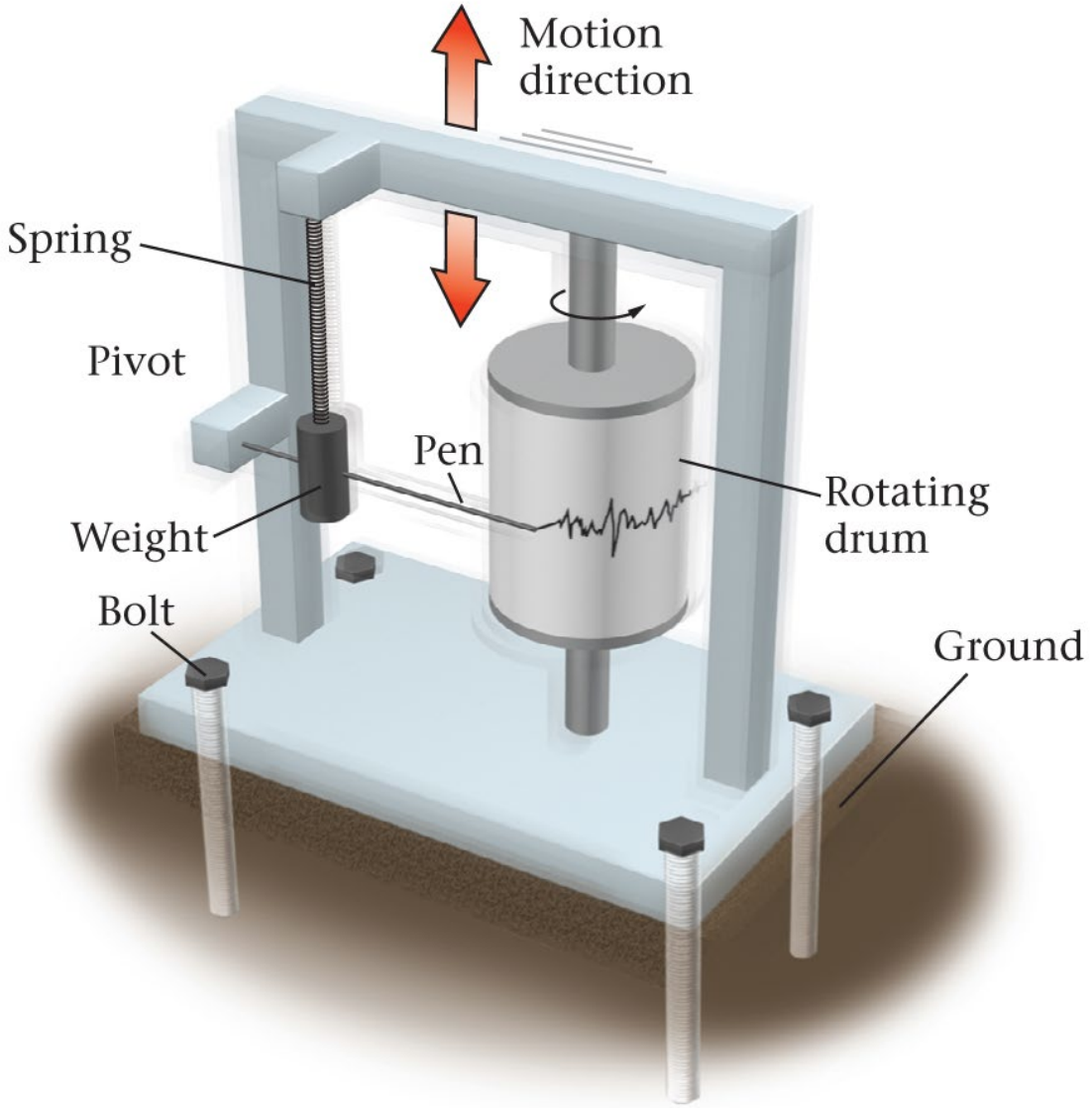
- **Direct** measurement of the P and S-wave intensities.

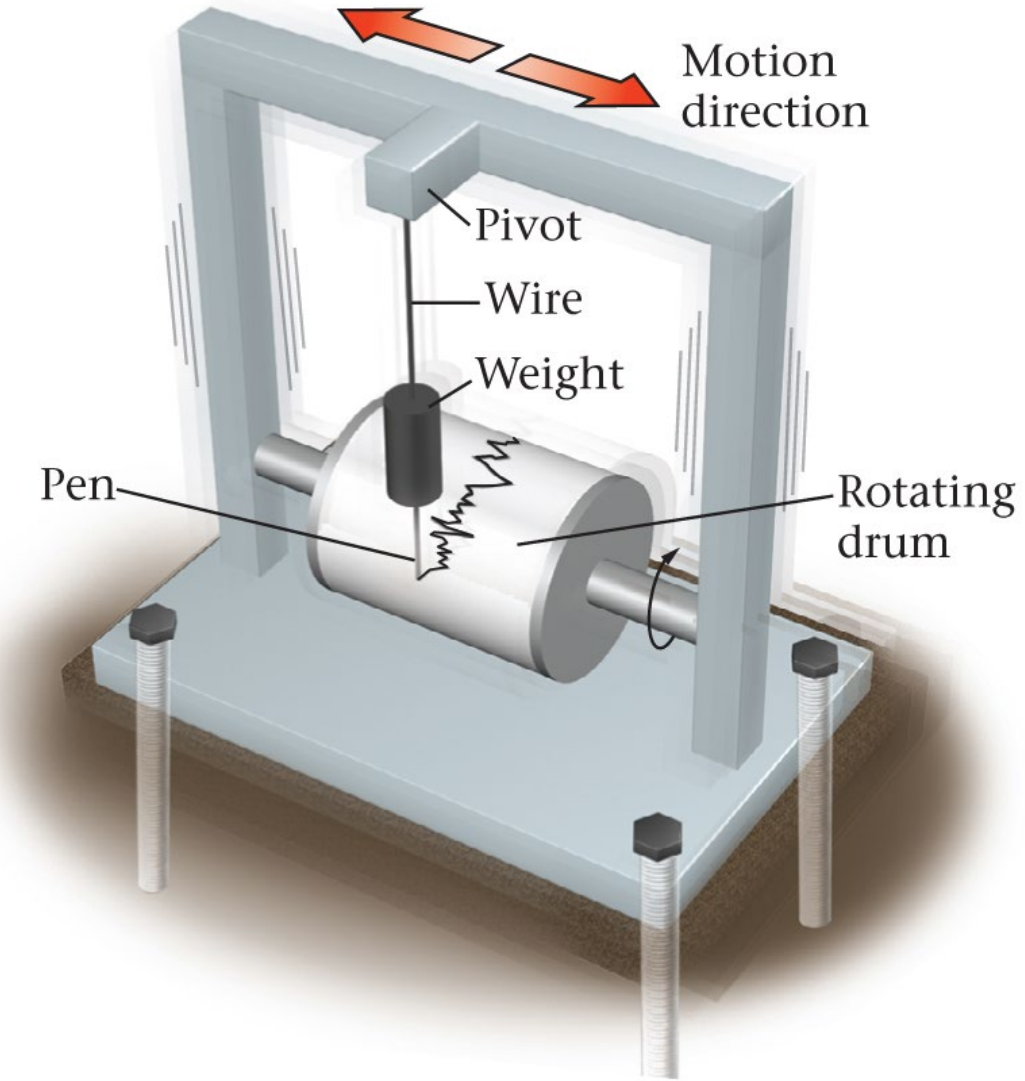


Seismometer

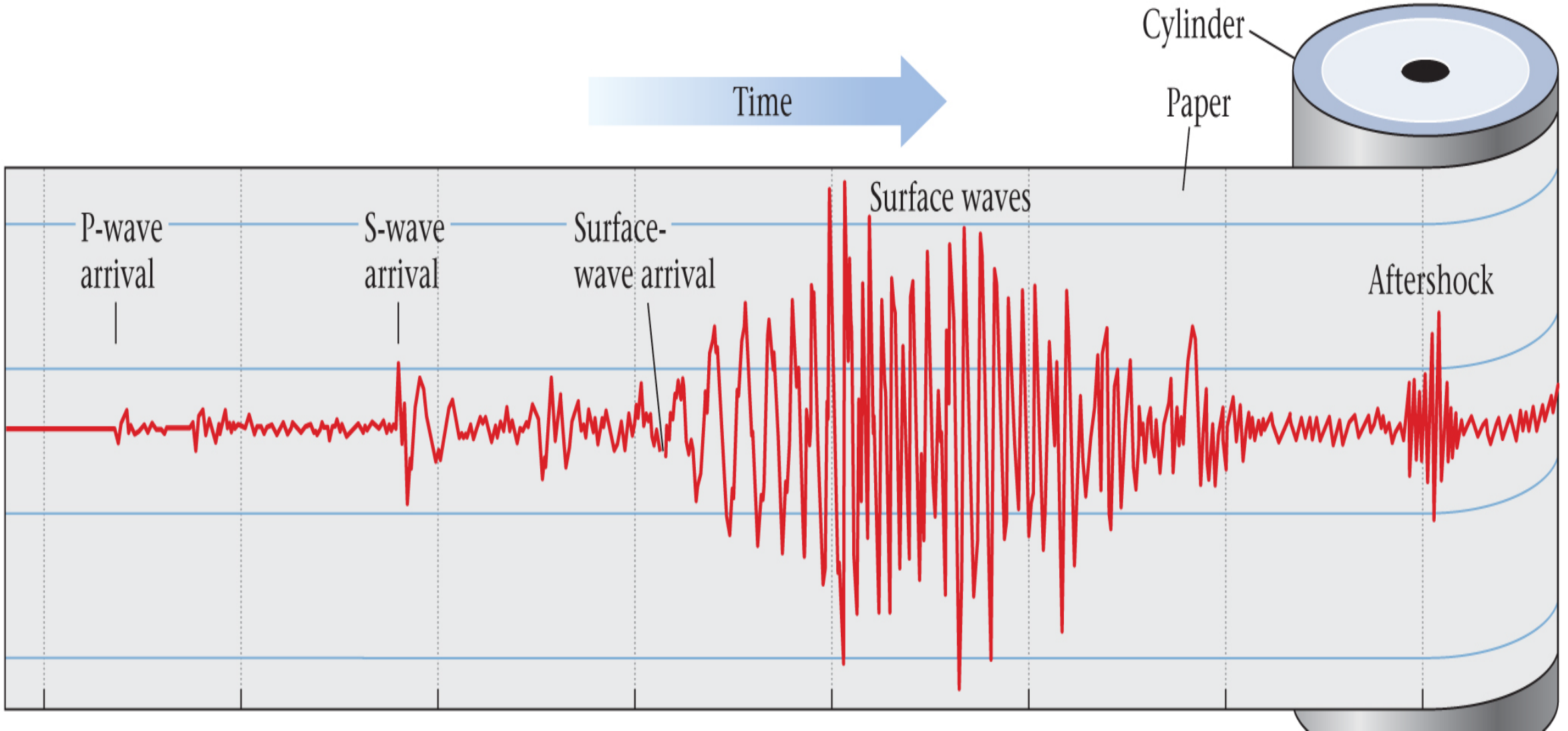

P-waves
(a)
Compressions
Vibration direction
Dilations
Undisturbed rock
Wave propagation


S-waves
Amplitude
(b)
Vibration direction
Wavelength
Undisturbed rock
Wave propagation

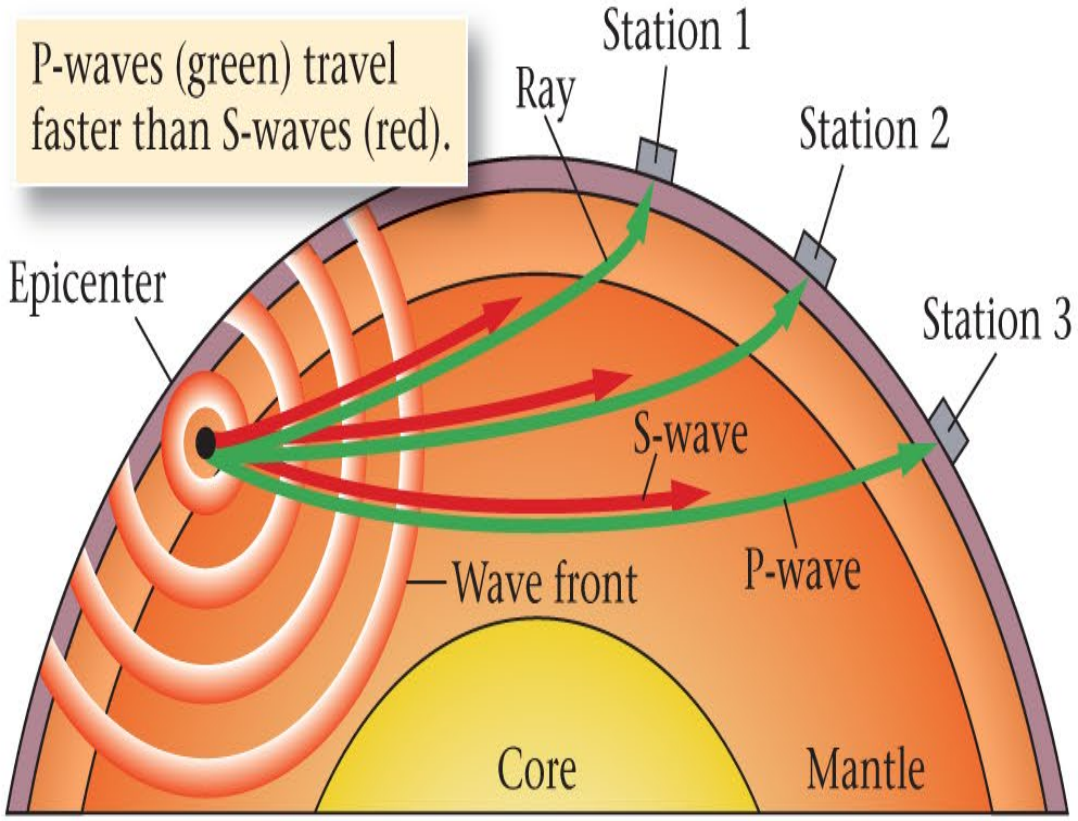

Motion direction
Spring
Pivot
Pen
Weight
Bolt
Rotating drum
Ground

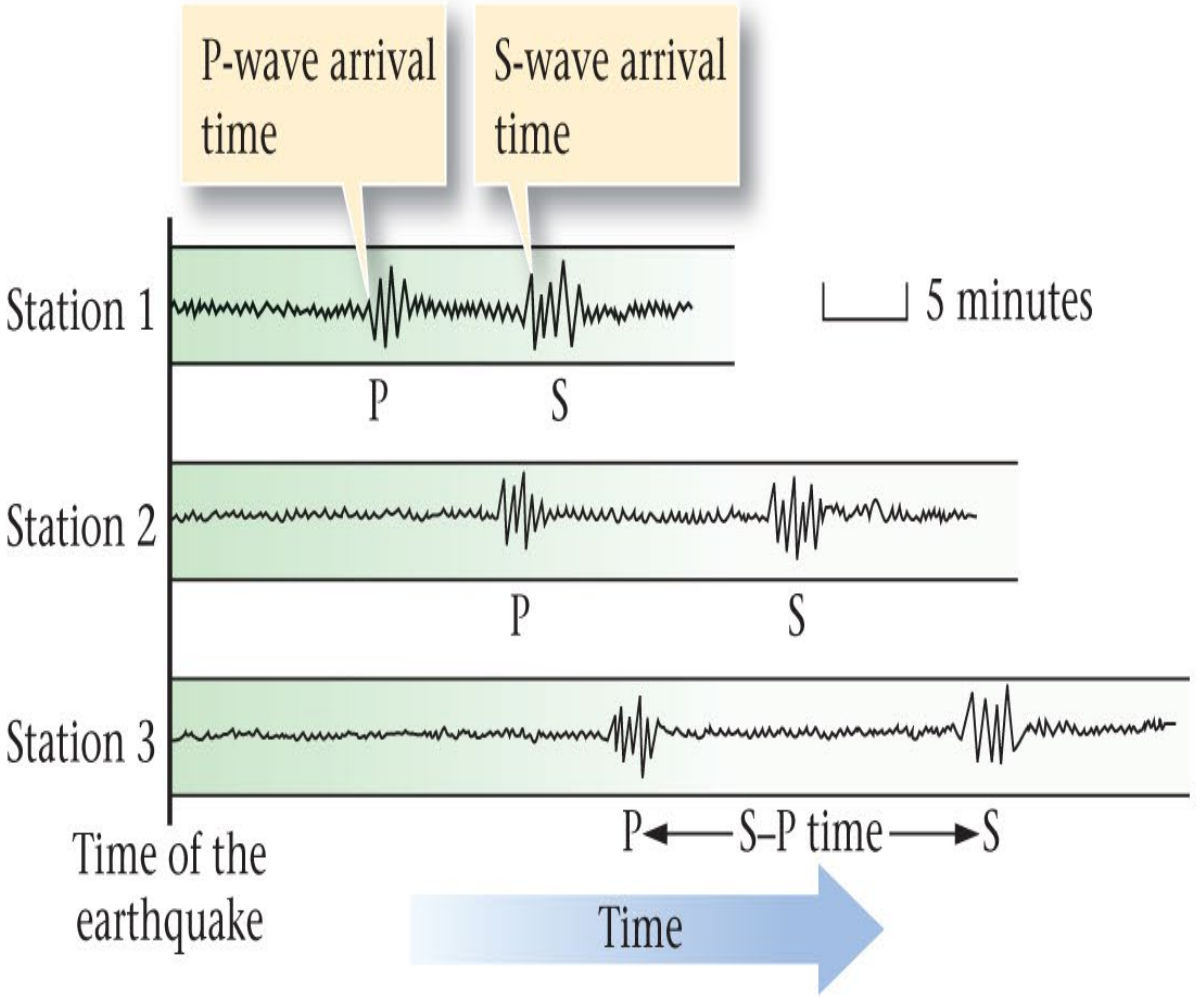

Motion direction
Pivot
Wire
Weight
Pen
Rotating drum

Reading Seismic Lines

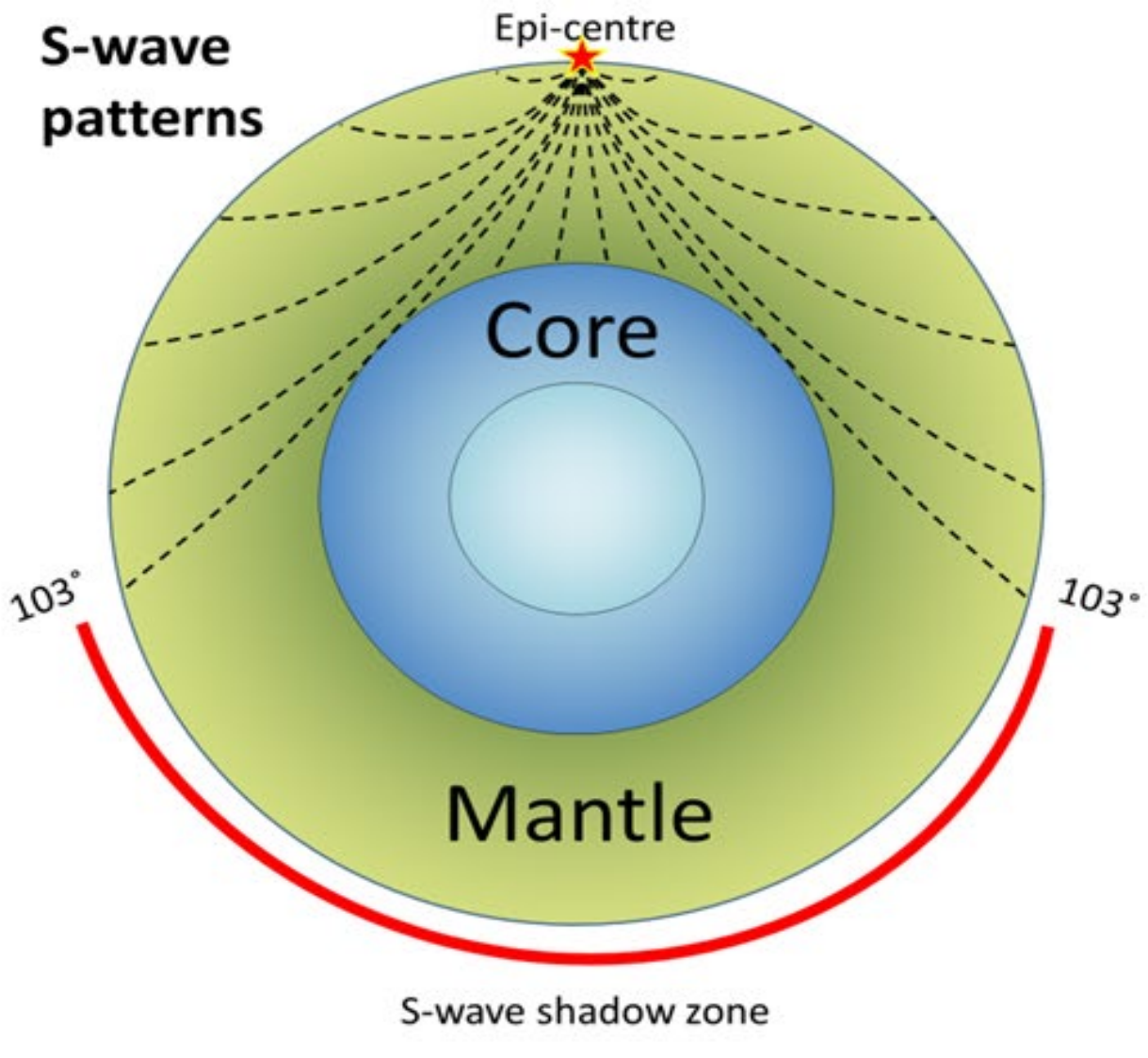


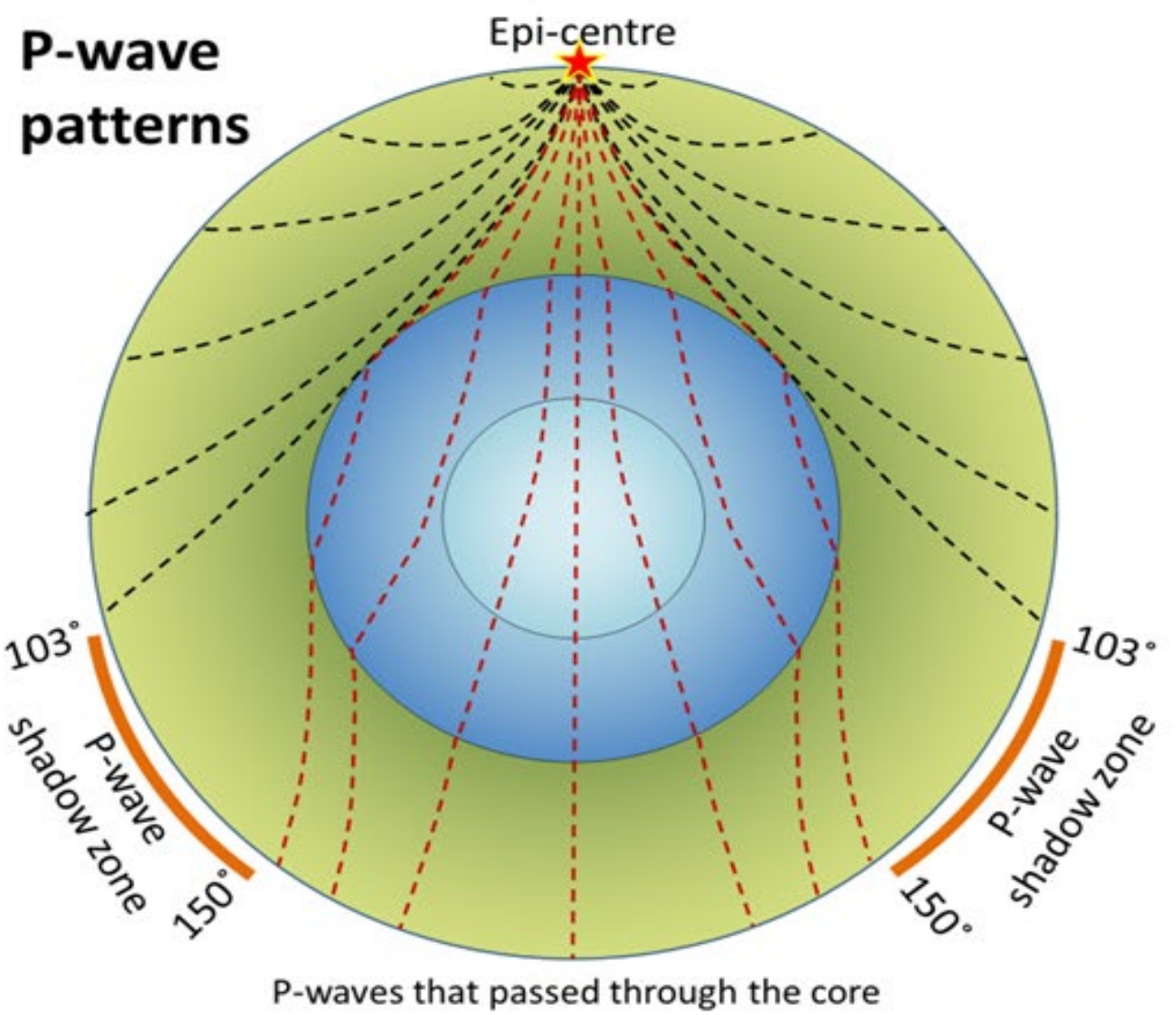
P-waves Vs S-Waves & the Earth's Interior





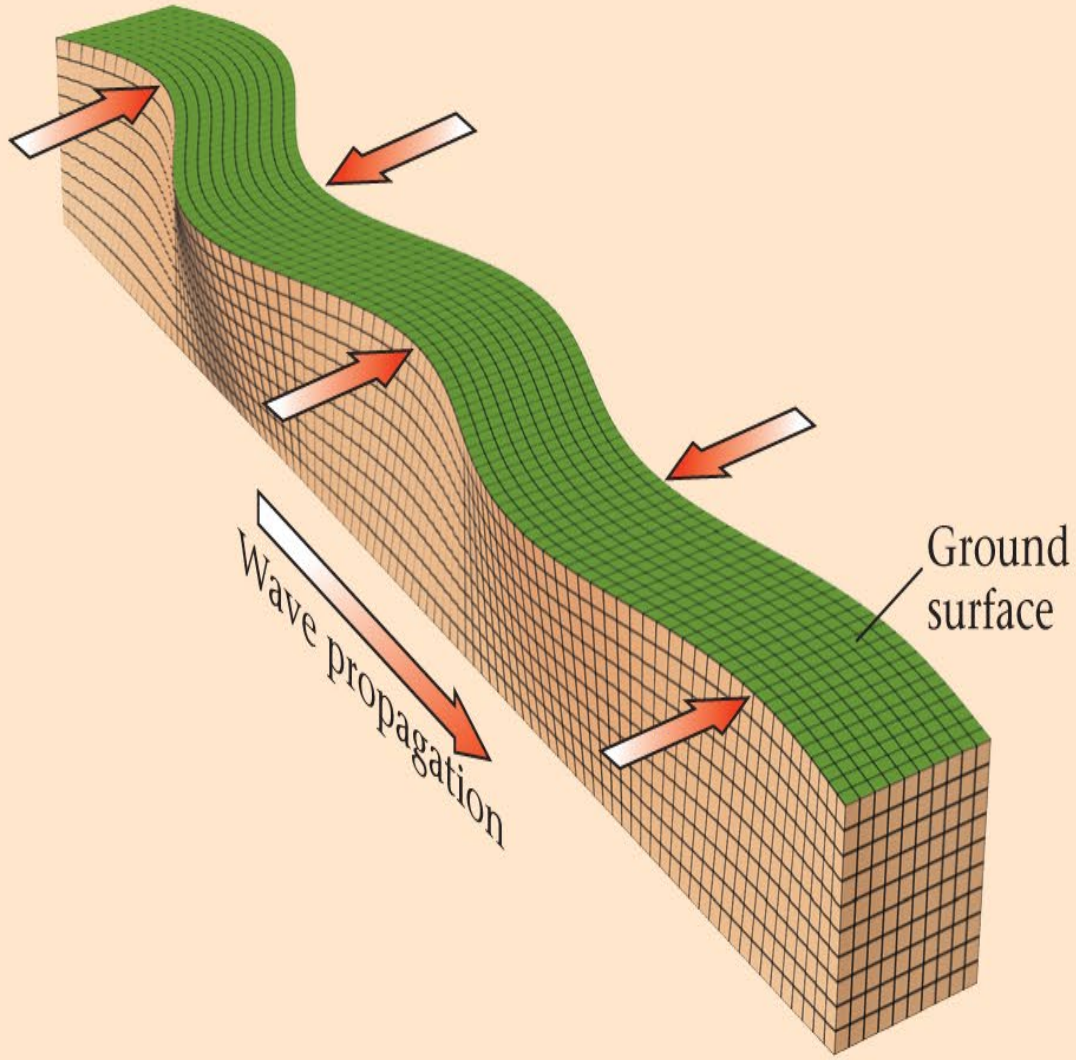
Triangulation


S-wave patterns
Epi-centre
Core
Mantle
103°
103°
S-wave shadow zone

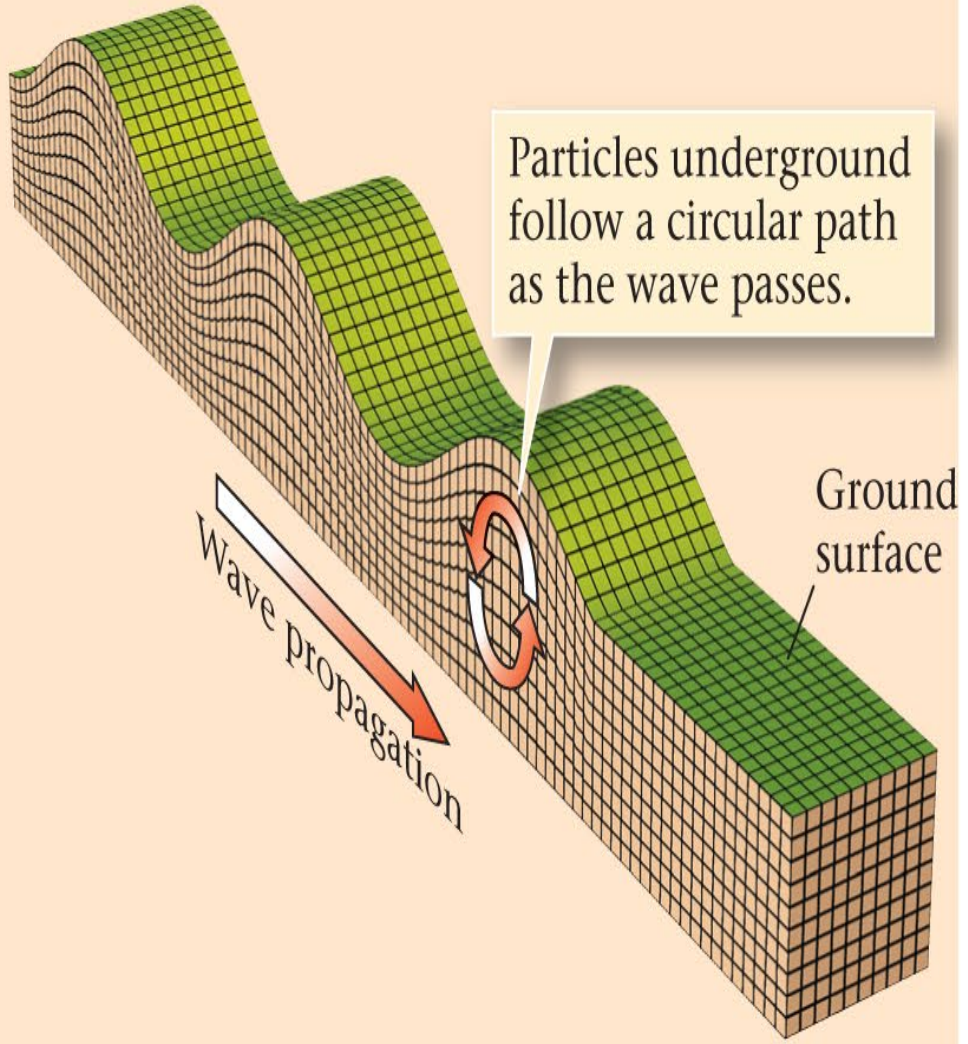

P-wave patterns
Epi-centre
103°
P-wave shadow zone
150°
103°
P-wave shadow zone
150°
P-waves that passed through the core

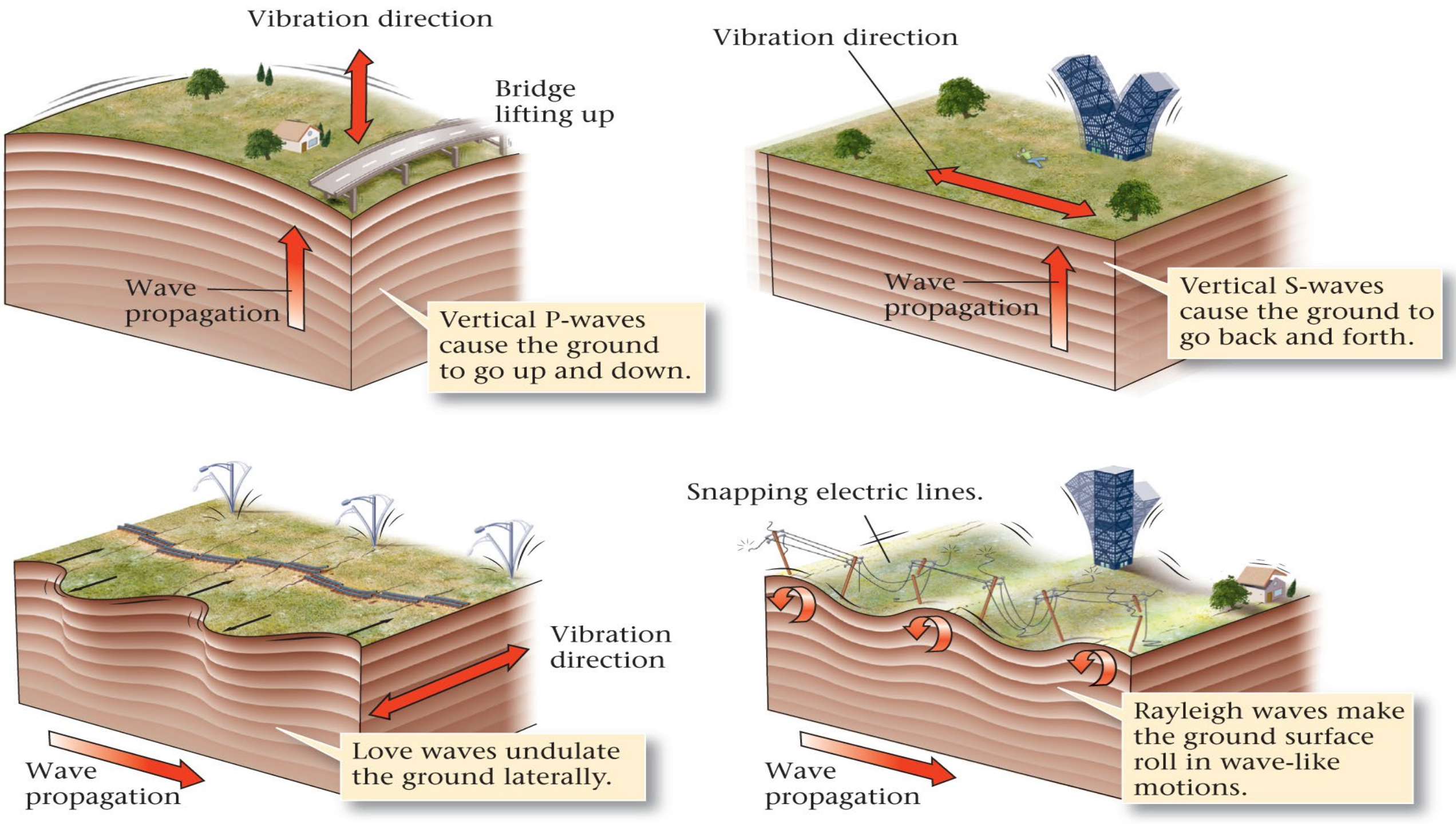
More wave types

L-waves



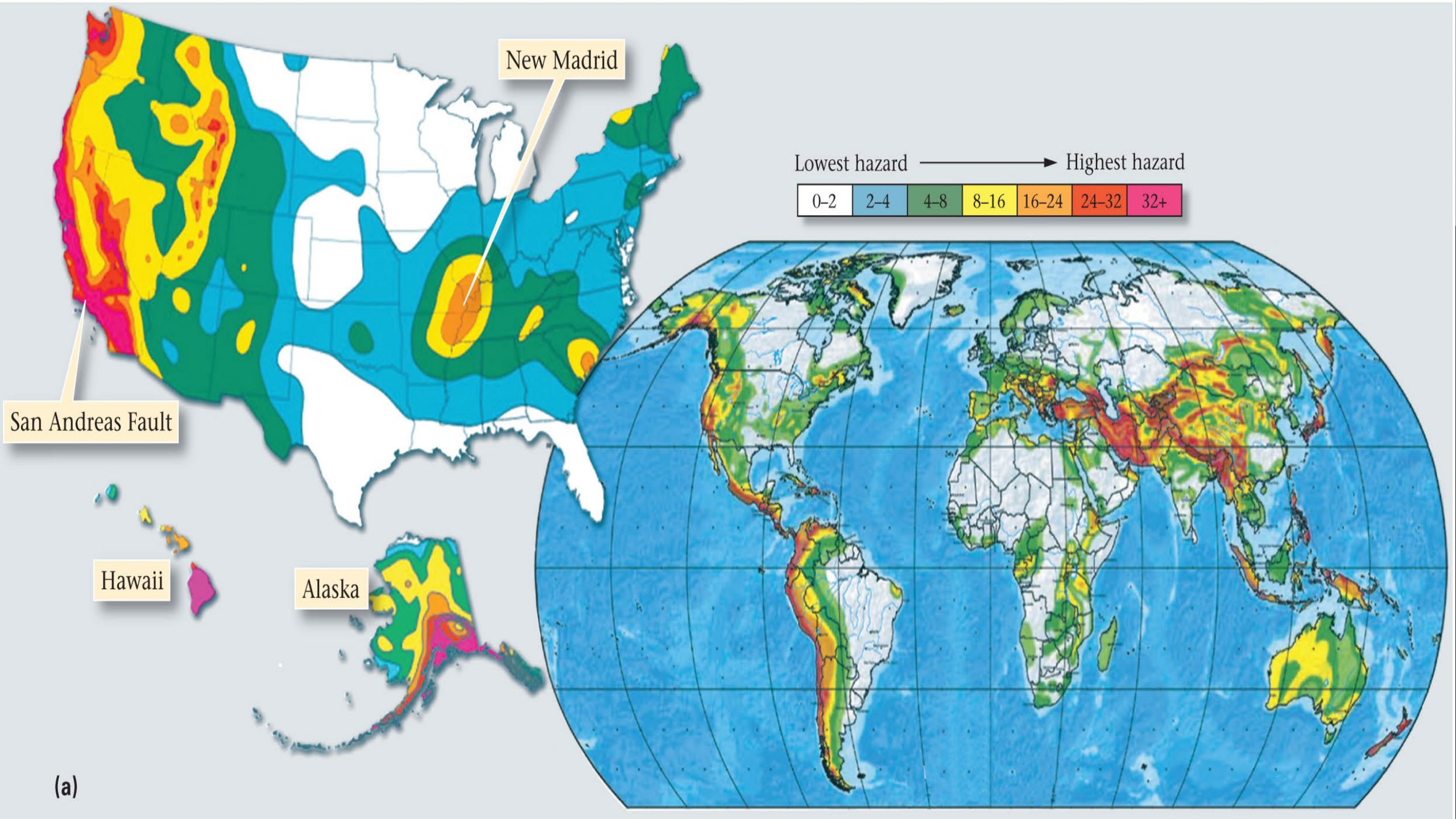
R-waves



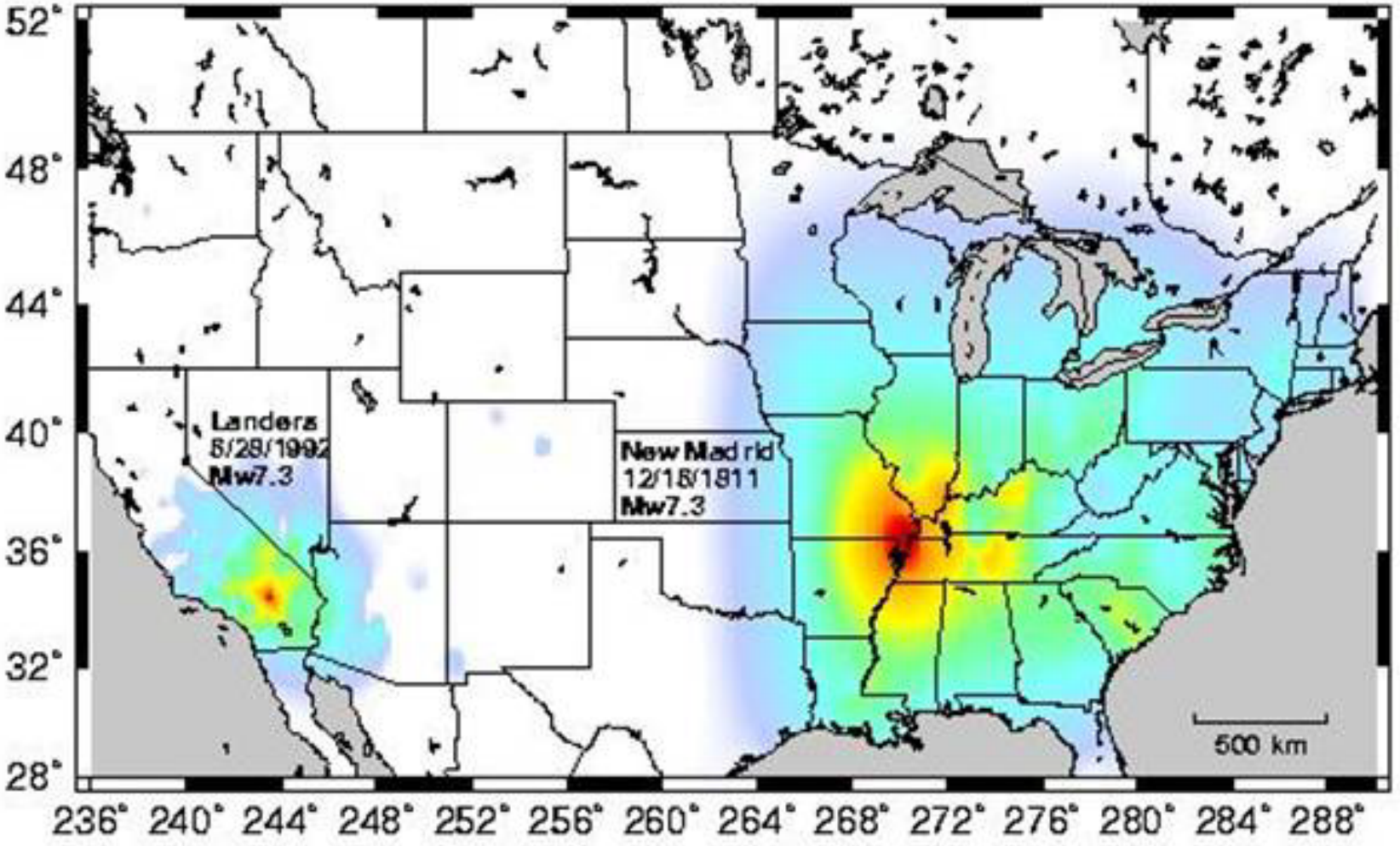

Vibration direction
Bridge lifting up
Wave propagation
Vertical P-waves cause the ground to go up and down.
Vibration direction
Wave propagation
Vertical S-waves cause the ground to go back and forth.
Vibration direction
Wave propagation
Love waves undulate the ground laterally.
Snapping electric lines.
Wave propagation
Rayleigh waves make the ground surface roll in wave-like motions.

Intra-plate Earthquakes

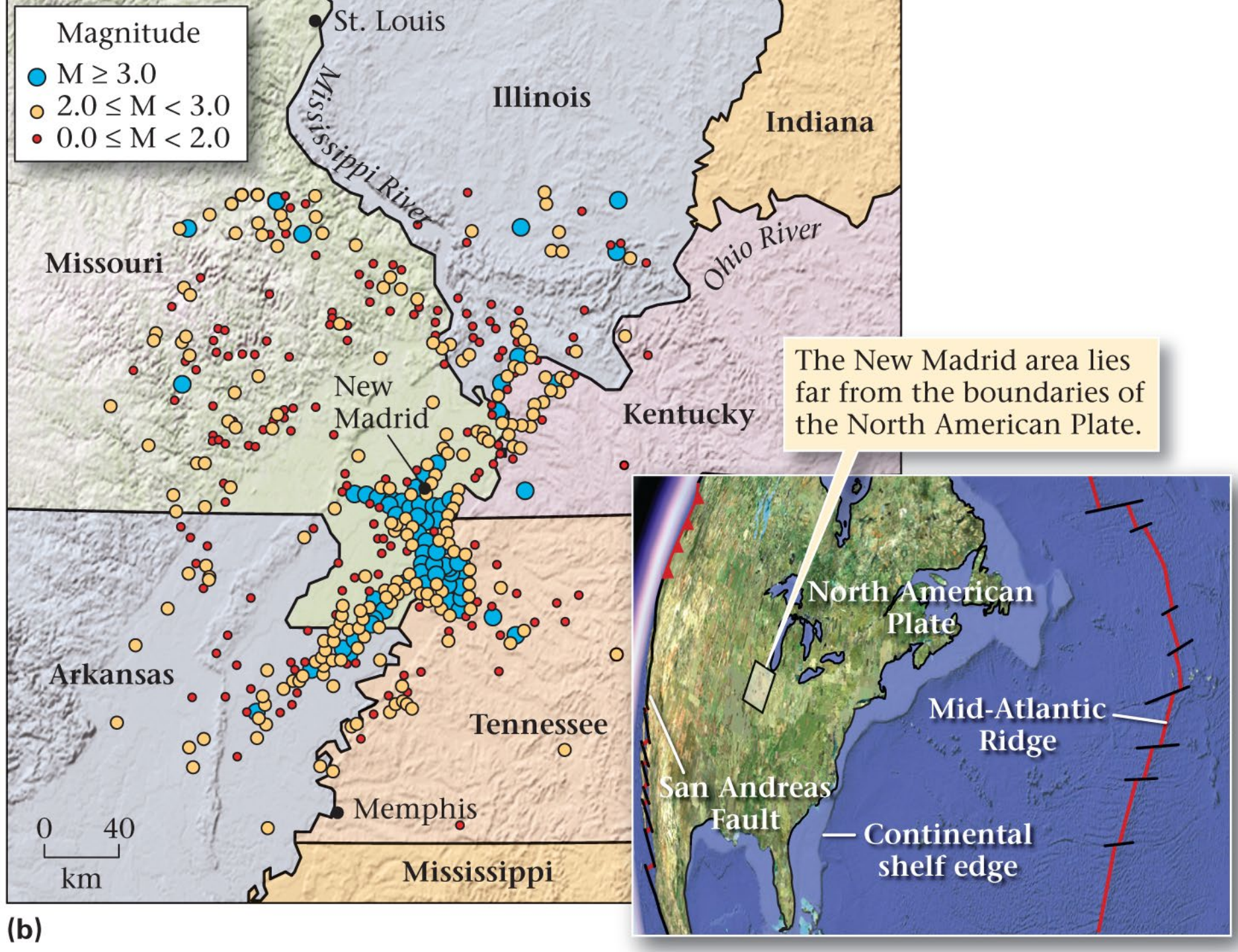
- Deeply buried / Typically do not break the ground surface.
- Strong rock with few breaks
  - Seismic waves move rapidly
  - Increased ground motion
  - Increased surface damage


New Madrid
San Andreas Fault
Hawaii
Alaska
Lowest hazard
Highest hazard
0–2
2–4
4–8
8–16
16–24
24–32
32+
(a)

The 1812 New Madrid Earthquake



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+


Magnitude
M ≥ 3.0
2.0 ≤ M < 3.0
0.0 ≤ M < 2.0
St. Louis
Illinois
Indiana
Mississippi River
Ohio River
Missouri
New Madrid
Kentucky
Arkansas
Tennessee
Memphis
Mississippi
0 40
km
The New Madrid area lies far from the boundaries of the North American Plate.
North American Plate
Mid-Atlantic Ridge
San Andreas Fault
Continental shelf edge
(b)

Plum River Fault