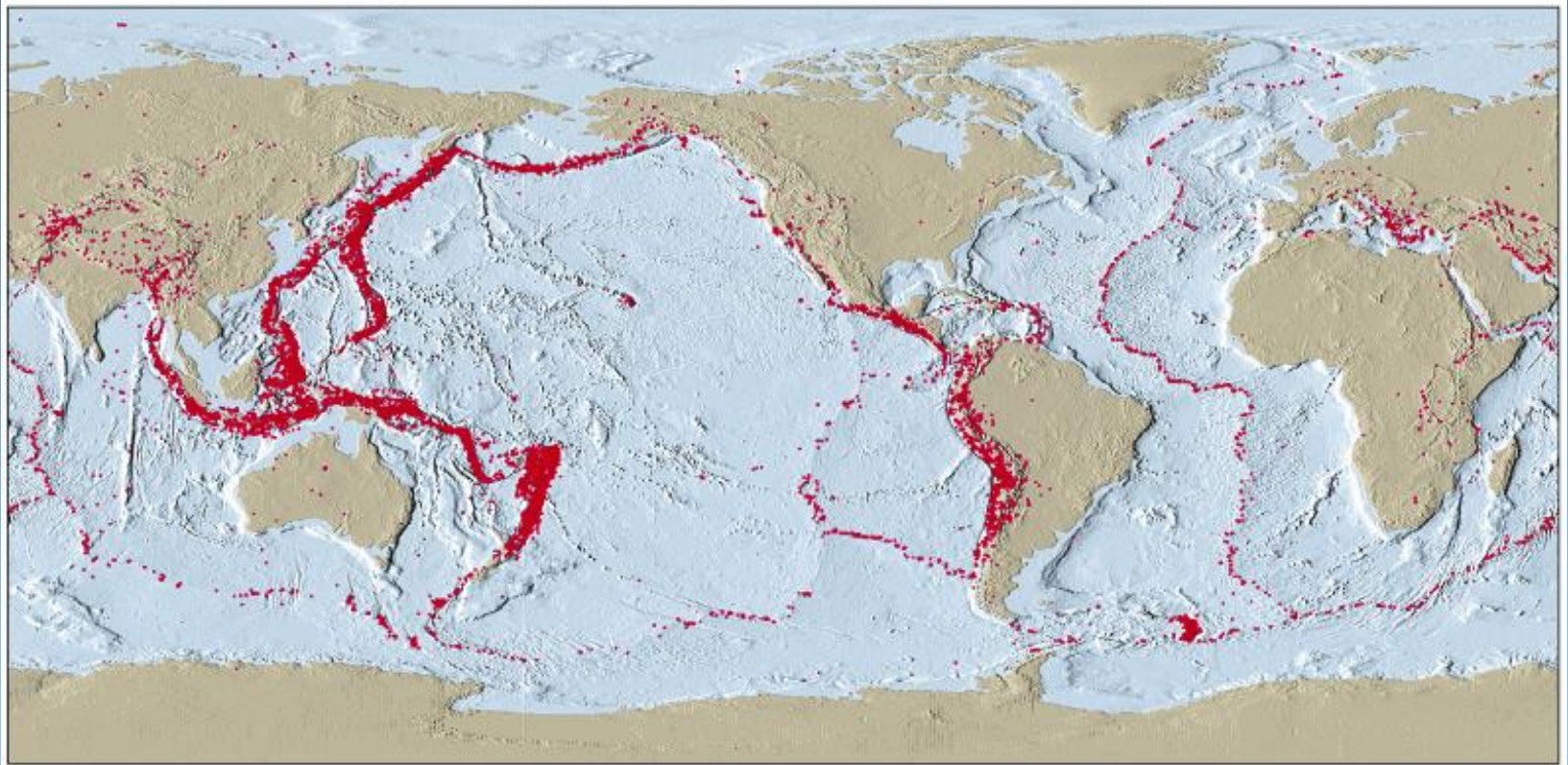


Our Hazardous Environment

GEOG-1110



Chapter 3

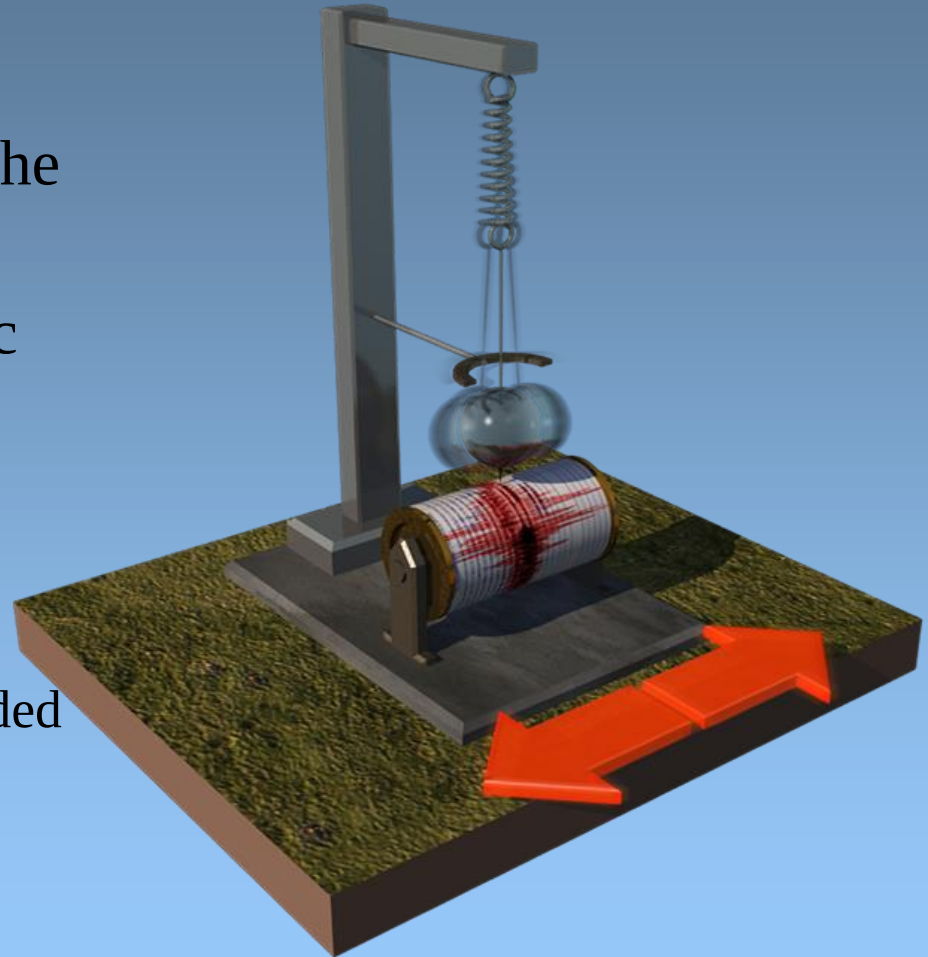
Earthquake Hazards

Earthquake basics

- An earthquake is a shaking of the ground caused by rocks rupturing under stress (definition)
- Most earthquakes are generated along fault zones
- Focus = place within Earth where the rocks rupture
 - 0-750 km deep
 - mostly <60 km deep
- Epicenter = location on Earth's surface directly above the focus
 - damage is most severe near the epicenter
- Generally speaking, deep-focus earthquakes do not cause intense shaking

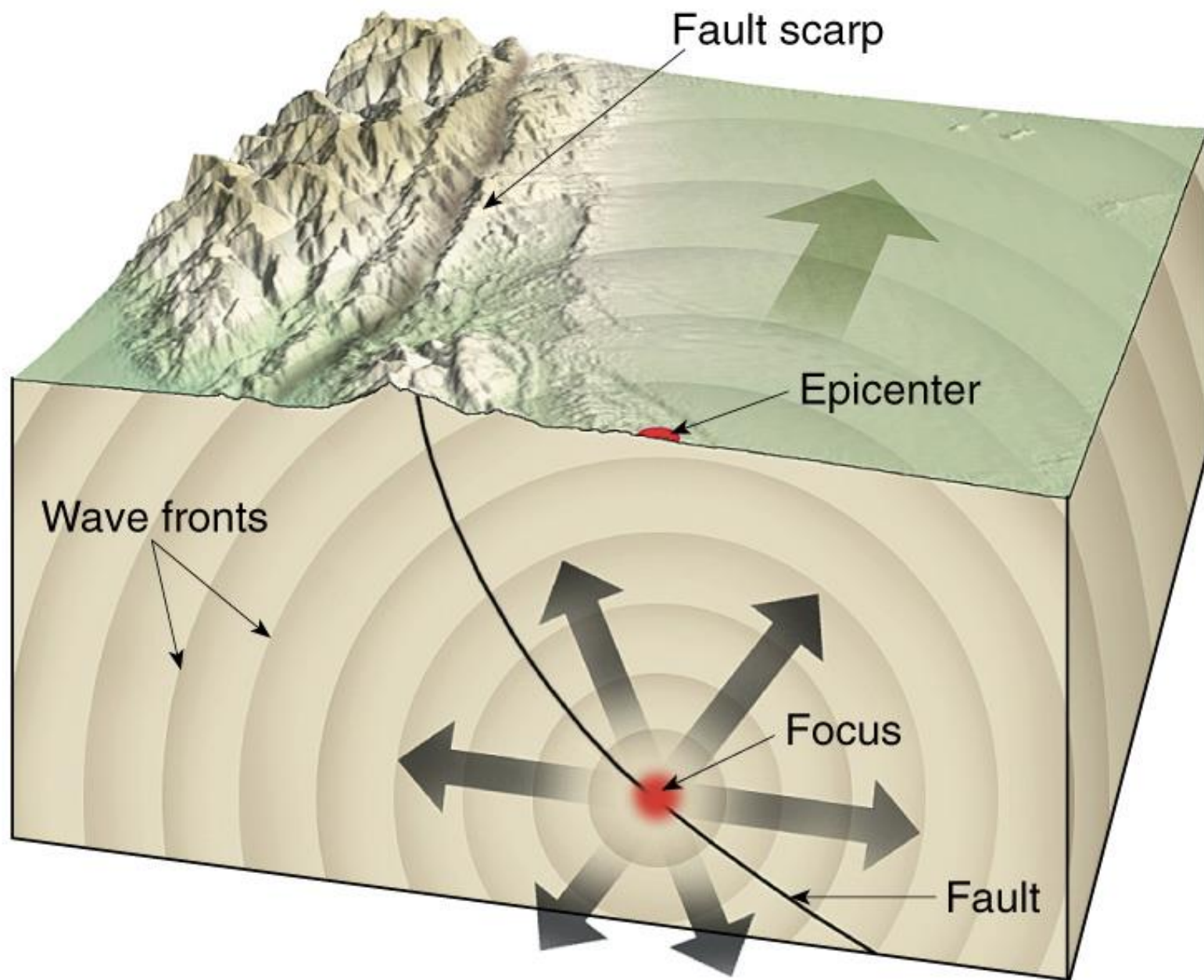
Seismology

- Seismology is the study of earthquake waves
- Dates back ~ 2000 years to the Chinese
- Seismometers record seismic waves
 - Based on inertia
 - A single seismometer reads motion in one direction only
 - Several seismometers are needed to accurately measure an earthquake
 - Seismometers produce charts called seismograms



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Measures horizontal movement



What causes the shaking?

- Elastic rebound theory
 - first the rocks are stressed
 - next the rocks experience elastic deformation
 - at some point the rocks break
 - then rocks on either side of the fault return to their original
 - the elastic snap of the rocks returning to their original shape causes the ground to shake

Movement along Faults

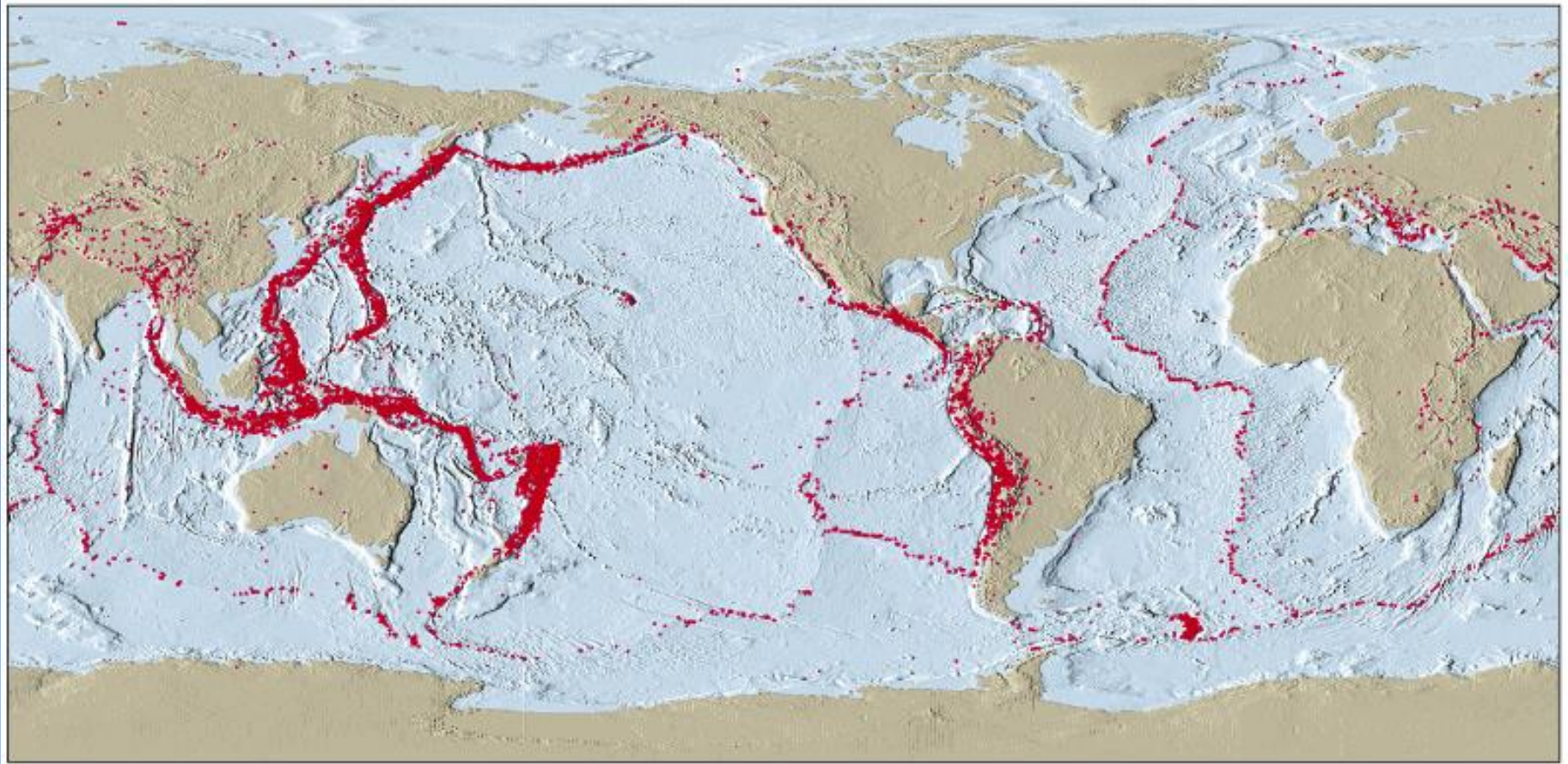
- Types of motion along a fault
 - Creep (no earthquakes)
 - Regular slip (many small earthquakes)
 - Stick-slip
 - Elastic energy is stored for many years
 - Large earthquakes occur when these sections slip
 - Earthquakes occur about every 50 - 200 years
- The San Andreas can serve as an example of all of these:
 - Displacement occurs on separate segments 100 km - 200 km long
 - Various segments show different types of movement

Distribution of earthquakes

- Most earthquakes occur along plate boundaries (>90%)
- Intraplate earthquakes usually occur along ancient weak zones within the crust
 - hot spots
 - New Madrid, Missouri, 1811-1812 7.9
- The USGS estimates over a million quakes occur every day
- Most of these earthquakes are too small to feel
- Deeper earthquakes only occur at subduction zones

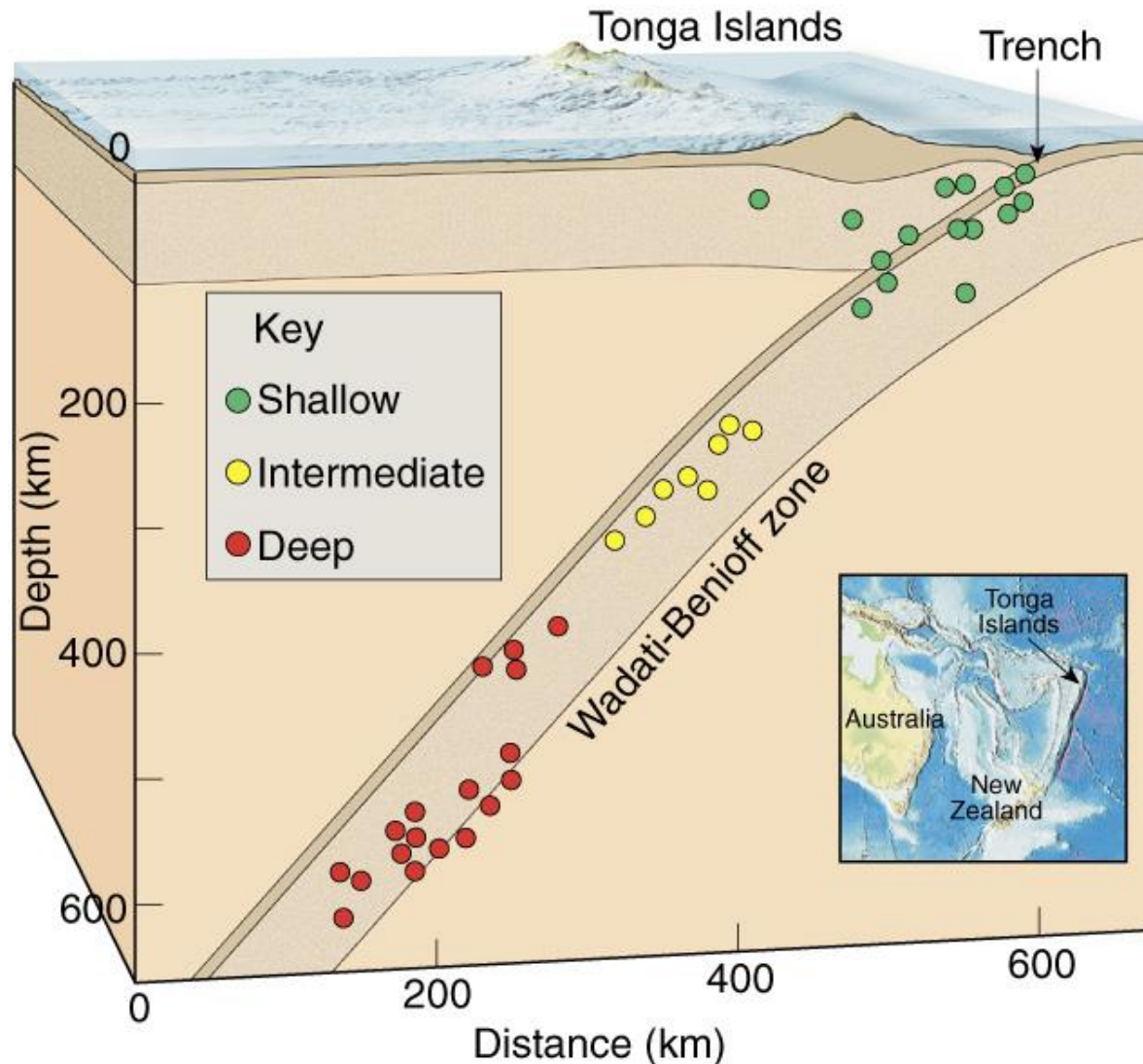
Worldwide distribution of earthquake epicenters 1980-1990

(Richter magnitude >5.0)



Tarback and Lutgens

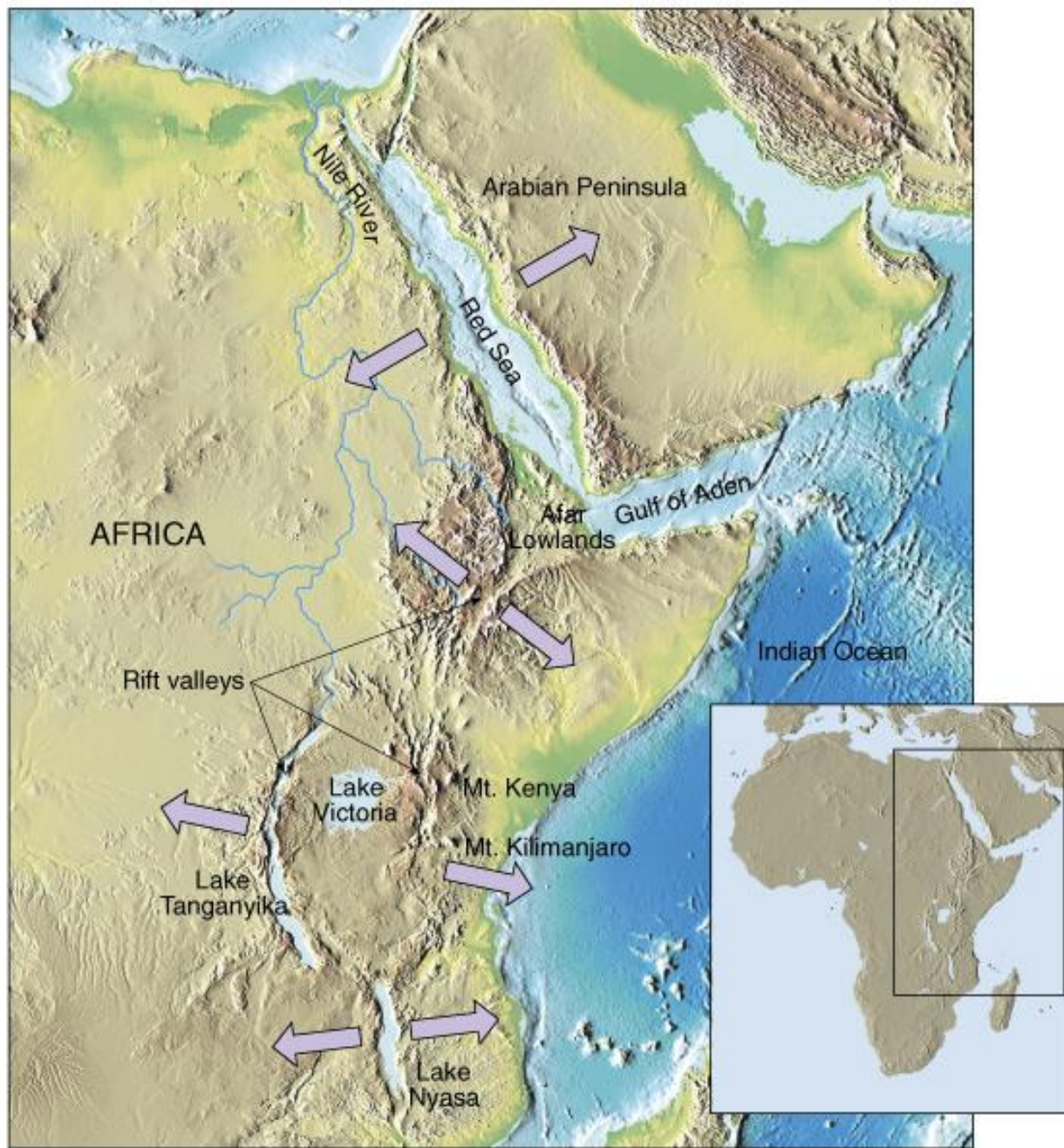
Earthquake distribution along a subduction zone (AKA Benioff zone)

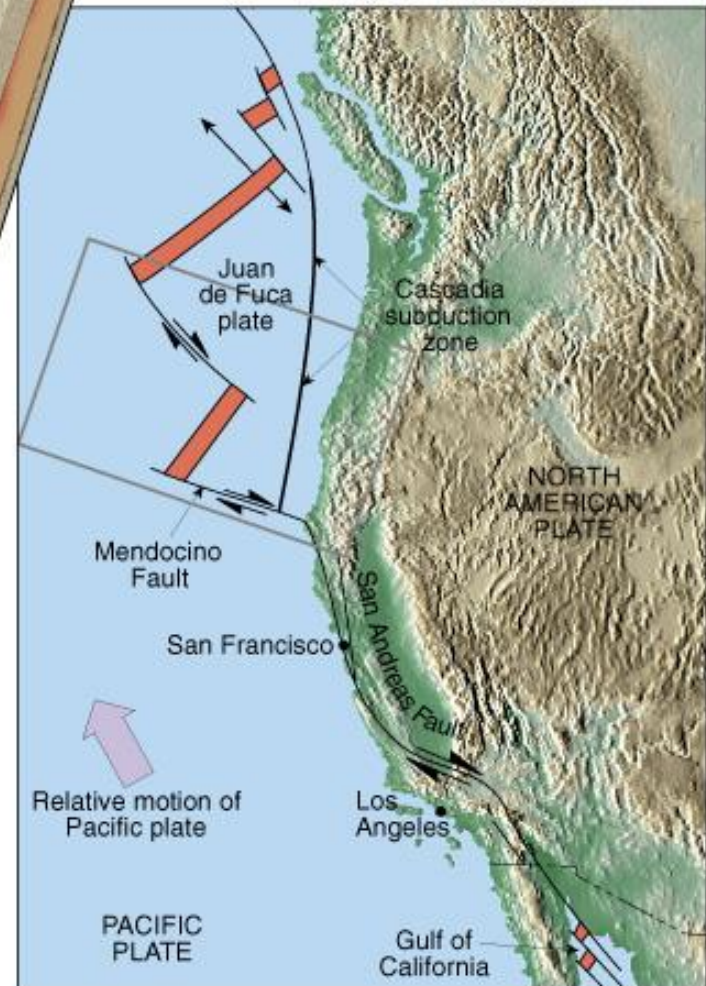
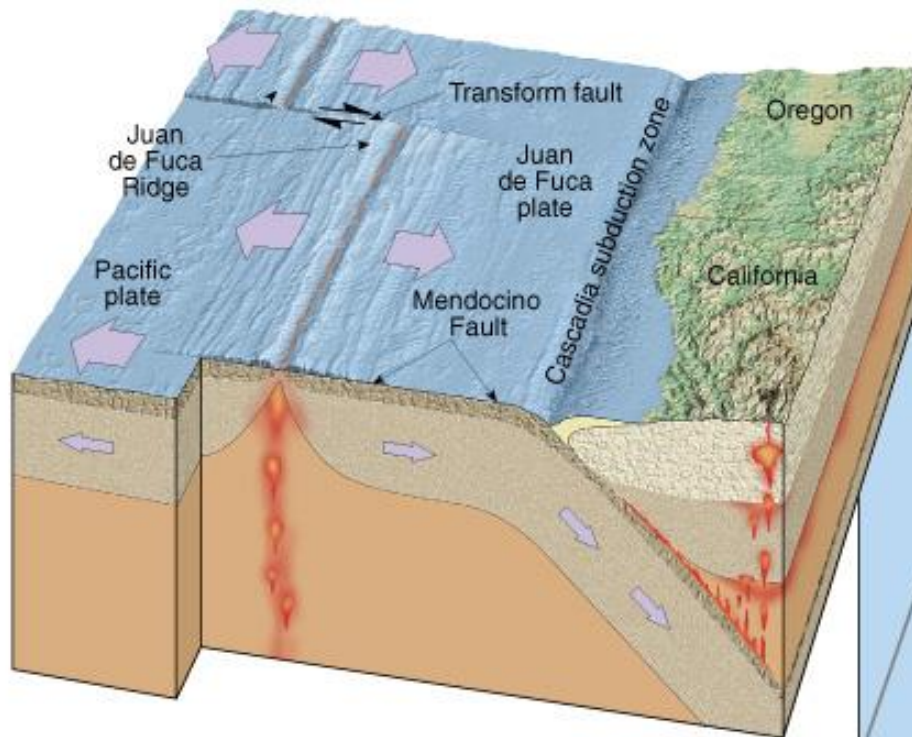


Types of Earthquakes

(plate boundary earthquakes)

- Divergent margins (shallow focus earthquakes)
 - tensional forces / normal faults
 - tend to be associated with less powerful earthquakes
 - East African Rift Valley, Rio Grande Rift (USA)
- Convergent margins (shallow - deep focus earthquakes)
 - compressional forces / reverse faults and thrust faults
 - earth quakes range from weak to very strong
 - volcanic arcs and island arcs ,Pacific northwest.....
- Transform Margins (shallow focus earthquakes)
 - shearing forces (with small areas of tension and extension)
 - associated very powerful earthquakes
 - San Andreas Fault (stick slip versus creep)





Intraplate earthquakes

- Basin and Range earthquakes (shallow focus)
 - part of the Pacific coast tectonic setting (not truly intraplate)
 - medium-strength quakes common, strong quakes possible
 - the entire region is still active
- Mid-continent earthquakes (shallow focus)
 - Usually associated with deep-seated weak zones in the crust
 - some are associated with hot spots
 - can be very strong (New Madrid Missouri, 1811-1812; Charleston S.C. 1886)
- Human-induced earthquakes
 - water (dams and wells)
 - nuclear testing

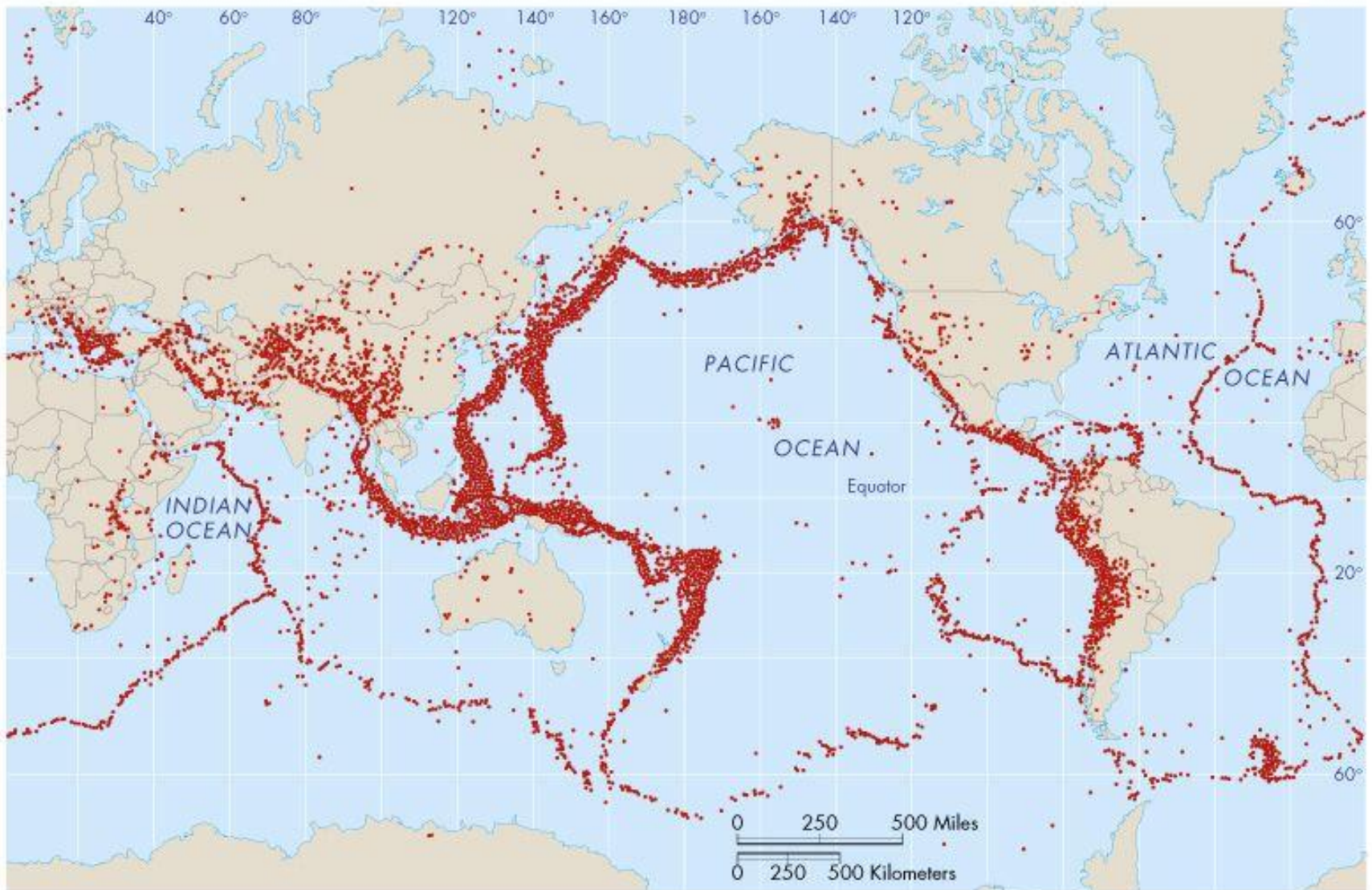
Natural hazards that are closely related to earthquakes

- Tsunamis
 - Waves generated by sudden change in ocean volume
 - Can be generated by earthquakes
- Seiches
 - Waves in lakes, reservoirs or bays created by earthquake
 - Can cause significant damage from flooding and dam failures
- Liquefaction
 - Water-rich soils and clays become liquefied during shaking
 - Many related problems
- Changes in elevation
 - This can be local or regional
 - Ground surface can go up or down
- Landslides
 - Frequently triggered by earthquakes
 - This is a big problem for dams and lakes
- Fires
 - Frequently follow shortly after an earthquake
 - Lots of fuel and ignition sources with no water supply to put them out
- Disease
 - Usually due to sanitation problems

Physiographic Provinces of the Western United States, including the Basin and Range

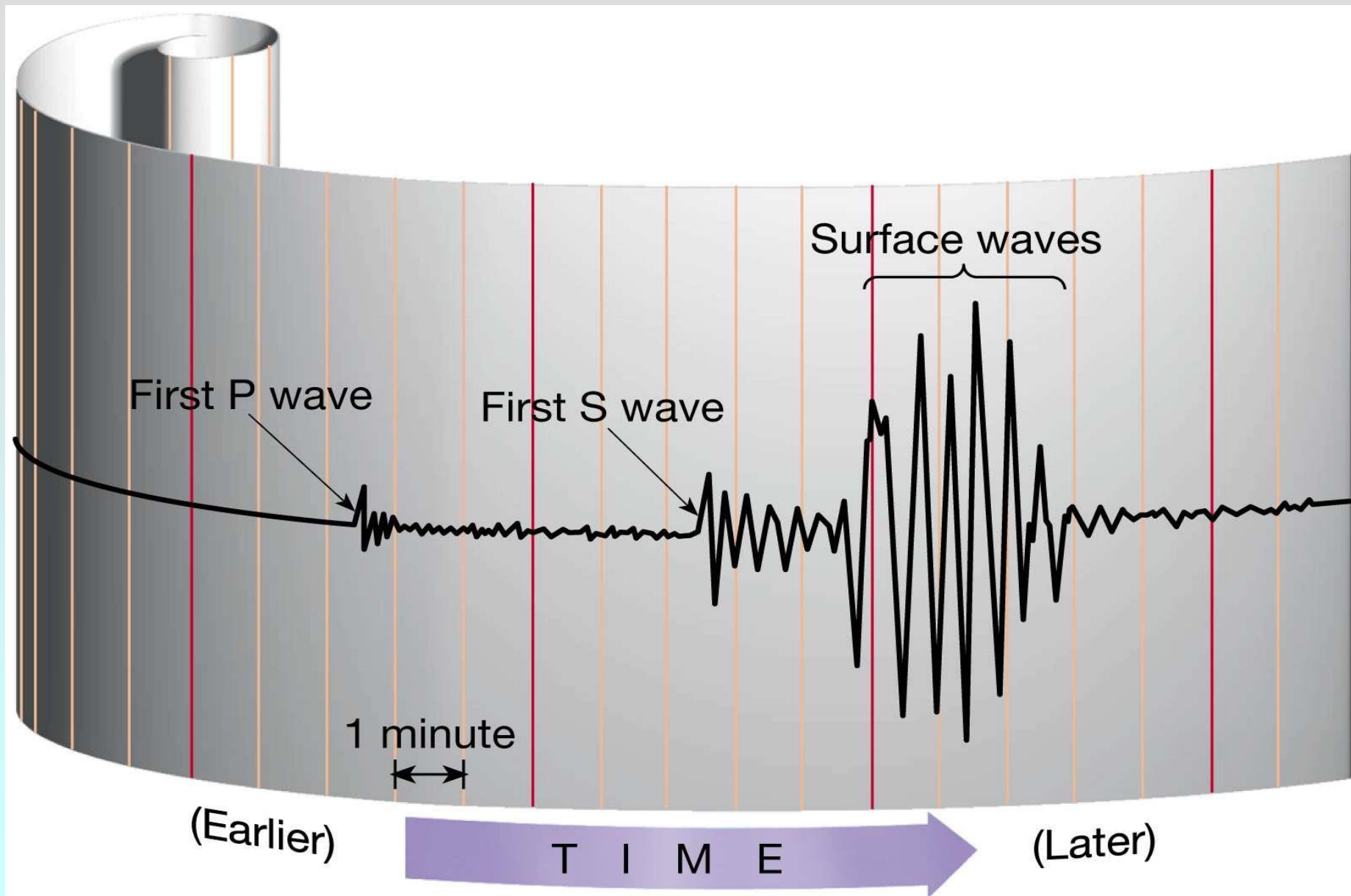


Earthquake distribution



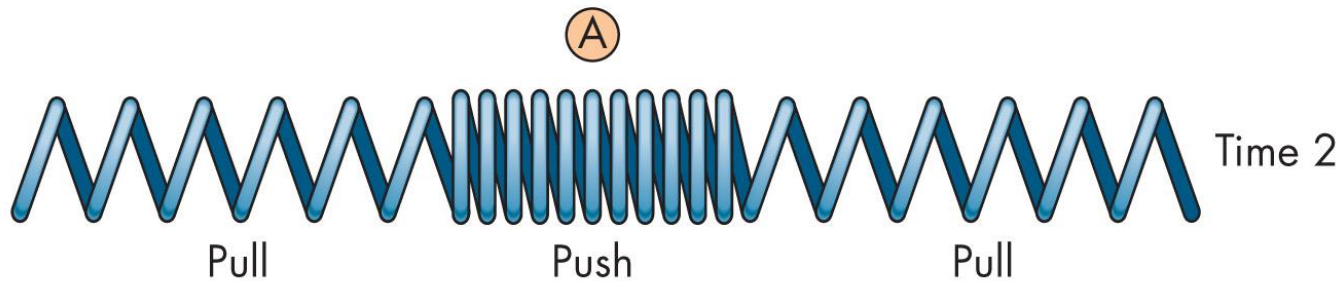
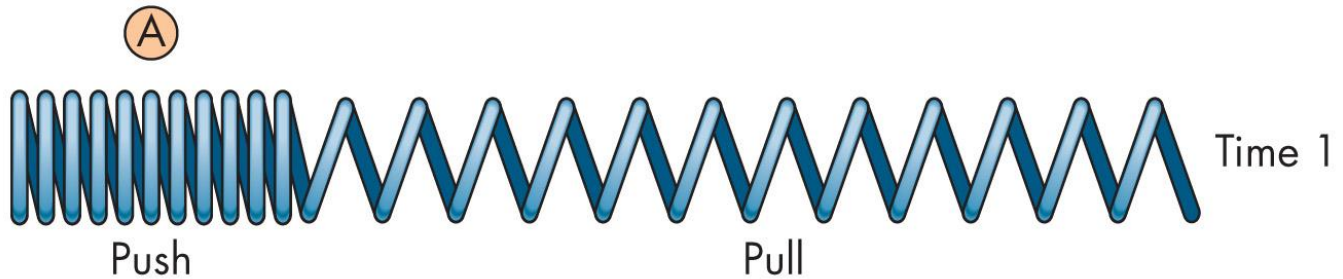
Seismic Waves

- Two basic types
 - Body Waves
 - P-waves (compression, “push-pull waves”, AKA primary wave)
 - S-waves (shearing, AKA secondary wave)
 - Surface waves
 - Love waves (shearing)
 - Rayleigh waves (backwards elliptical motion)
- Surface waves do most of the damage to structures
- P-waves are fastest
- S-waves are next fastest
- Surface waves only travel along surfaces (not through bodies)



P-wave

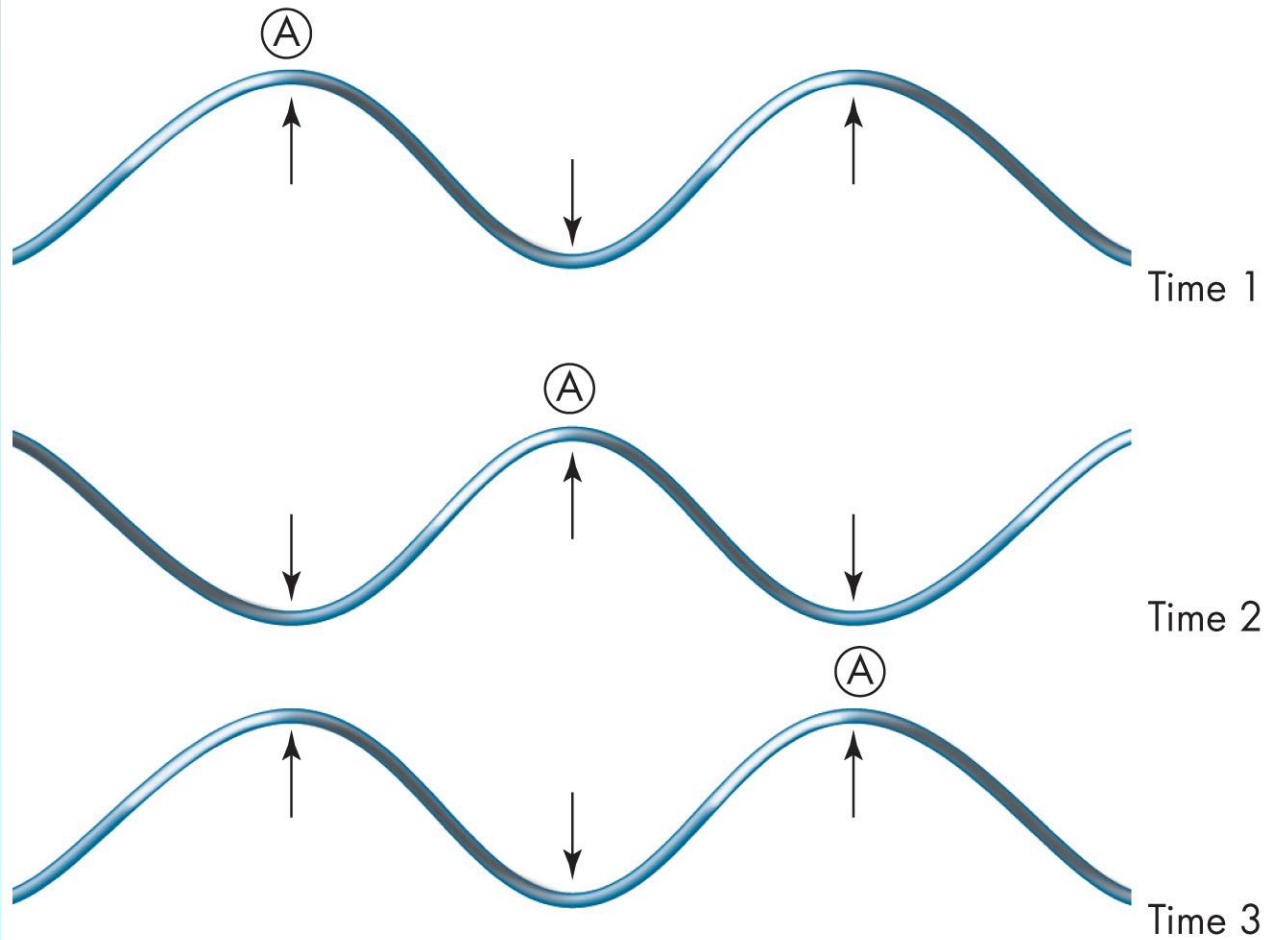
P wave: Direction of propagation 



(a)

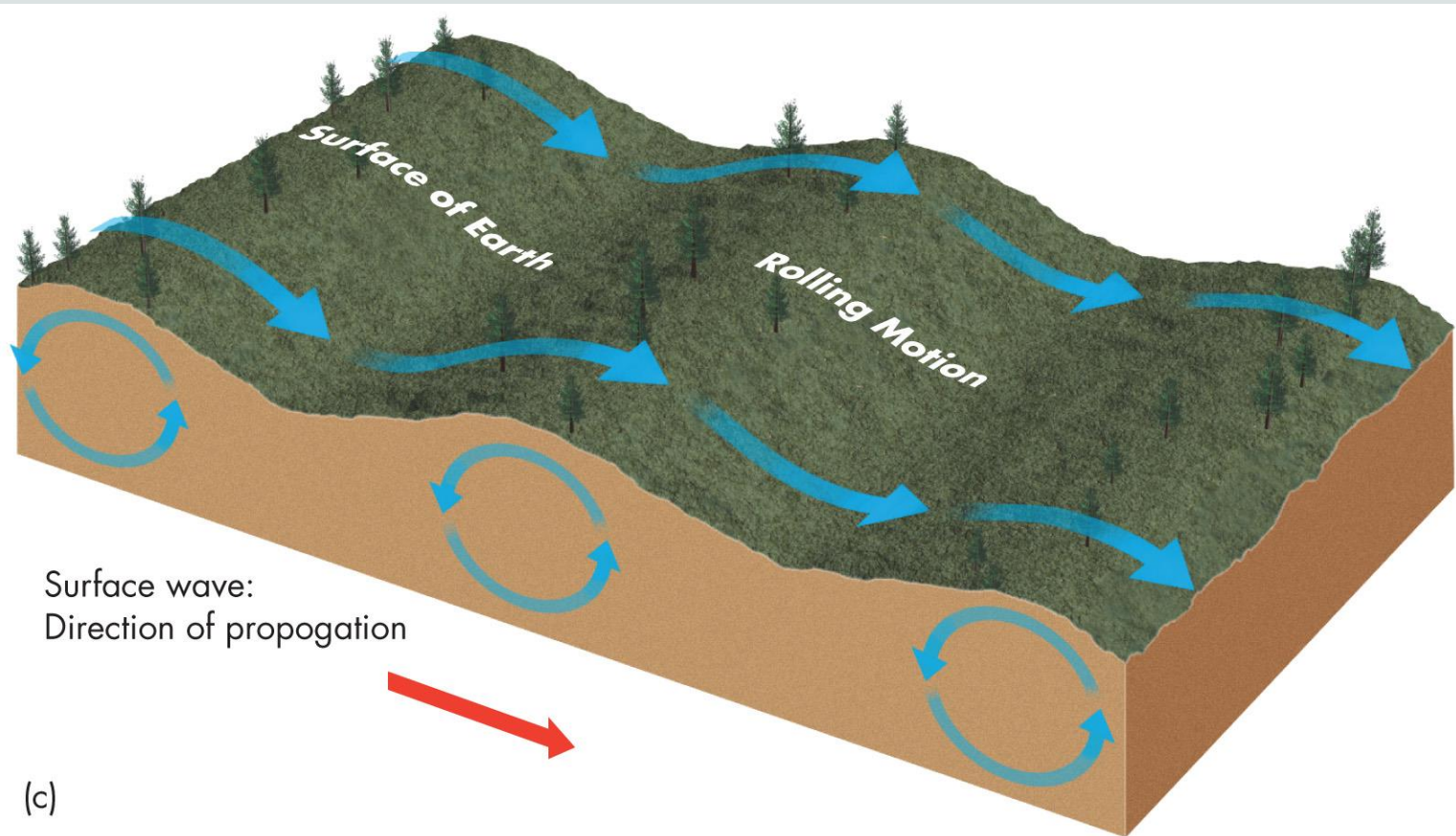
S-wave

S wave: Direction of propagation 



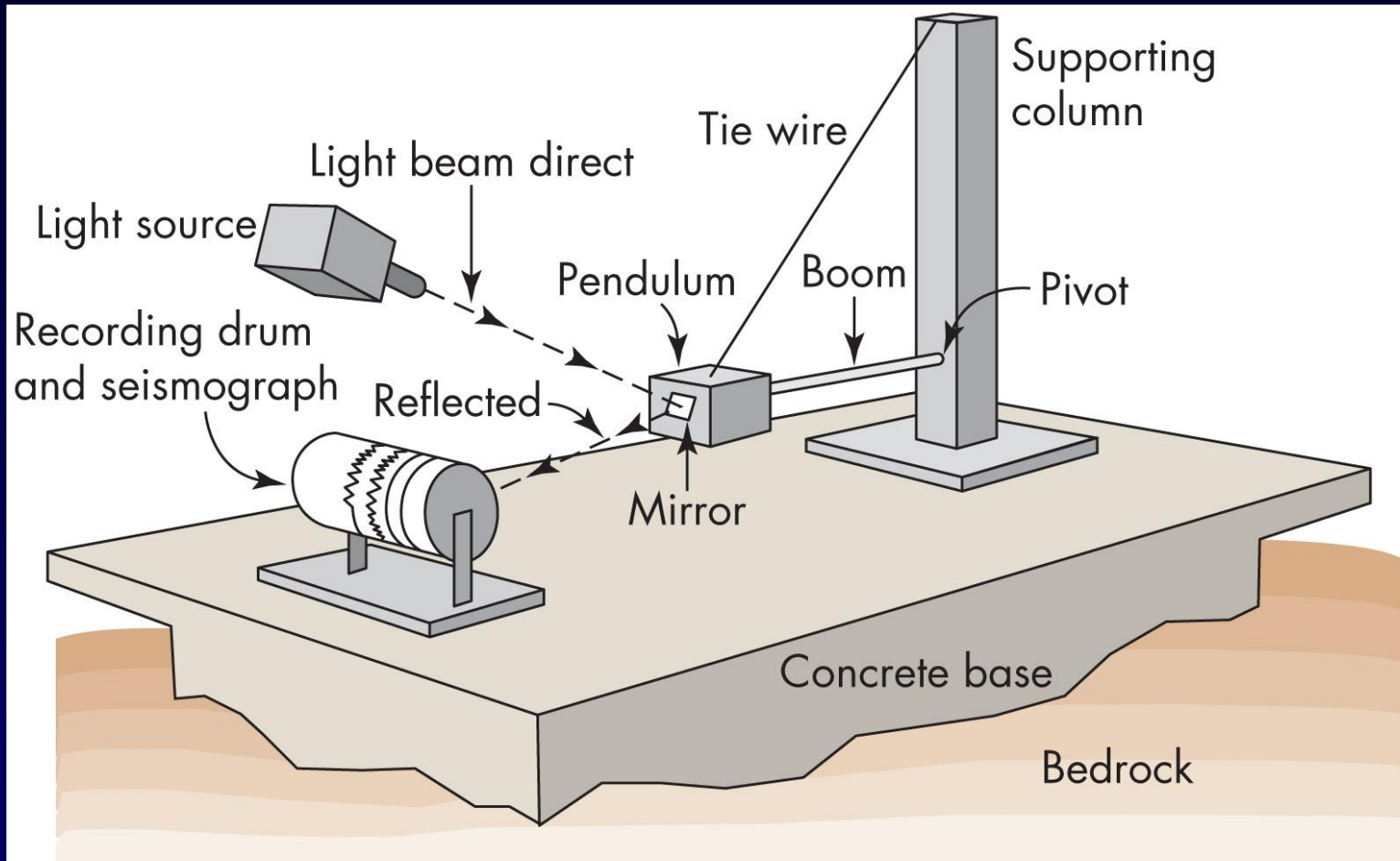
(b)

Surface waves



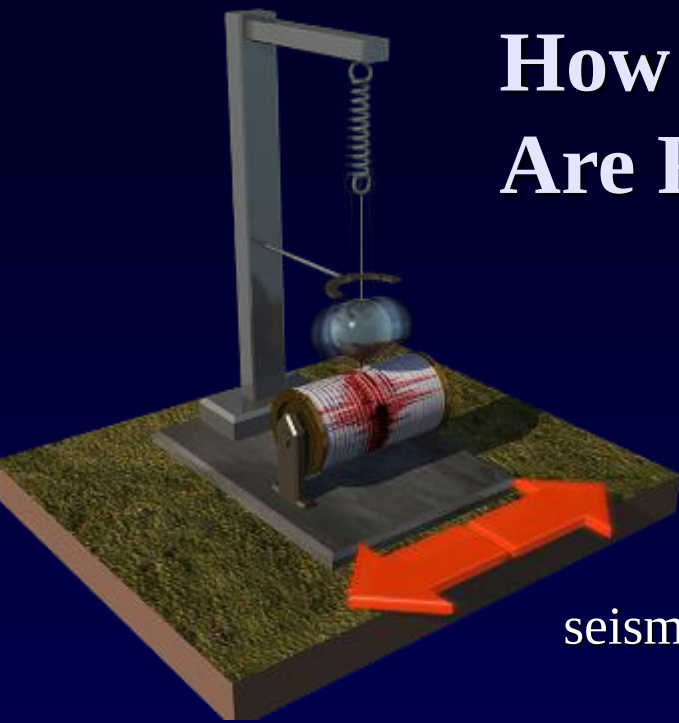
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Seismograph



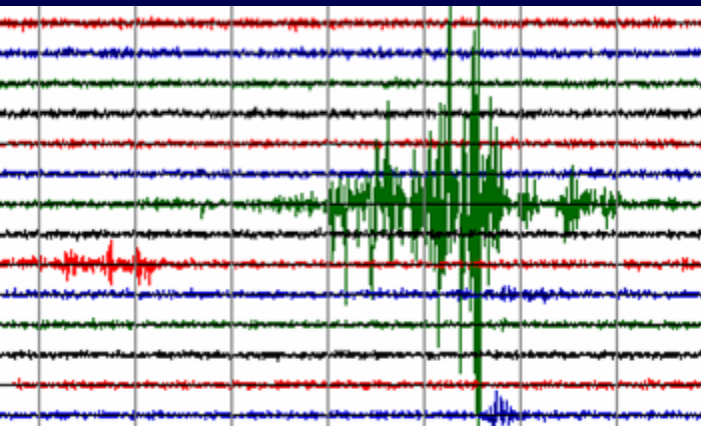
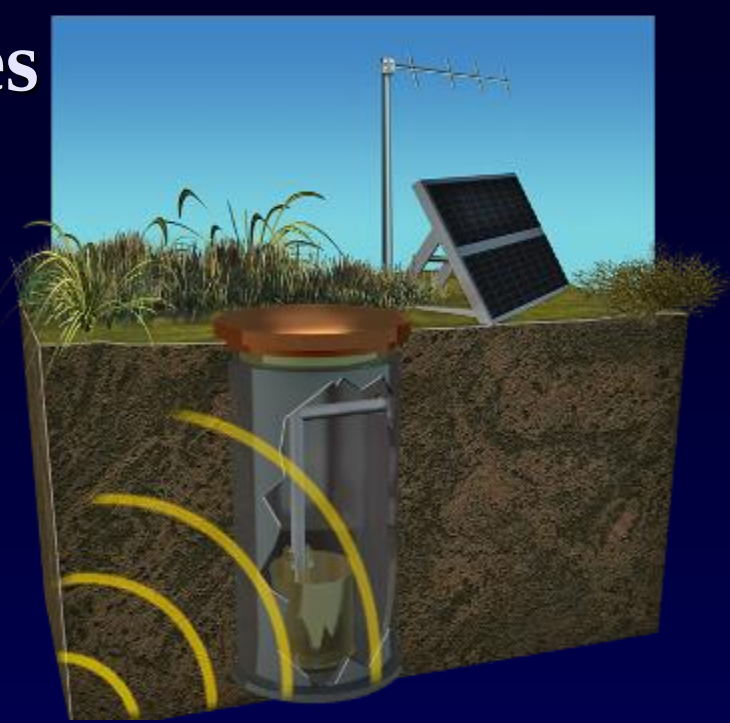
(a)

How Seismic Waves Are Recorded



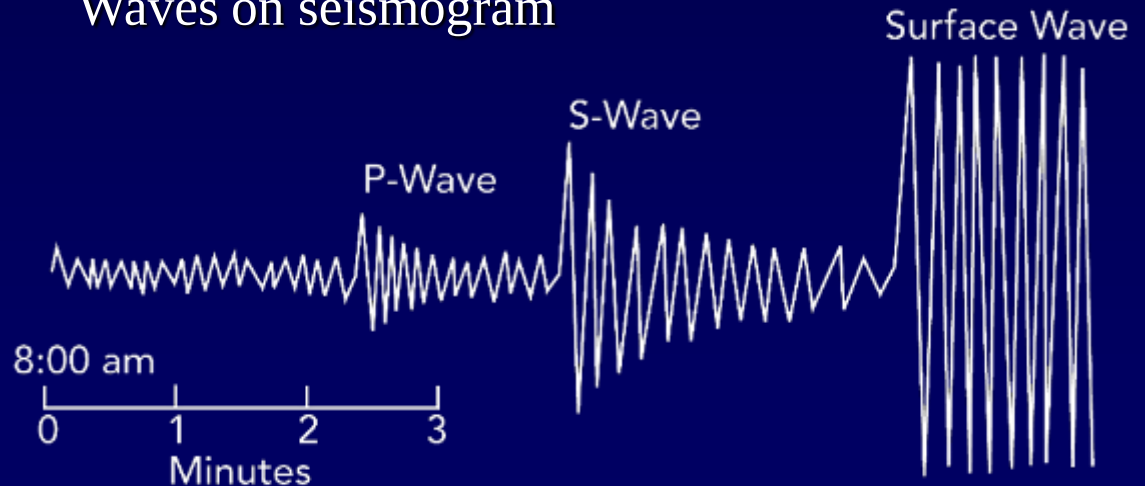
Basic
seismometer

Modern
seismometer



Seismogram

Waves on seismogram



Detecting, measuring, and locating an earthquake

- Seismographs are machines that detect seismic waves
 - need at least three machines/station
- Two common ways to measure an earthquake
 - intensity (local damage)
 - **Modified Mercalli Scale** measures damage
 - sensitive to distance and geology
 - magnitude (total energy released)
 - **Richter Scale** based on wave amplitude
 - not linear (10-fold amplitude increase/step)
 - energy released increase is 32-fold/amplitude step
- Locating an earthquake
 - need three readings from different locations

TABLE 5.4 Modified Mercalli Intensity Scale (abridged)

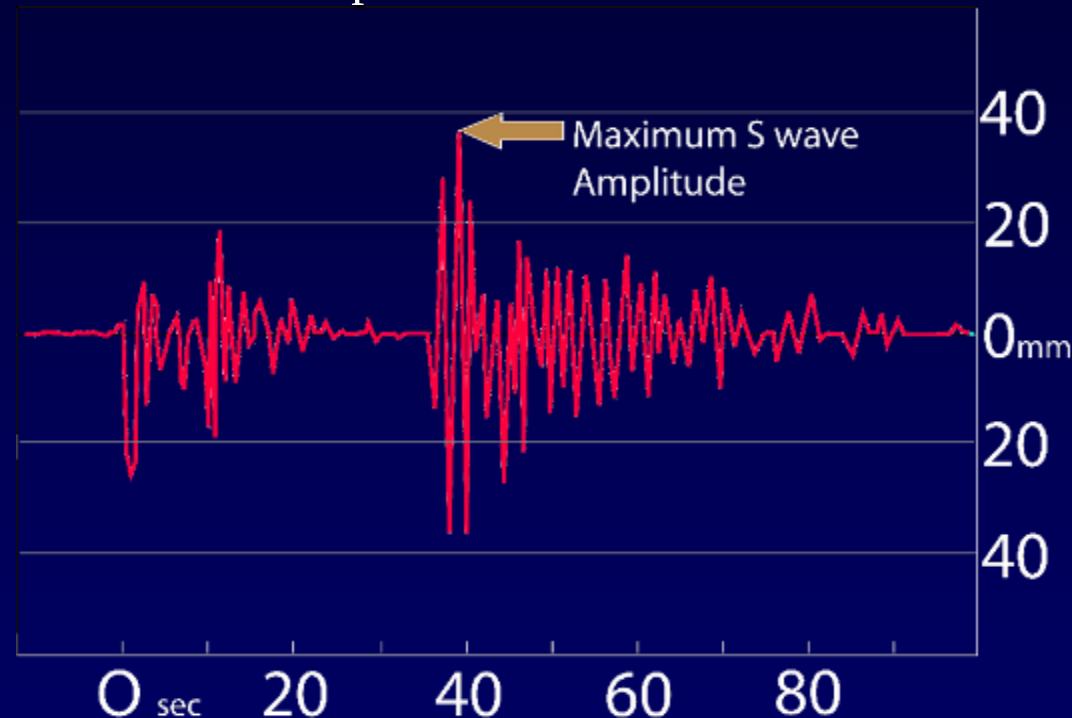
Intensity	Effects
I	Felt by very few people.
II	Felt by only a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration feels like the passing of a truck.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound; sensation like heavy truck striking building; standing motor cars rock noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows, and so on, broken; a few instances of cracked plaster; unstable objects overturned; disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage is slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures; panel walls thrown out of frame structures; fall of chimneys, factory stacks, columns, monuments, walls; heavy furniture overturned; sand and mud ejected in small amounts; changes in well water; disturbs persons driving cars.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings are shifted off foundations. Ground cracked conspicuously. Underground pipes are broken.
X	Some well-built wooden structures are destroyed; most masonry and frame structures with foundations destroyed; ground badly cracked. Rails bent. Landslides considerable from riverbanks and steep slopes. Shifted sand and mud. Water is splashed over banks.
XI	Few, if any (masonry) structures remain standing. Bridges are destroyed. Broad fissures are formed in ground. Underground pipelines are taken out of service. Earth slumps and land slips on soft ground occurs. Train rails are bent.
XII	Damage is total. Waves are seen on ground surfaces. Lines of sight and level distorted. Objects are thrown upward into the air.

TABLE 16.2 Earth Magnitudes and Expected World Incidence

Richter Magnitudes	Effects Near Epicenter	Estimated Number per Year
<2.0	Generally not felt, but recorded.	600,000
2.0–2.9	Potentially perceptible.	300,000
3.0–3.9	Felt by some.	49,000
4.0–4.9	Felt by most.	6200
5.0–5.9	Damaging shocks.	800
6.0–6.9	Destruction in populous regions.	266
7.0–7.9	Major earthquakes. Inflict serious damage.	18
8.0	Great earthquakes. Cause extensive destruction to communities near epicenter.	1.4

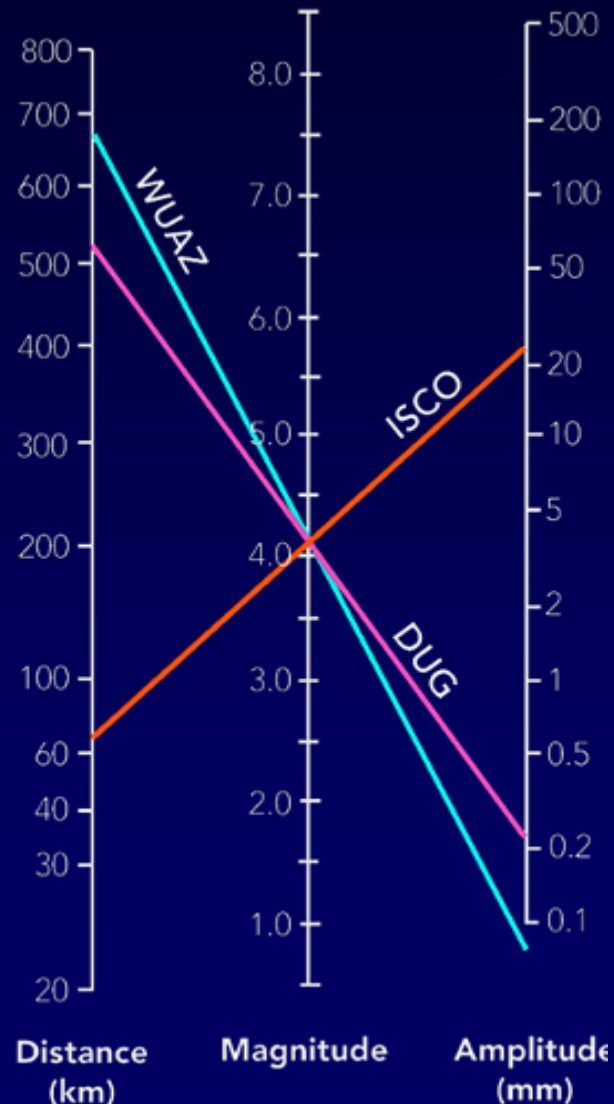
Measuring the Size of an Earthquake

For local magnitude
(Richter): Measure S-
wave amplitude

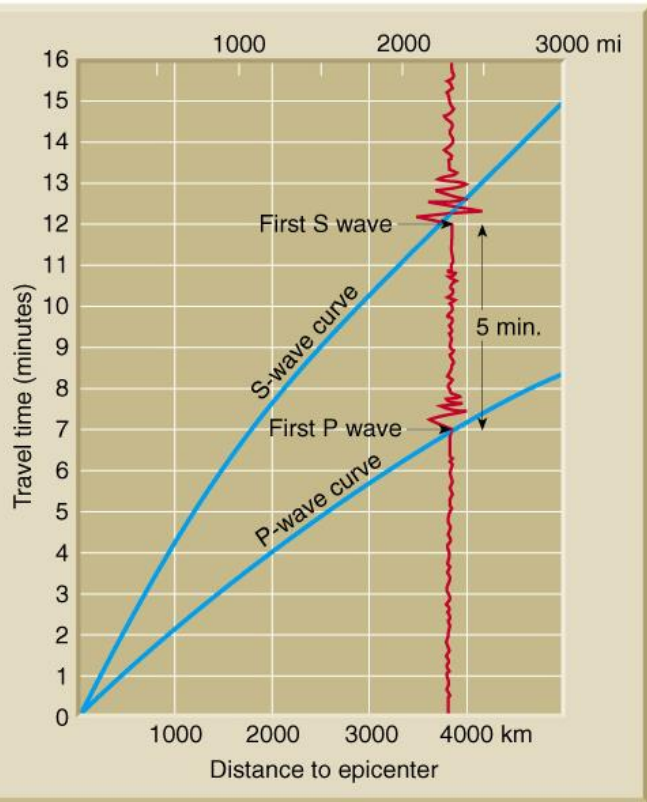


There are other ways we measure the size of
an earthquake

Connect amplitude and
distance on plot



Determining the location of an earthquake epicenter



Factors controlling damage from earthquakes

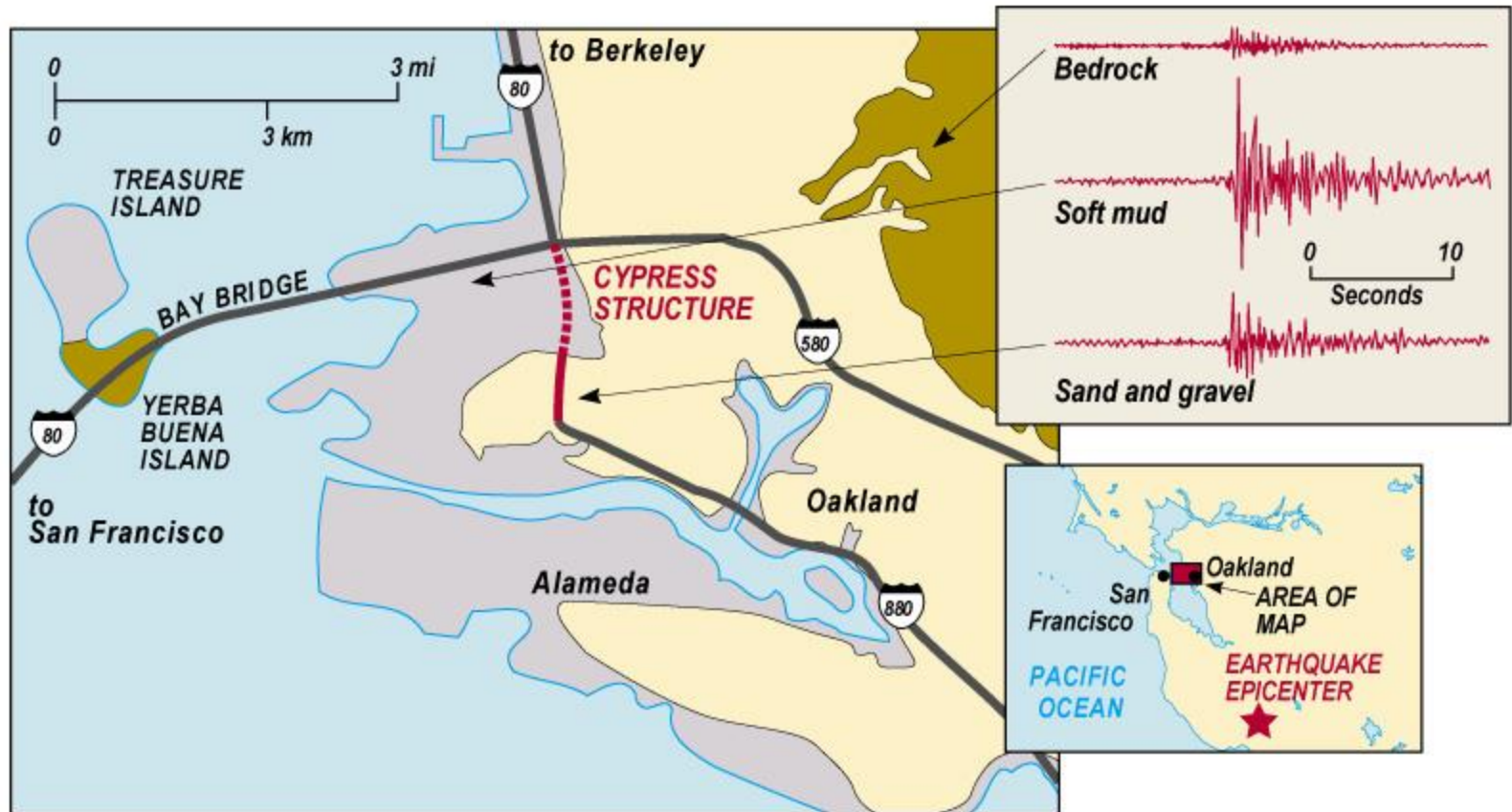
- Geology
 - at the surface and at depth
- Structures,
 - architecture
 - materials
 - density
- Population
 - density
 - distribution
- Utilities
 - distribution network
 - quality/preparedness
- Emergency response plans and aftershocks

Factors that affect shaking during an earthquake

- Earthquake magnitude
 - Generally the larger the magnitude the stronger the shaking
 - Doesn't always hold true (see factors below)
- Distance from the epicenter
 - Usually the closer you are the stronger the shaking
 - This doesn't always hold true because of some of the other factors listed below (ex., Mexico City, 1985)
- Depth to focus
 - Deeper earthquakes generally shake less
 - Again, there are exceptions to this
- Nature of first motion
 - Orientation of first motion (horizontal, vertical, inclined....)
 - Direction of rupture
- Local geology
 - This can be a huge factor (Loma Prieta & Mexico City)
 - Clays and loose material can amplify seismic waves
 - Liquefaction

Direction of rupture and supershears

- The direction of the ground rupture can affect how the energy and shaking from an earthquake are distributed
- Supershears occur when the rupture travels faster than the s-waves (shear waves)
 - This causes s-waves to pile up at the front of the wave and may result in stronger seismic events
 - This phenomenon is often compared to a sonic boom
 - This can explain why some earthquakes cause more damage than other similar earthquakes



Damage from earthquakes

- Buildings, roads and other structures
 - collapse (pancake, pounding,)
 - tilt (fissures, uplift/subsidence, liquefaction)
 - other (facades, ornamentation, chimneys, corner damage)
- Fires
 - broken gas mains + downed electric lines = fires
 - broken water mains + road damage = no fire fighting capacity
- Liquefaction
 - water saturated soil, sand, & clay turns to liquid during quake
 - can cause landslides, structure collapse, & amplification
- Landslides (shaking can trigger landslides)
- Uplift/subsidence (large areas move up or down)
- Tsunami (harbor wave in Japanese, more later)

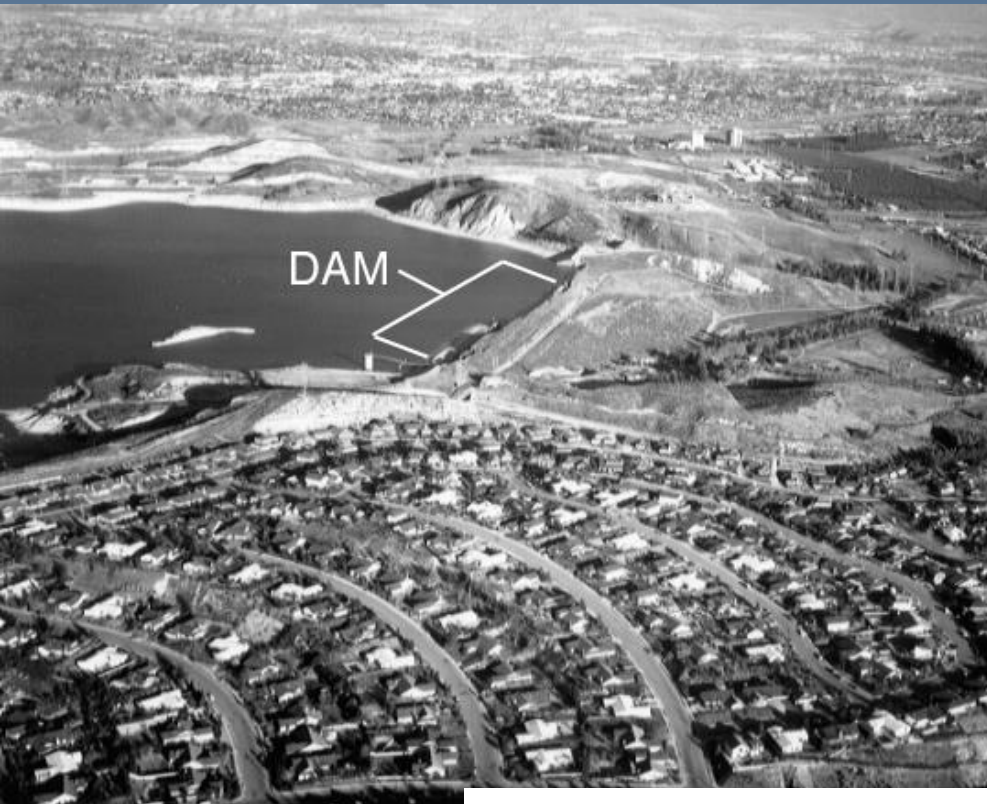
What can you expect during an earthquake

- Eyewitness accounts on the 1st movement from the quake varies from quake to quake
- Apparently the sound varies, but most people report hearing some type of noise
- People notice different things from objects shaking to surface waves
- People report general confusion and hysteria
- Many people report disorientation and shock
- People report difficulty driving and walking

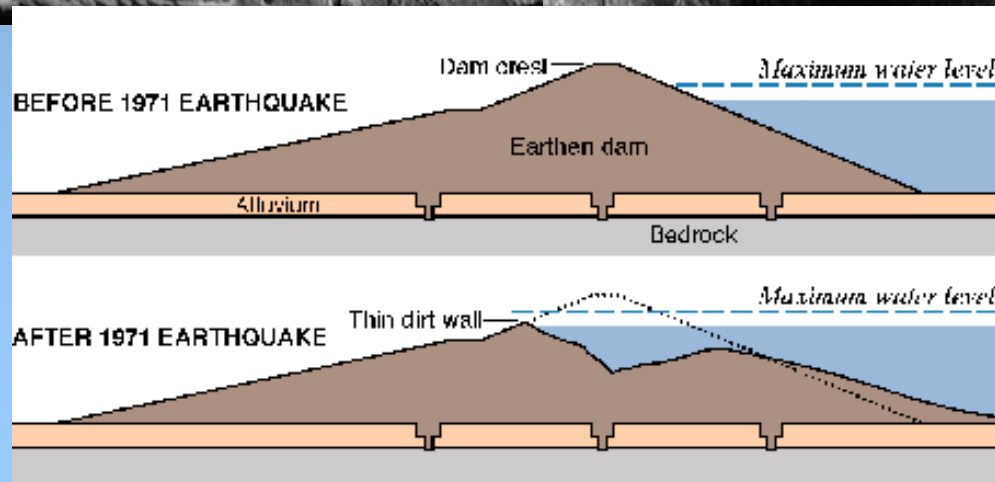
After the earthquake

- No water, electricity, natural gas, sanitation
- No police or firemen (often martial law)
- No fresh food (milk, vegetables, meat)
- Roads are impassible (nobody in or out)
- Aftershocks
- looting, violence, general civil disobediance
- Lots of scam artists
- This may last a few days to many months

San Fernando earthquake 1971, 6.5, near-failure of dam



Large dam
built 1912-1915
130' deep
1.6 miles long
80,000 people
evacuated



Photos & X-sec
USGS

The Mexico City Earthquake of 1985

- September 19, 1985
- The epicenter was located ~30 miles off the coast of Mexico in the Pacific Ocean
- ~109 miles from Mexico City
- 8.1 magnitude
- 7.5 aftershock 36 hours later
- ~10,000 deaths
- Damage due to liquefaction



Mexico City, 1985, 8.1

Top floor collapse due to pounding



C. Arnold, Building Systems Development, Inc.

Mexico City, 1985, 8.1

Liquefaction related building collapse, note pillar and slab construction



Loma Prieta Earthquake, 1989

- “World Series Earthquake”
- September 17, 1989
- 7.1/6.9 magnitude
- 60 miles S-SE of San Francisco
- 66 dead
- \$10 billion in damage



Loma Prieta Earthquake, 1989, 7.1

Typical 1st floor damage to building in San Francisco



Loma Prieta, 1989, 7.1

Small landslide due to earthquake Scott's Valley, CA



Northridge Earthquake, 1994

- January 17, 1994
- \$20 billion in damage
- Occurred on a blind thrust fault
- 57 dead



Damage to bridge, Northridge earthquake, 1994, 6.7



USGS

Northridge, 1994, 6.7

Kaiser Permanente building



M. Celebi, USGS

Northridge 1994, 6.7

2nd view CSU Northridge parking garage built in 1991



M Celebi, USGS

Northridge, 1994, 6.7

Utility failure, gas main fires



An Overview of the San Andreas Fault



The San Andreas near San Francisco

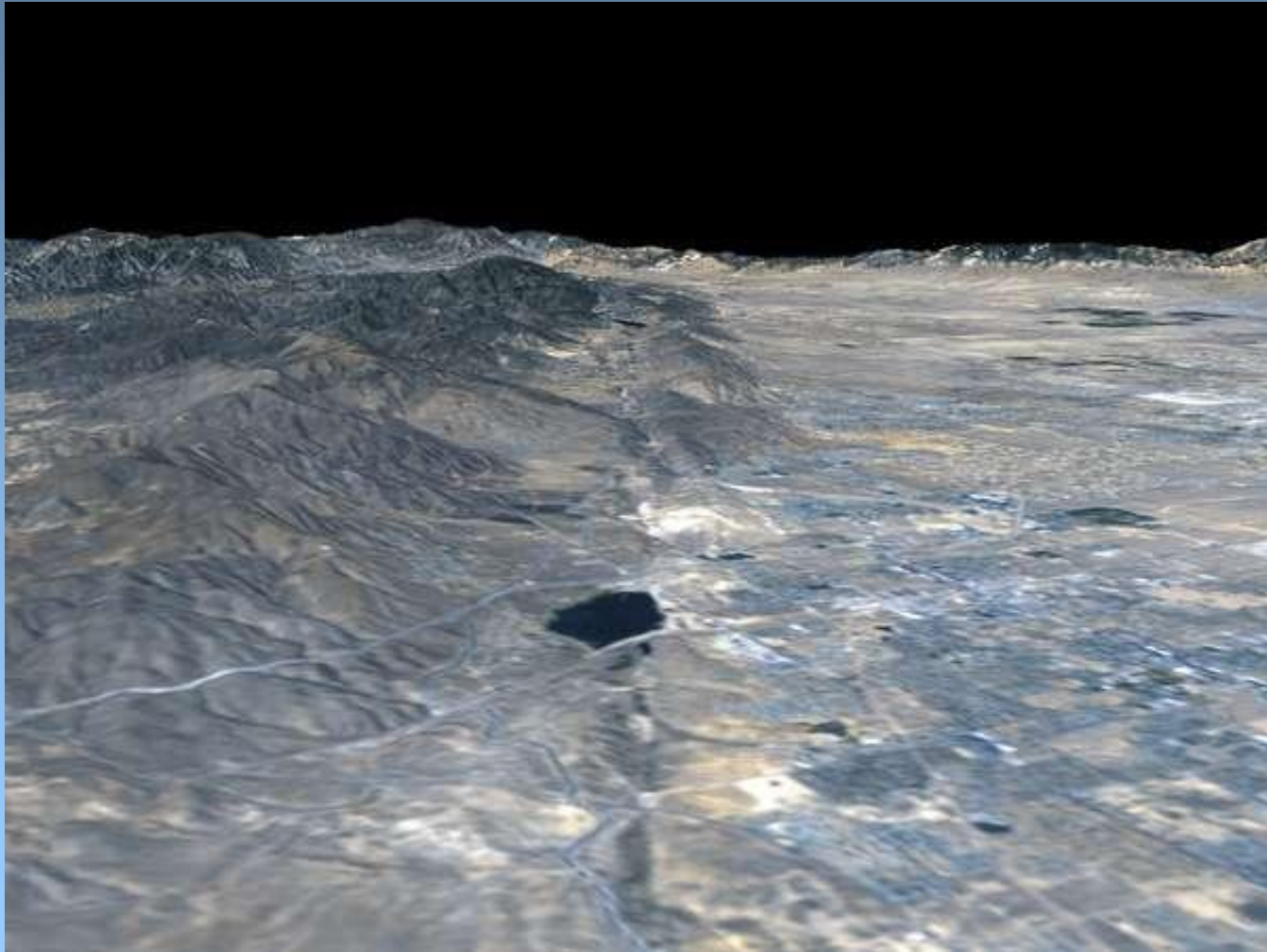


An Aerial Photo
of the
San Andreas
near
San Francisco



Modified Landsat Image of the San Andreas Fault near Palmdale, CA

(view looking from the south towards the north)



Aerial photo of the Palmdale area showing the San Andreas Fault, 1935

(view looking from the north towards the south)



The San Andreas Fault at the Highway 14 Road cut, Palmdale, CA



Earthquake forecasting

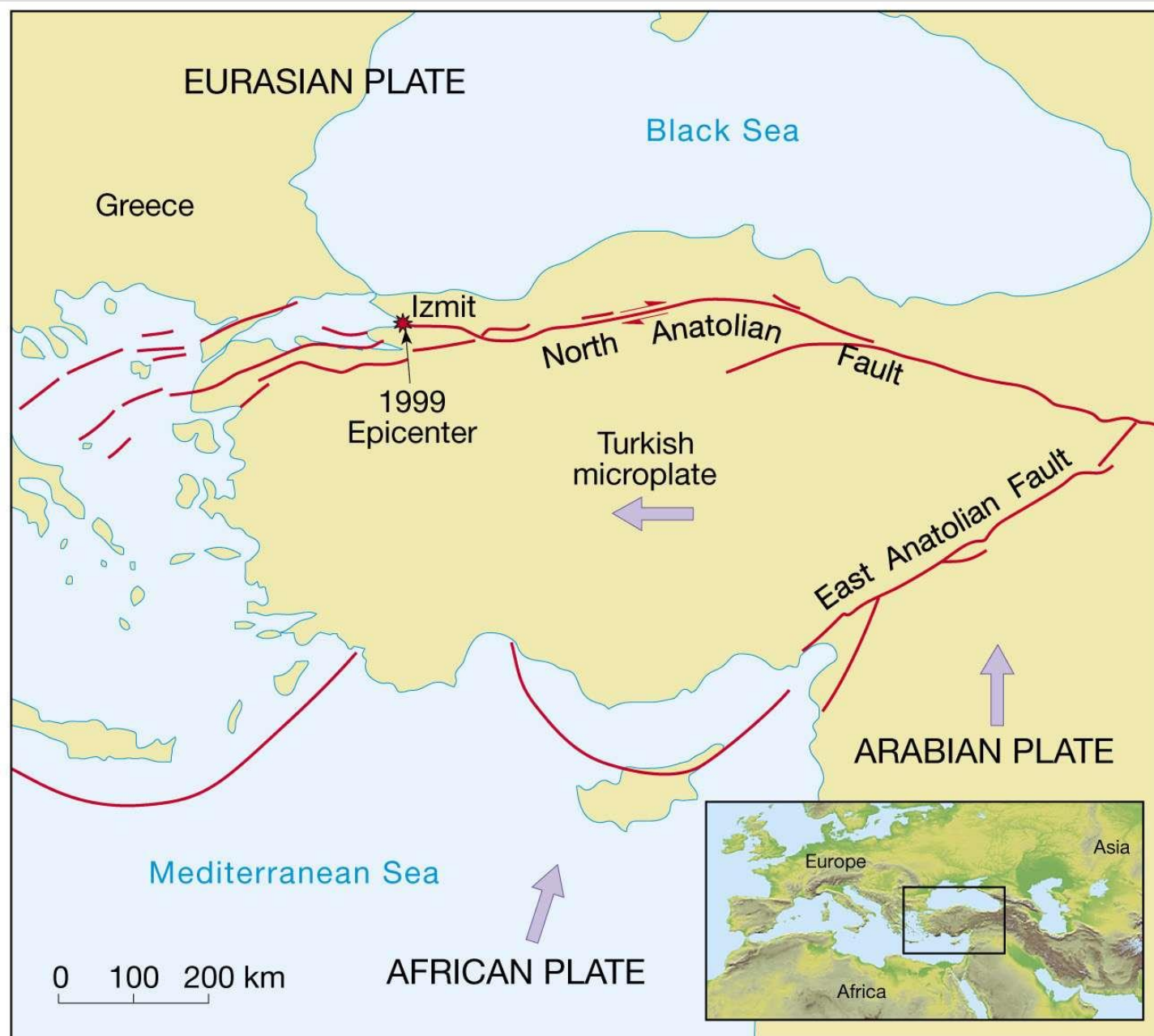
- “young but advancing endeavor”
- Clues to earthquakes
 - Rock changes
 - fractures, strain, conductivity, radon gas...
 - Seismic gaps
 - Animal behavior (China)
 - Statistics (probabilities)
 - Determining historic faulting intervals using sediments

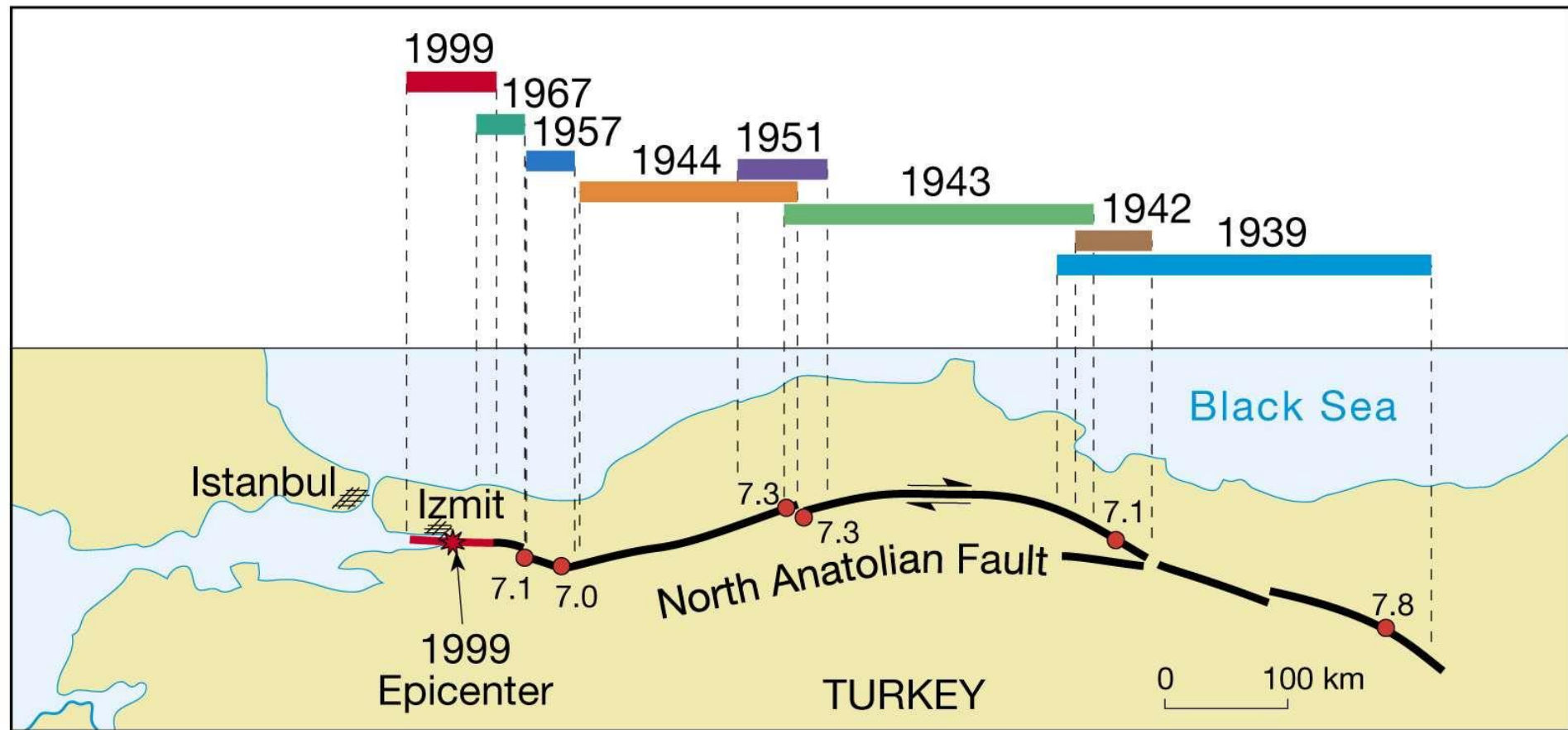
Forecasting versus Prediction

- Similar to weather
 - Forecasts are given as “chance” or probability
 - Based on statistics
 - Prediction gives specific information
 - Based on historical precedent
- Forecasts tend to sound more optimistic
 - Ex. 50% chance of a 7.0 quake in the next 30 years
- Prediction tends to sound more pessimistic
 - Ex. An 8.0 earthquake occurs here every 75 years
- The USGS switched from prediction to forecasting during the Reagan administration (Reagan was from California)
- Seismologists seem to be returning to prediction

Seismic gaps







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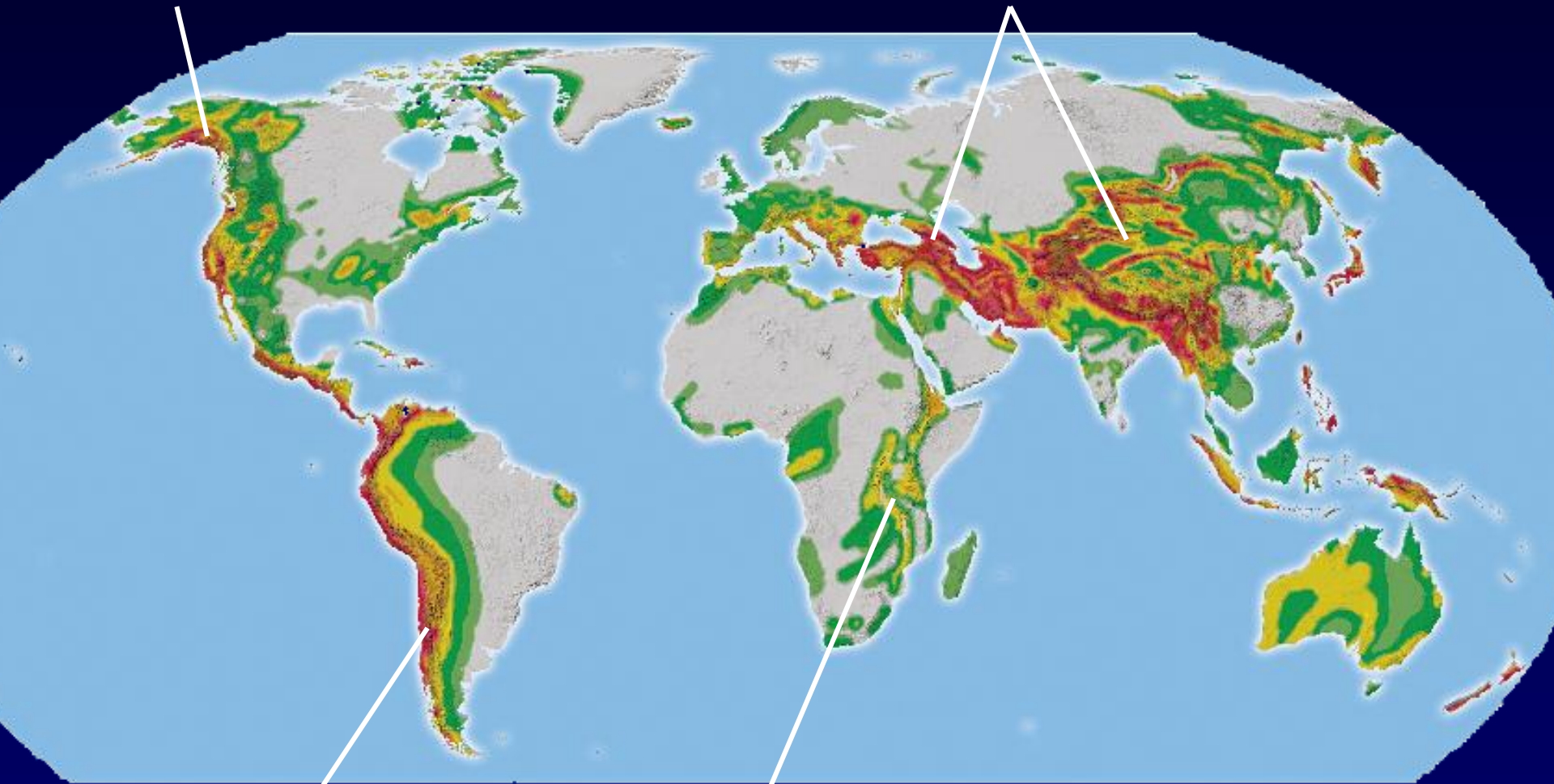
Earthquake probabilities in California 1998-2018



What areas are most likely to experience earthquakes?

Near plate boundaries

Messy collision zones

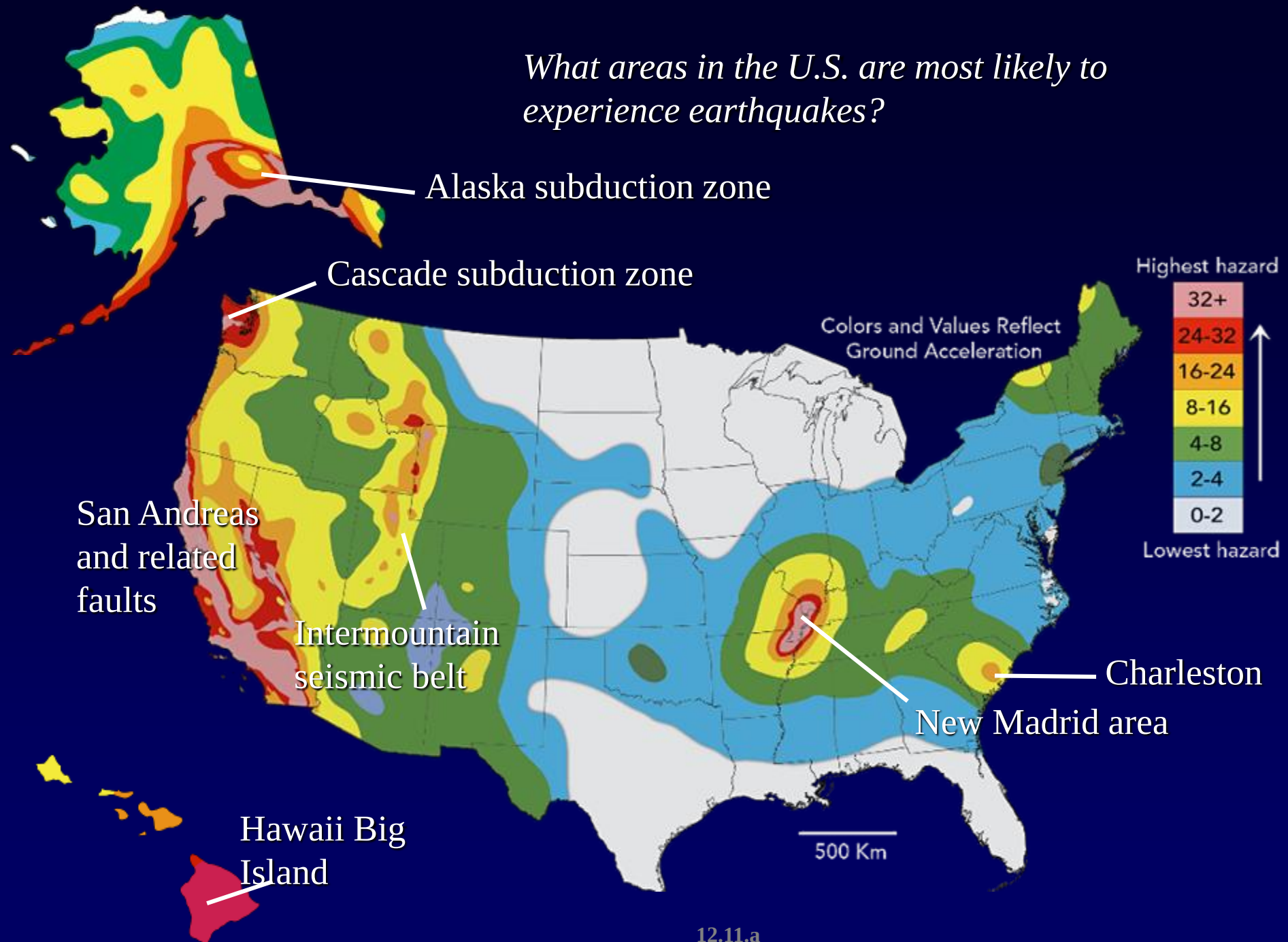


Subduction zones

Continental rifts

12.11.a

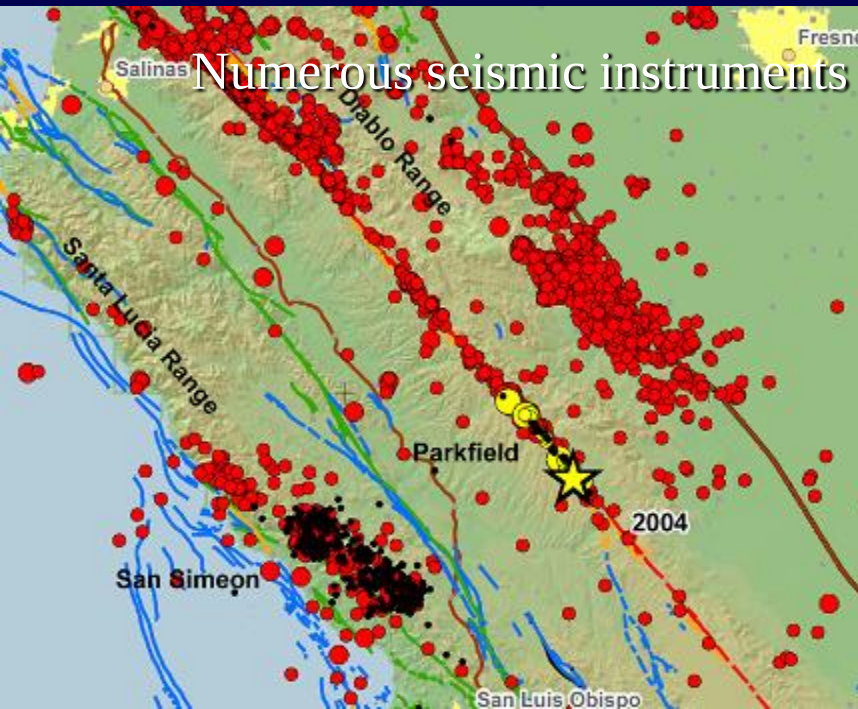
What areas in the U.S. are most likely to experience earthquakes?



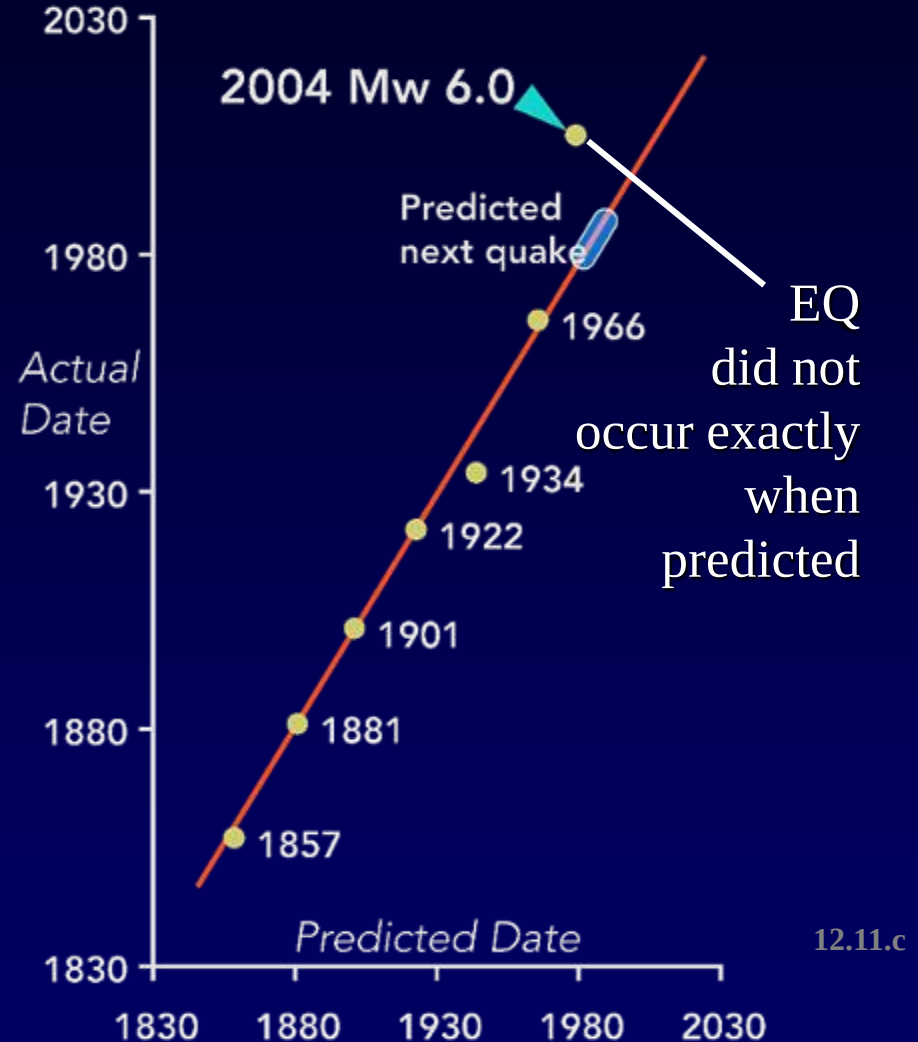
Short-Term Earthquake Prediction



Lasers monitor movement along fault

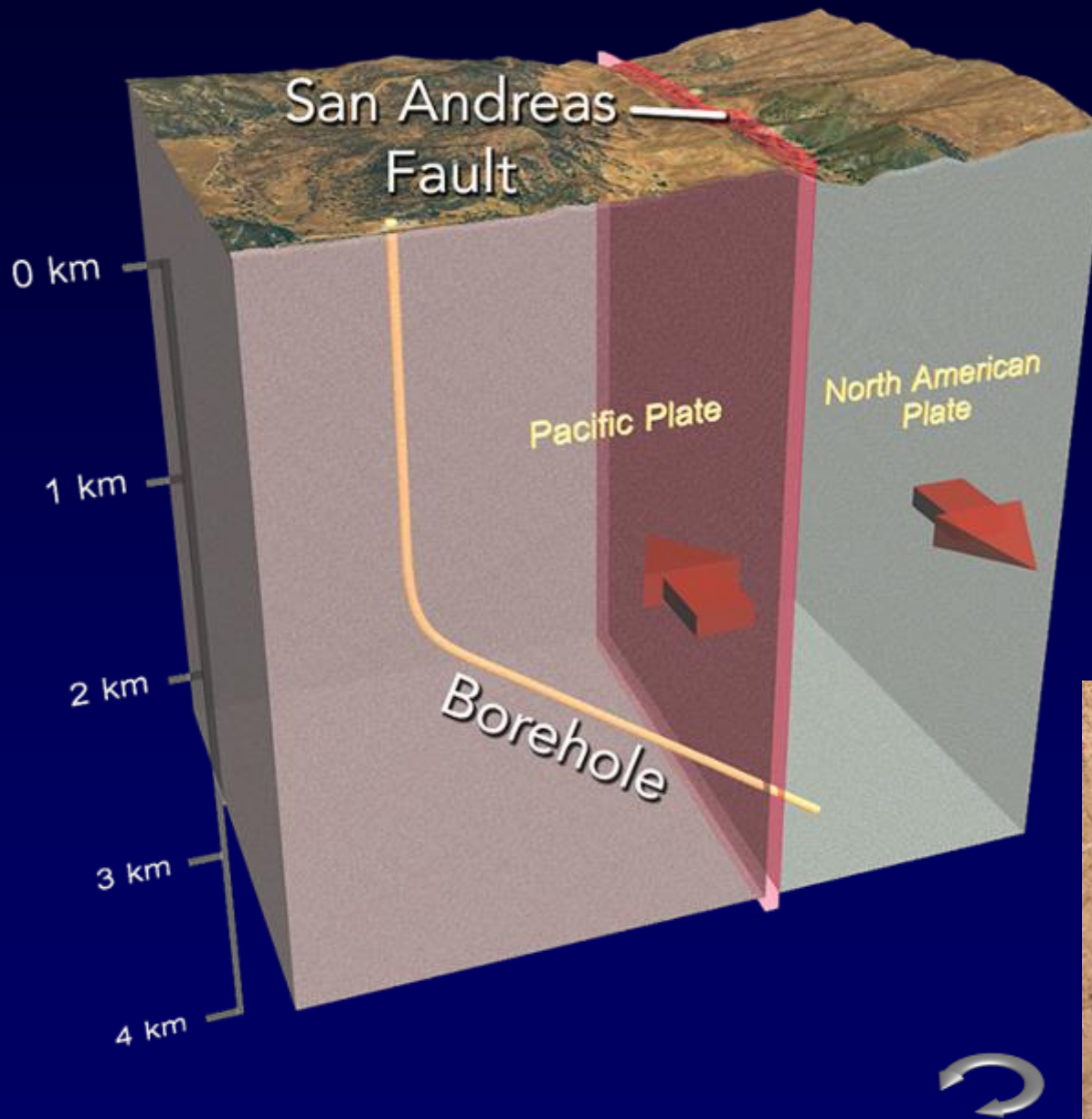


Numerous seismic instruments



Predictions based on past history of Parkfield segment

Studying the San Andreas Fault



Drilled into fault at depth to investigate rocks and conditions

Studies of shallow trenches to document history



Historic Earthquakes

- Help us predict the future
- Help us understand earthquakes
- Show us where big quakes occur
- Show us our mistakes

Most Destructive Known Earthquakes on Record in the World

(50,000 deaths or more)

Date	Location	Deaths	Mag.	Comments
January 23, 1556	China, Shansi	830,000		
July 27, 1976	China, Tangshan	255,000*	8	estimated death toll as high as 655,000.
August 9, 1138	Syria, Aleppo	230,000		
May 22, 1927	China, near Xining	200,000	8.3	Large fractures.
December 22, 856+	Iran, Damghan	200,000		
December 16, 1920	China, Gansu	200,000	8.6	Major fractures, landslides.
March 23, 893+	Iran, Ardabil	150,000		
September 1, 1923	Japan, Kwantō	143,000	8.3	Great Tokyo fire.
December 28, 1908	Italy, Messina	70,000-100,000	7.5	Deaths from earthquake and tsunami.
September, 1290	China, Chihli	100,000		
November, 1667	Caucasia, Shemakha	80,000		
November 18, 1727	Iran, Tabriz	77,000		
November 1, 1755	Portugal, Lisbon	70,000	8.7	Great tsunami.
December 25, 1932	China, Gansu	70,000	7.6	
May 31, 1970	Peru	66,000	7.8	\$530,000 damage, great rock slide, floods.
1268	Asia Minor, Silicia	60,000		
January 11, 1693	Italy, Sicily	60,000		
May 30, 1935	Pakistan, Quetta	30,000-60,000	7.5	Quetta almost completely destroyed.
February 4, 1783	Italy, Calabria	50,000		
June 20, 1990	Iran	50,000	7.7	Landslides.

* Official casualty figure

+ Note that these dates are prior to 1000 AD. No digit is missing.

USGS (Data compiled from several sources.)

THE TEN LARGEST EARTHQUAKES IN THE UNITED STATES

#	Mag	Date	Location
1	9.2	March 28, 1964	Prince William Sound, Alaska
2	8.8	March 9, 1957	Andreanof Islands, Alaska
3	8.7	February 4, 1965	Rat Islands, Alaska
4	8.3	November 10, 1938	East of Shumagin Islands, Alaska
4	8.3	July 10, 1958	Lituya Bay, Alaska
6	8.2	September 10, 1899	Yakutat Bay, Alaska
6	8.2	September 4, 1899	near Cape Yakataga, Alaska
8	8	May 7, 1986	Andreanof Islands, Alaska
9	7.9	February 7, 1812	New Madrid, Missouri
9	7.9	January 9, 1857	Fort Tejon, California
9	7.9	April 3, 1868	Ka'u District, Island of Hawaii
9	7.9	October 9, 1900	Kodiak Island, Alaska
9	7.9	November 30, 1987	Gulf of Alaska

The Ten Largest Earthquakes In The Contiguous United States

#	Mag	Date	Location
1	7.9	February 7, 1812	New Madrid, Missouri
	7.9	January 9, 1857	Fort Tejon, California *
3	7.8	March 26, 1872	Owens Valley, California *
	7.8	February 24, 1892	Imperial Valley, California *
5	7.7	December 16, 1811	New Madrid, Missouri area
	7.7	April 18, 1906	San Francisco, California *
	7.7	October 3, 1915	Pleasant Valley, Nevada
8	7.6	January 23, 1812	New Madrid, Missouri
9	7.5	July 21, 1952	Kern County, California *
10	7.3	November 4, 1927	West of Lompoc, California
	7.3	December 16, 1954	Dixie Valley, Nevada
	7.3	August 18, 1959	Hebgen Lake, Montana
	7.3	October 28, 1983	Borah Peak, Idaho

* = probably related to the San Andreas Fault system

Data from the USGS

Mitigation

Mitigation is a buzzword used by people working in the field of hazard loss reduction. Mitigation is defined as "any action taken to permanently eliminate or reduce the long-term risk to human life, property, and function from hazards" (Mitigation, 10/97).

- Education
- Building codes
- Zoning
- Prediction & evacuation
- Prevention (fluid injection??)
- Government & individual preparation
 - Supplies & planning