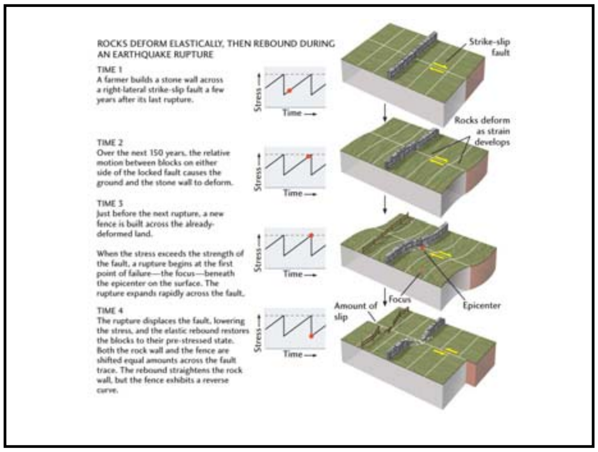
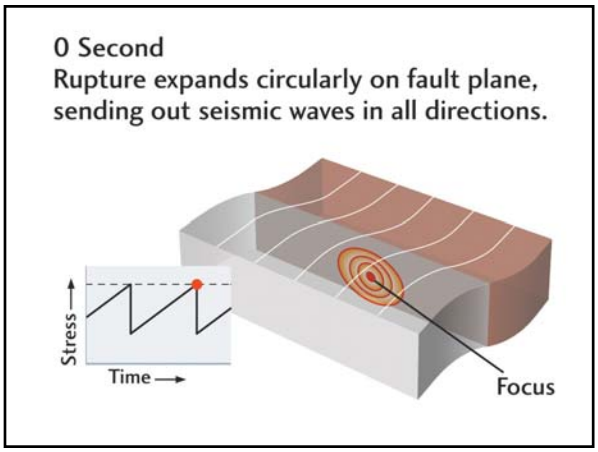
Earthquakes

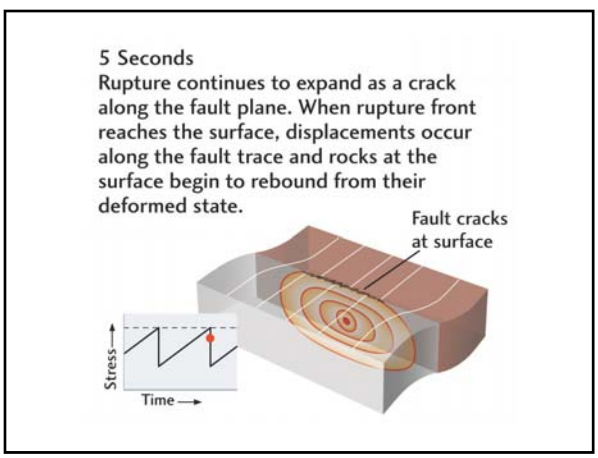
- **earthquake:** movement of rock bodies past other
- **fault:** locus of the earthquake movement
- faults come at all scales, mm to separation of lithospheric plates (*e.g.*, San Andreas).

Elastic Rebound

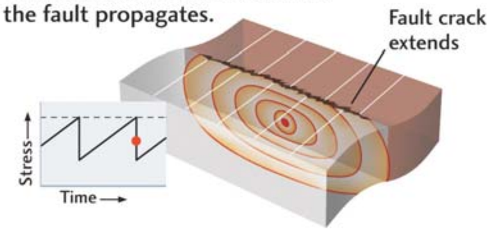
- Stress builds up in rocks until it exceeds the strength of rock
- Elastic deformation is expressed in rocks between earthquakes


ROCKS DEFORM ELASTICALLY, THEN REBOUND DURING AN EARTHQUAKE RUPTURE
TIME 1
A farmer builds a stone wall across a right-lateral strike-slip fault a few years after its last rupture.
TIME 2
Over the next 150 years, the relative motion between blocks on either side of the locked fault causes the ground and the stone wall to deform.
TIME 3
Just before the next rupture, a new fence is built across the already-deformed land.
When the stress exceeds the strength of the fault, a rupture begins at the first point of failure—the focus—beneath the epicenter on the surface. The rupture expands rapidly across the fault.
TIME 4
The rupture displaces the fault, lowering the stress, and the elastic rebound restores the blocks to their pre-stressed state. Both the rock wall and the fence are shifted equal amounts across the fault trace. The rebound straightens the rock wall, but the fence exhibits a reverse curve.
Stress
Time
Strike-slip fault
Rocks deform as strain develops
Focus
Epicenter
Amount of slip

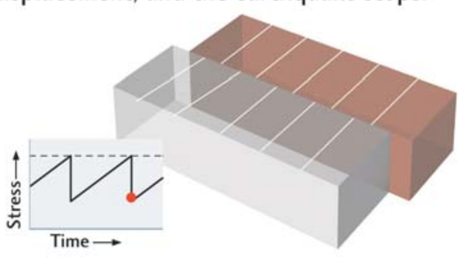

0 Second
Rupture expands circularly on fault plane, sending out seismic waves in all directions.
Stress
Time
Focus


5 Seconds
Rupture continues to expand as a crack along the fault plane. When rupture front reaches the surface, displacements occur along the fault trace and rocks at the surface begin to rebound from their deformed state.
Fault cracks at surface
Stress
Time

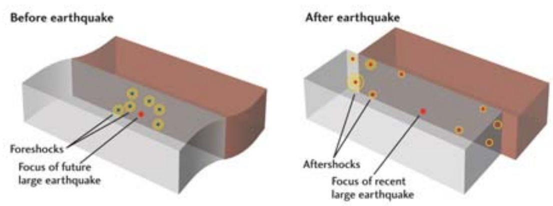
10 Seconds
Rupture front progresses down the fault plane, reducing the stress and allowing rocks on either side to rebound. Seismic waves continue to be emitted in all directions as the fault propagates.



20 Seconds
Rupture has progressed along the entire length of the fault. The fault has reached its maximum displacement, and the earthquake stops.



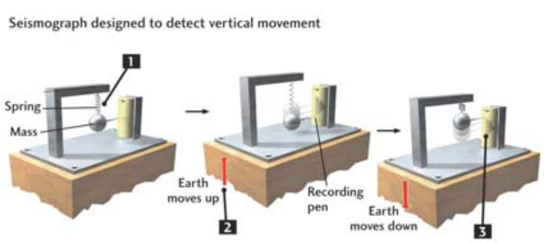
A fence built across the San Andreas fault near Bolinas, California, is offset by nearly 3 m after the great San Francisco earthquake

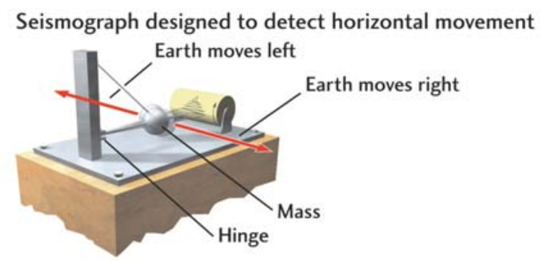


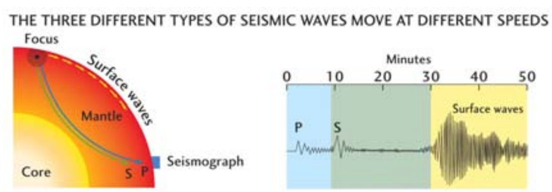
Earthquake terms

focus: site of initial rupture

epicenter: point on surface above the focus

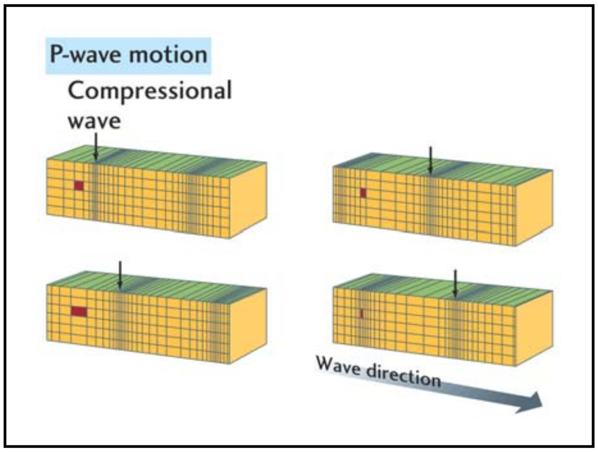


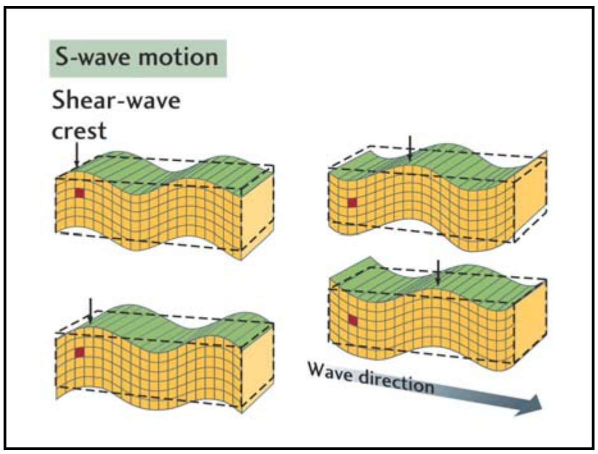


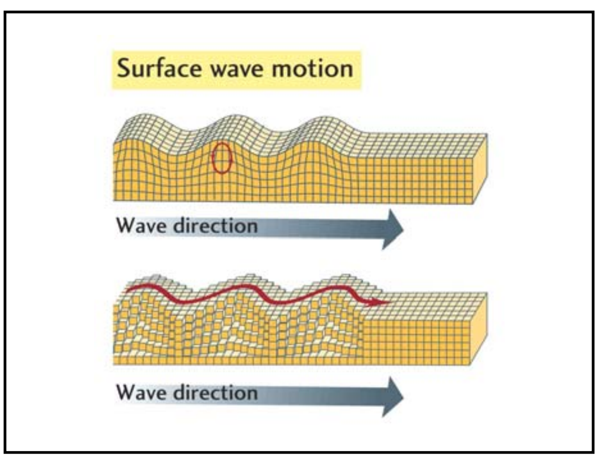


Two Kinds of Waves From Earthquakes

- ***P waves*** **(compressional) 6–8 km/s. Parallel to direction of movement (slinky), also called primary waves. Similar to sound waves.**
- ***S waves*** **(shear) 4–5 km/s. Perpen-dicular to direction of movement (rope); also called secondary waves. Do not pass through liquids.**

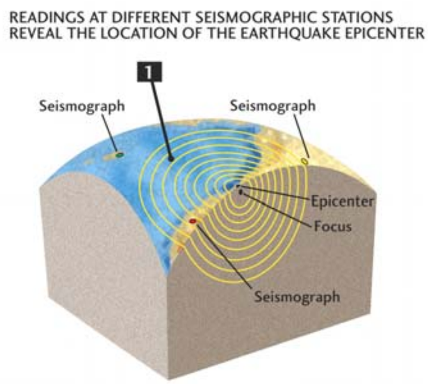

P-wave motion
Compressional
wave
Wave direction

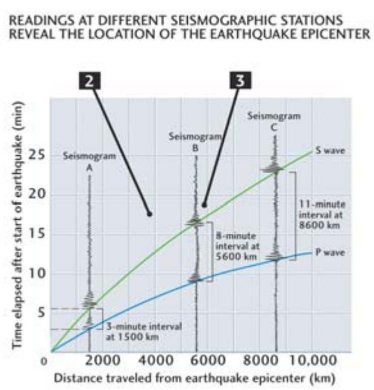

S-wave motion
Shear-wave
crest
Wave direction

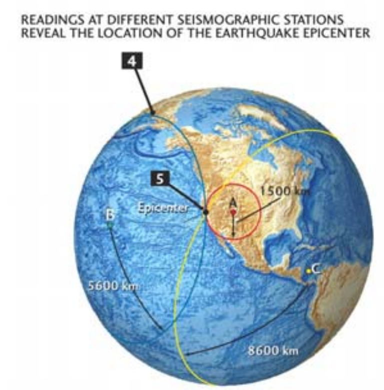

Surface wave motion
Wave direction
Wave direction

Locating an Epicenter

- The difference between the arrival times of the P and S waves at a recording station is a function of the distance from the epicenter.
- Therefore, you need at least three stations to determine the location of an epicenter.







Measuring the Force of Earthquakes

1. *Surface displacement*

- 1964 Alaska earthquake displaced some parts of the seafloor by ~ 50 ft.
- 1906 San Francisco earthquake moved the ground ~8.5 ft.

2. *Size of area displaced*

   Alaska — 70,000 sq. miles

Measuring the Force of Earthquakes

3. *Duration of shaking*

   Up to tens of seconds

4. *Intensity scales*

   Based on damage and human perception

5. *Magnitude scales*

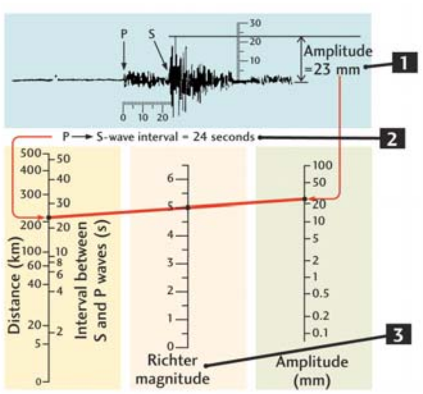
   based on amount of energy released

Richter scale

- Richter scale: amount of energy received 100 km from epicenter
- Largest quake ever recorded = 8.9 (rocks not strong enough for more).
- Earthquakes less than M = 2 are not felt by people.
- Scale is *logarithmic*:

Increase 1 unit = 10 times greater shaking

Increase 1 unit = 30 times greater energy



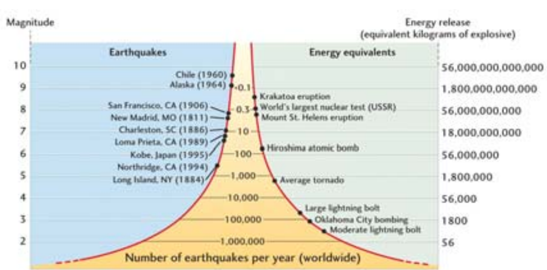


Table 19.1 Modified Mercalli Intensity Scale

Intensity Level	Description
I	Not felt except by a very few under especially favorable conditions.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck.
IV	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.

Table 19.1 Modified Mercalli Intensity Scale

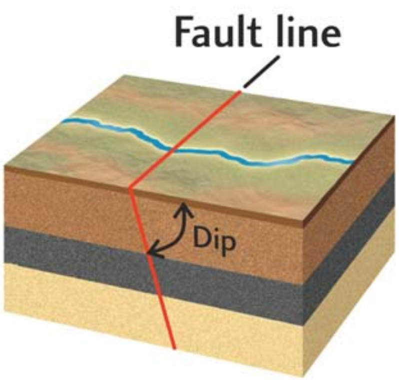
Intensity Level	Description
VII	Damage negligible in buildings of good design and construction; slight to moderate damage in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
XI	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
XII	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

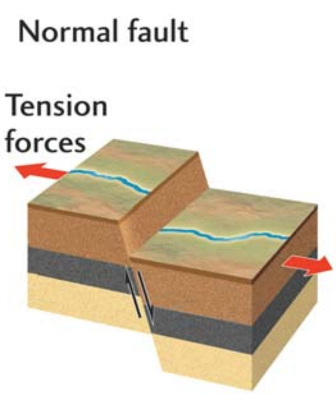
Intensities Associated With the 1811 Earthquake at New Madrid, Missouri

note a shortcoming of intensity scales: not very many people lived to the west of this EQ so no intensity observations are available.

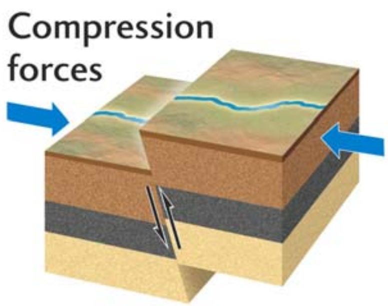
Determining the Type of Earthquake From Seismic Data

Fault motion of different kinds of faults (normal, reverse, strike-slip) will produce distinctive seismic wave characteristics

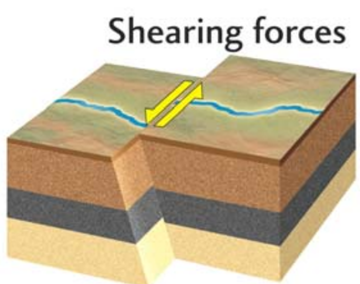


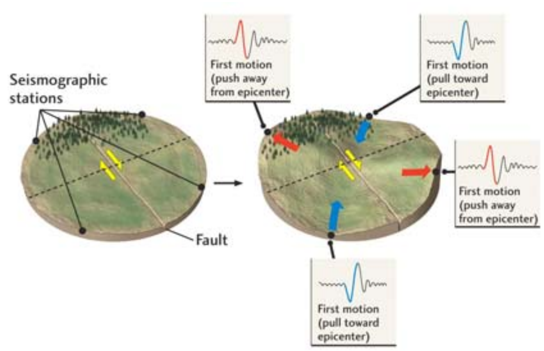


Thrust fault



Strike-slip fault

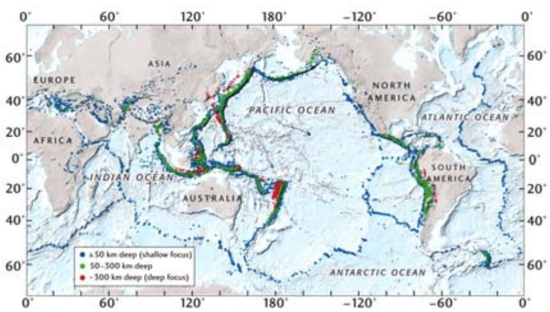


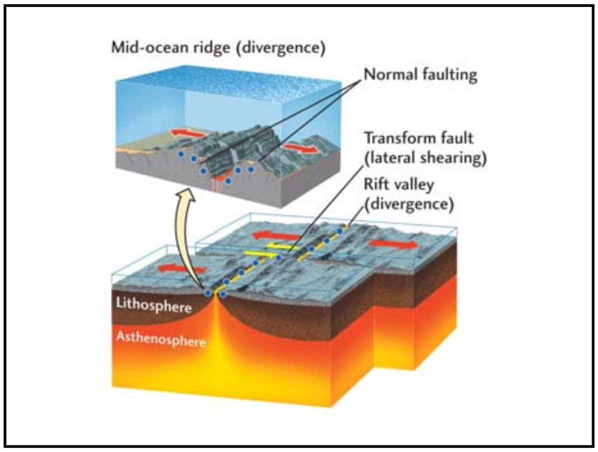


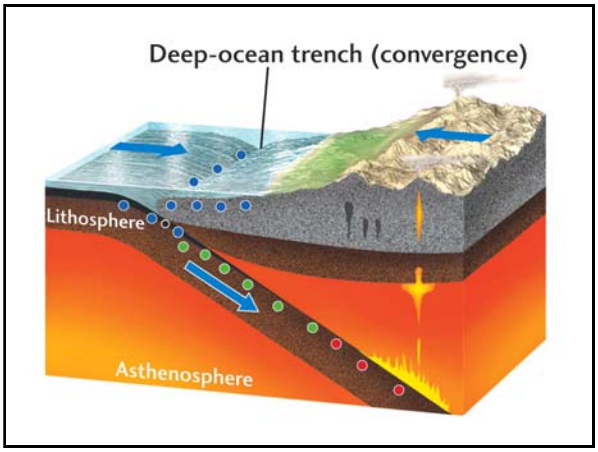
A fence built across the San Andreas fault near Bolinas, California, is offset by nearly 3 m after the great San Francisco earthquake

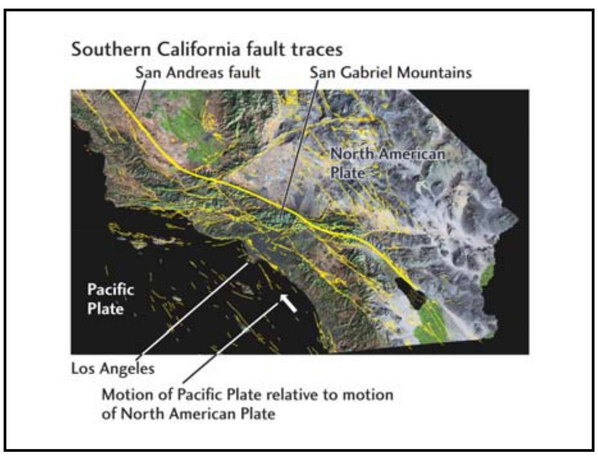
Distribution of Earthquakes

- not random
- focused around plate margins (but also seen in plate interiors)




Mid-ocean ridge (divergence)
Normal faulting
Transform fault (lateral shearing)
Rift valley (divergence)
Lithosphere
Asthenosphere


Deep-ocean trench (convergence)
Lithosphere
Asthenosphere


Southern California fault traces
San Andreas fault
San Gabriel Mountains
North American Plate
Pacific Plate
Los Angeles
Motion of Pacific Plate relative to motion of North American Plate

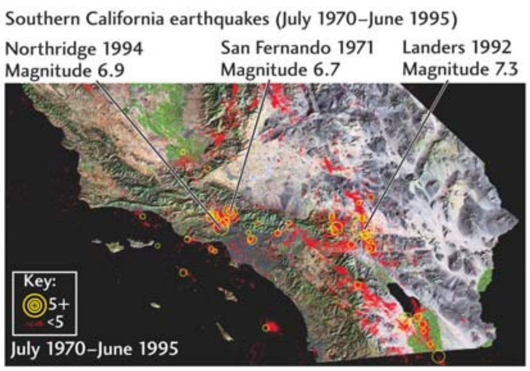


Table 19.2 Recent Earthquakes of Special Interest

Event	Magnitude	Geologic Effects	Destruction
Loma Prieta, California October 1989	7.1	Maximum intensity in parts of Oakland and San Francisco; landslides; soil liquefaction; small tsunami at Monterey	60 killed; 3757 injured; U.S. $7 billion in damage
Landers, California June 1992	7.3	Surface faulting along a 70-km segment with as much as 5.5 m of horizontal displacement and 1.8 m of vertical displacement	1 killed; 400 injured; substantial damage
Northridge, California January 1994	6.9	A maximum uplift of 15 cm occurred in Santa Susana Mountains; many rockslides; ground cracks; soil liquefaction	58 killed; 7000 injured; 20,000 homeless; U.S. $20 million in damage
Northern Bolivia June 1994	8.2	At 637 km depth, the largest deep earthquake on record; first earthquake from this part of South America to have been felt in North America including Canada	Several people killed
Kobe, Japan January 1995	6.9	Surface faulting for 9 km with horizontal displacement of 1.2 to 1.5 m; soil liquefaction	5502 killed; 36,896 injured; 310,000 homeless; severe damage

Table 19.2 Recent Earthquakes of Special Interest

Event	Magnitude	Geologic Effects	Destruction
Northern Iran May–June 1997	7.3	Landslides; rare sequence of large earthquakes	1567 killed; 2300 injured; 50,000 homeless; extensive damage
Papua New Guinea July 1998	7.0	Tsunami as high as 7 m	3000 killed; several villages destroyed
Izmit, Turkey August 1999	7.4	Seventh in a series since 1939; migrating westward along the strike-slip North Anatolian fault; maximum right-lateral displacement of 5 m	15,600 killed; thousands missing
Gujarat, India January 2001	8.0	Intraplate earthquake with no surface rupture	20,000 killed
Denali, Alaska November 2002	7.9	Largest earthquake in continental North America since 1906; multiple event with 400 km surface break; extensive landsliding	Very little in remote wilderness areas; Trans-Alaska pipeline unbroken at specially engineered crossing of Denali fault trace

Damage Due to Earthquakes

1. **ground movement**
   "Earthquakes don't kill people, buildings kill people."

2. **fire**

3. **tidal waves (tsunami)**
   generate speeds up to 500–800 km/hr in open ocean; only ~ 1m high but get larger when water gets shallow.

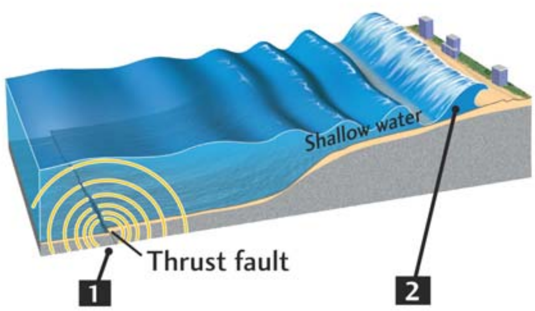
Damage due to earthquakes

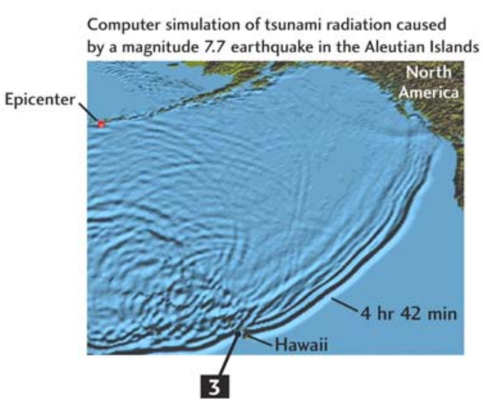
4. **landslides**
   - all kinds of mass wasting
   - liquefaction – sudden loss of strength in water-saturated sediment
   - buildings fall down intact
5. **Flood**
   - dam break
   - courses of rivers change

Northridge, CA in 1994

Kobe, Japan in 1995

Tsunami generation





Tsunami damage in Indonesia (1992)

Earthquake Prediction

- Long term—imprecise (but possible)
- Short term—precise (very difficult)
- We can't stop earthquakes, so we have to be prepared for them

Potential Earthquake Hazard, USA

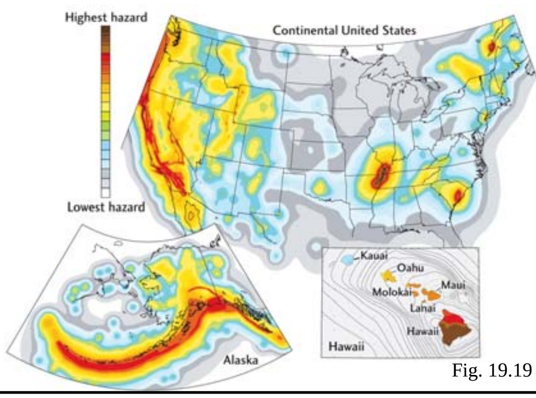
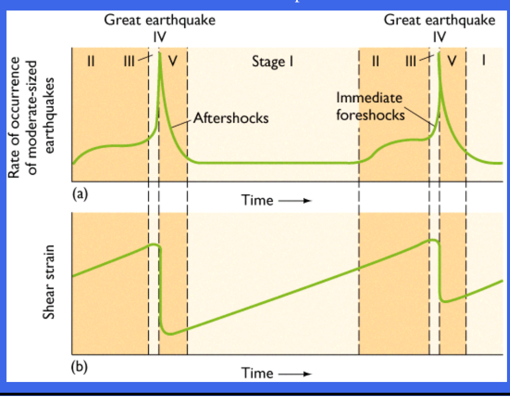


Fig. 19.19

Potential Earthquake Hazard, Worldwide

Seismic Gap Method



Earthquake Prediction

- Small earthquakes
- Ground tilting
- Change in water levels in wells
- Change in acoustic or electrical properties
- Animal behavior?

Fig. 19.22

Box 19.1

Box 19.2