Earthquake hazards

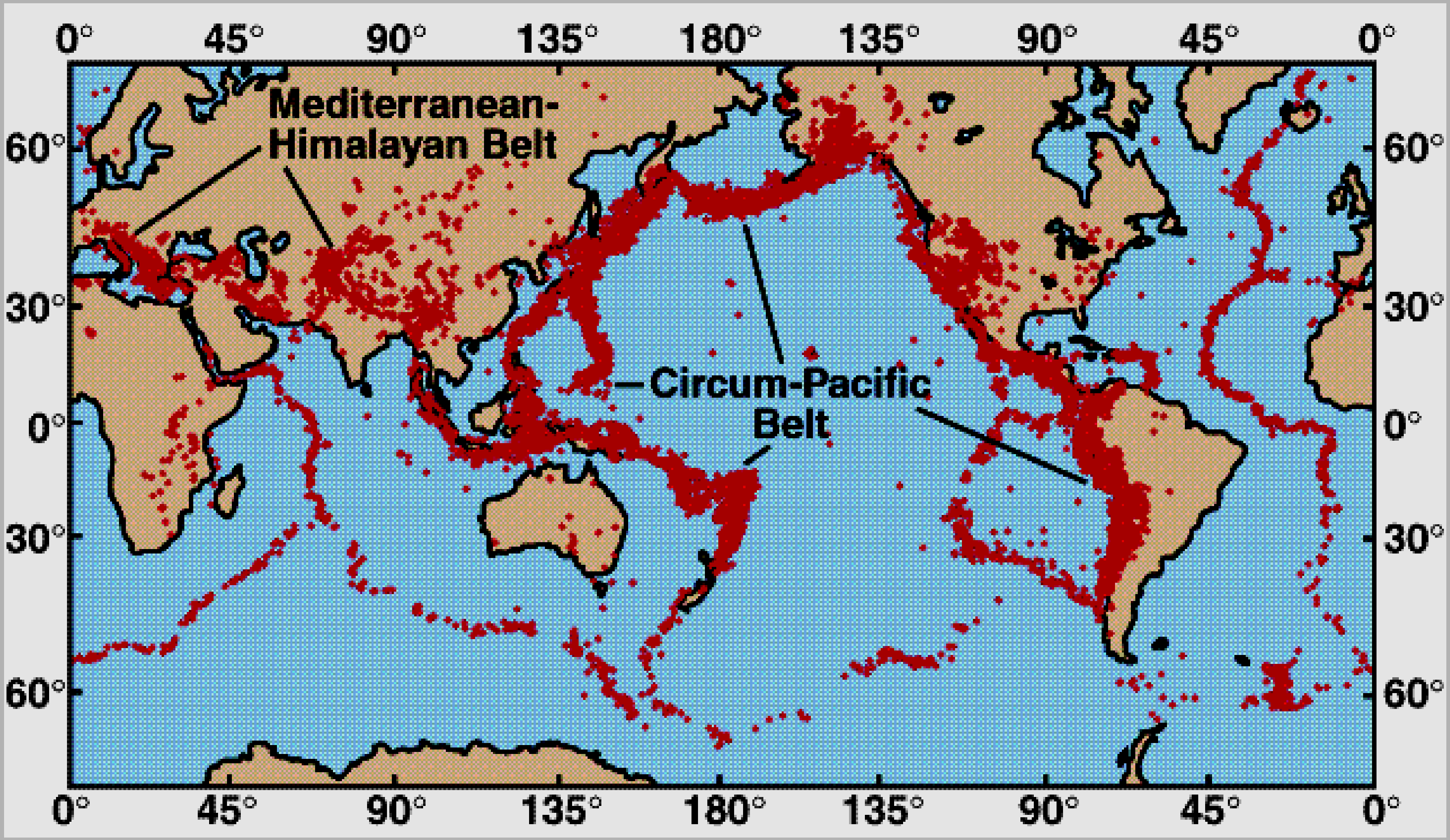
San Francisco, Calif., 1989
Wicander and Monroe (2002)

Magnitude 6.1, Takhar Province, Afghanistan,
February 4, 1998, Chernicoff et al. (2002)

Where and when ?

- 80% of all earthquakes occur in the circum-Pacific belt, a zone of seismic activity that nearly surrounds the Pacific Ocean basin. Along this belt, most quakes are associated with convergent plate boundaries but also occur along divergent and transform boundaries.
- 15% of all earthquakes occur along the largely convergent Mediterranean-Asiatic belt.
- The remaining 5% of earthquakes occur in plate interiors and along divergent margins. Intraplate earthquakes take place along ancient faults commonly associated with ancient, buried plate margins.
- On average, 150,000 earthquakes strong enough to be felt are recorded each year. Another 900,000 are recorded but are too small to be cataloged

World Earthquake distribution



Plummer et al. (2001)

What are the Hazards?

- The destructive effects of earthquakes include:
  - Ground shaking
  - Fire
  - Tsunami
  - Aftershocks
  - Landslides
  - Panic, disruption of vital services, and shock

The hazards

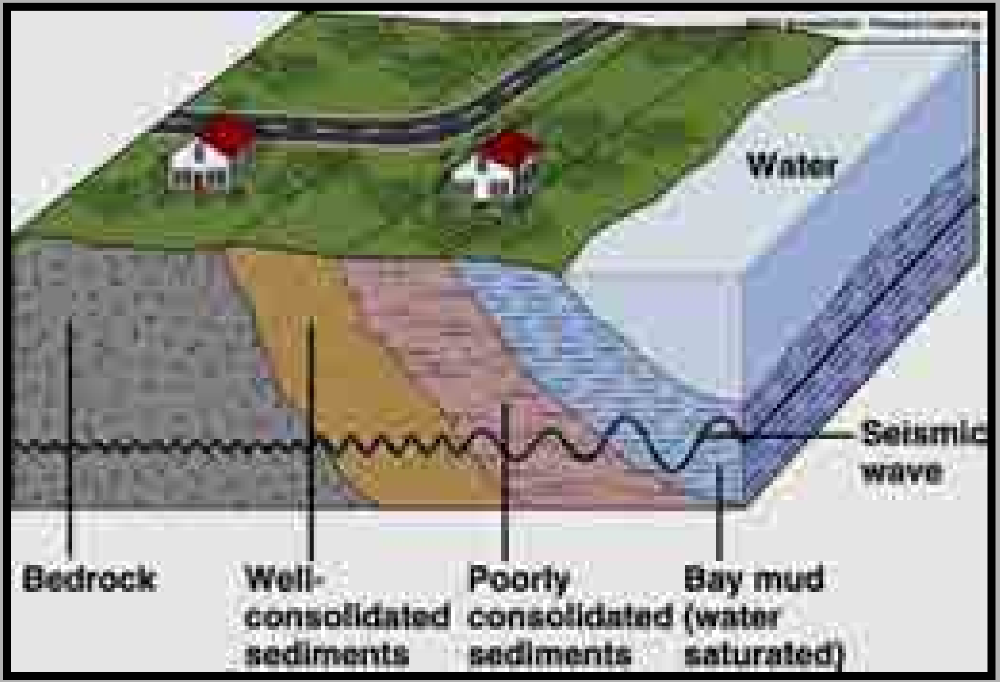
- The numbers of deaths and injuries depend on several factors: magnitude, duration of shaking, local geology, population density, distance from epicenter, construction practices, and disaster response planning.
- Even the time at which an earthquake occurs affects its destructiveness. Earthquakes during working hours in populated urban areas are most destructive and cause most fatalities and injuries.
- When the above factors are considered, it is obvious why small earthquakes are sometimes more destructive than larger ones.

Earthquake damage

San Francisco, Montgomery (2001)

Ground Shaking

The effects of ground shaking, toppling buildings, falling glass, etc., cause more injuries than any other earthquake hazard. In addition to magnitude and distance to epicenter, earth materials beneath a site (bedrock versus sediment) strongly influence the amplitude and duration of seismic waves, and thus ground shaking.



Wicander and Monroe (2002)

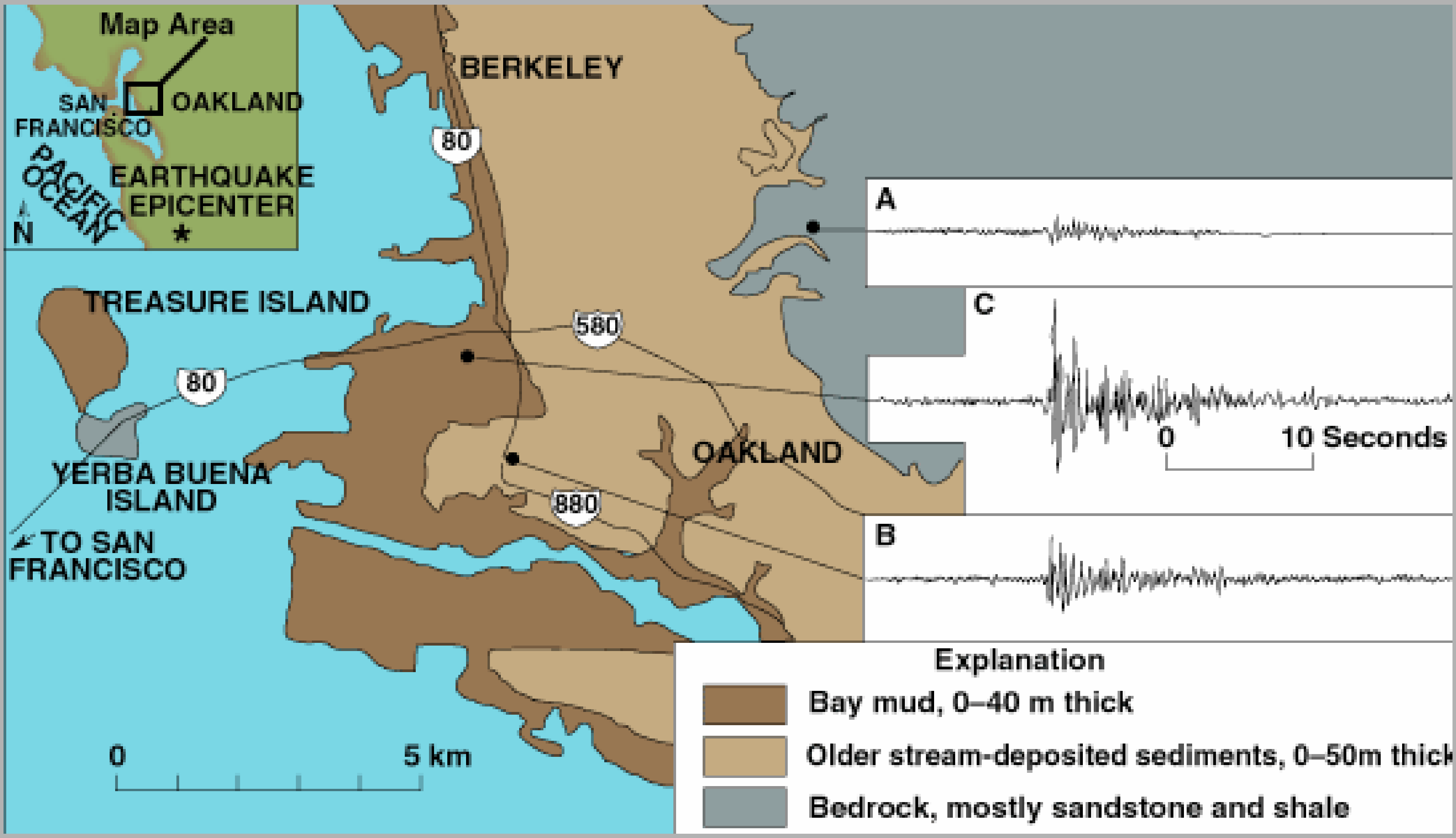
Amplitude and duration of S-waves is greater in poorly consolidated or water-saturated material than in bedrock. Structures built on bedrock suffer less ground shaking than those built on poorly consolidated or water-saturated material.

Loma Prieta, 1989

- On 17 October a magnitude 7.1 event at 5.04 PM rocked San Francisco
- A 25 mile long segment of the San Andreas fault ruptured moving 2m horizontally and 1.3m vertically
- 67 people killed
- $6 billion in damage

Collapse of I-880
Montgomery (2001)

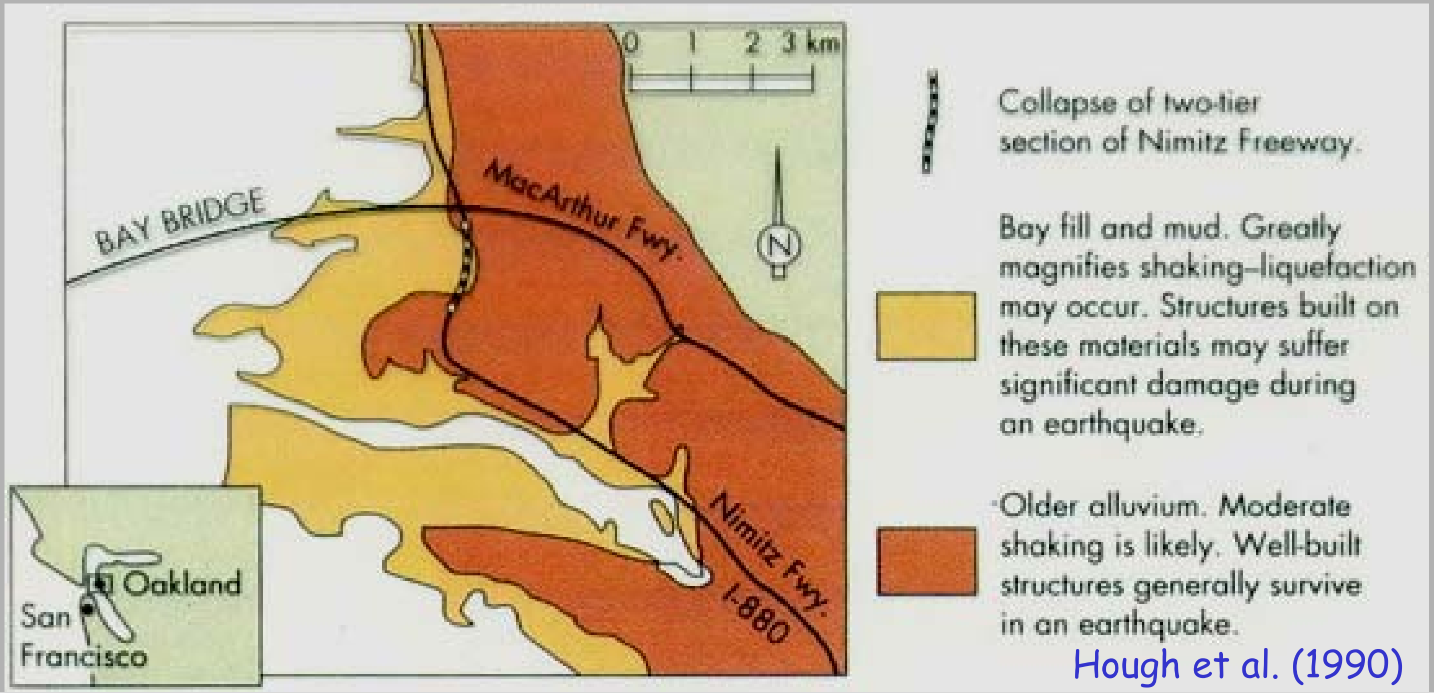
Loma Prieta earthquake



Montgomery (2001)

Loma Prieta

- **Much of the damage was caused by structural failure due to liquefaction in soft sediments and artificial fill**
- **The problem was most pronounced in the Marina district, much of which is built on reclaimed land. It's much safer to build on granite than on mud**

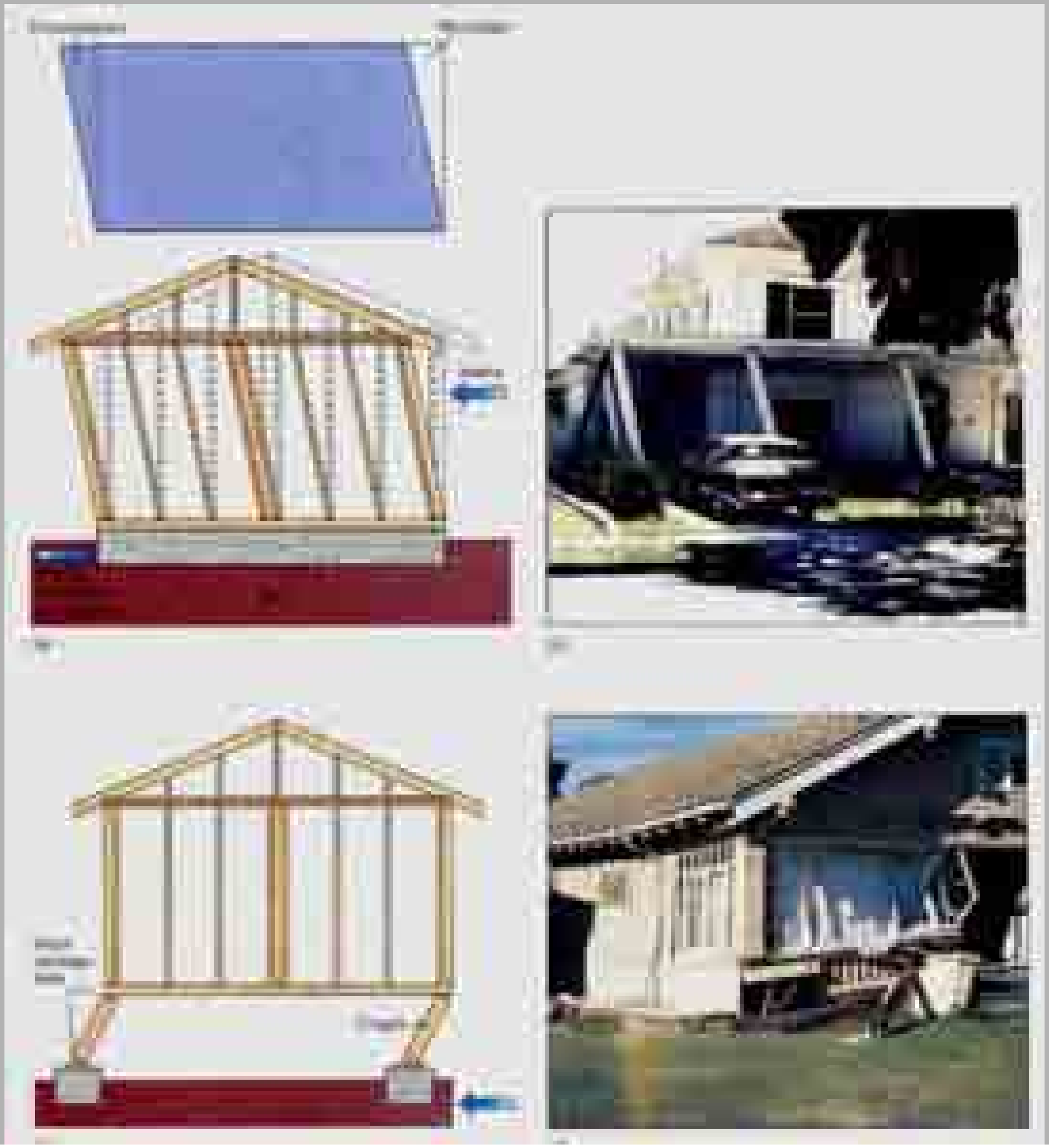


Hough et al. (1990)

Ground shaking

- Buildings must be designed to withstand the maximum horizontal ground shear (base shear) expected
- Base shear is expressed as a % age of the acceleration of gravity

Building failure



Flexible framed buildings may be deformed or knocked off their foundations

Pipkin and Trent (1997)

Ground Shaking

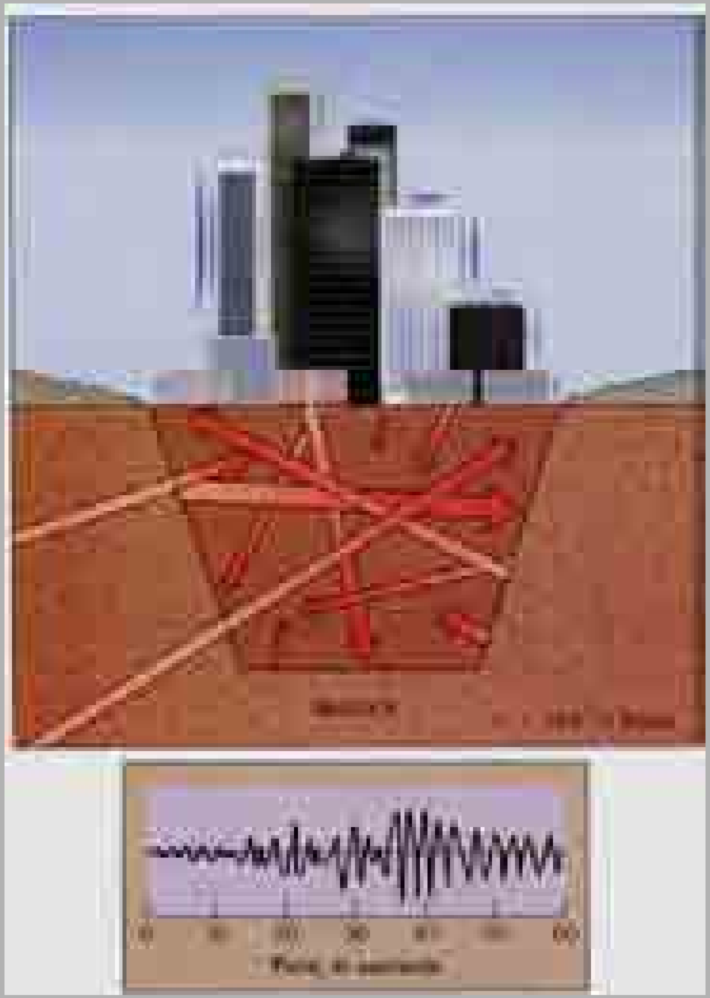
- Building material and type of construction can also affect the amount of damage done by ground shaking.
- Adobe and mud-walled buildings are most susceptible and nearly always collapse.
- Unreinforced brick and poorly built concrete structures are easily destroyed as occurred in Tangshan, China, in 1976. The entire city was nearly leveled when buildings, mostly unreinforced brick, collapsed.

Mexico City - resonance

- On September 19, 1985 a magnitude 8.1 quake struck southern Mexico near the Pacific coast causing little damage.
- 350 km away in Mexico City the earthquake waves caused high rise buildings to sway in increasingly wider arcs.
- 3,000 structures collapsed - 10,000 people died
- Mexico City is built on three geological zones:
  - a hilly zone underlain by hard rock
  - a transition zone
  - a zone underlain by soft, water-saturated sediments
- All serious damage occurred in zone 3

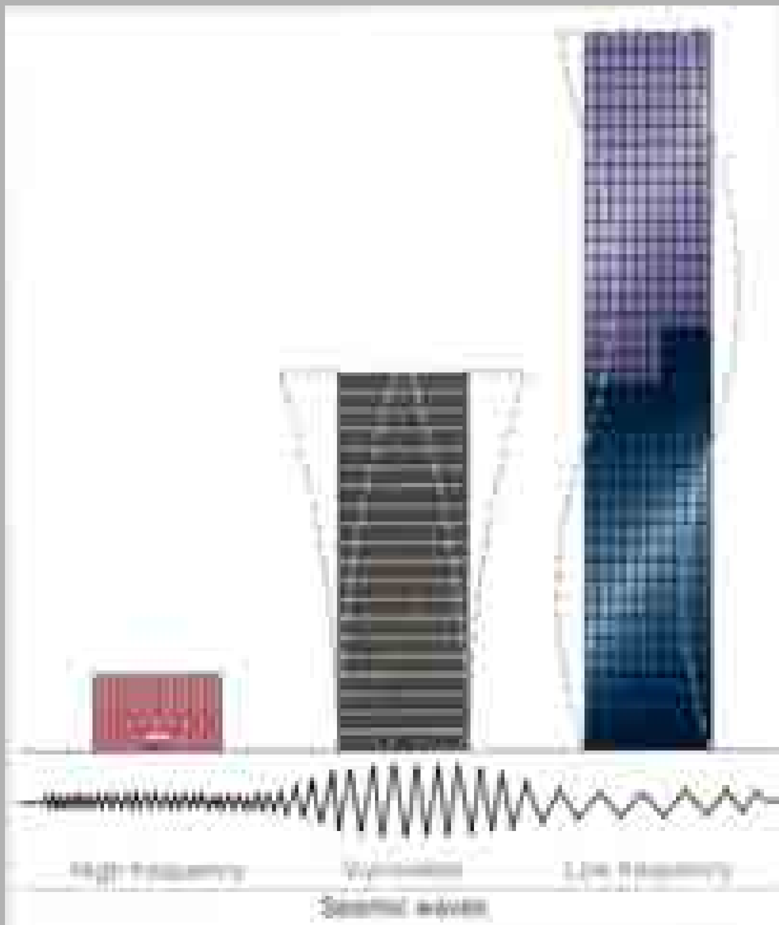
Mexico City - resonance

The sediments reacted like a bowl of gelatin causing rolling ground motions with long wave periods (2 seconds), not anticipated by building codes. The clays magnified the shockwaves 8 to 50 times



Seismic waves in the saturated and poorly consolidated lake bed beneath Mexico City, Pipkin and Trent (1997)

Mexico City - resonance



The effect of amplification of motion on structures of varying heights (low buildings have high frequency and tall buildings have low frequency), Pipkin and Trent (1997)

The building codes specified a period of 0.1 seconds per story, which meant that a 20-story building would have a natural oscillation period of 2 seconds

Mexico City, 1985

Montgomery (2001)

Liquefaction

The passage of seismic waves can cause the material on which buildings are constructed to behave as a fluid. This process, known as liquefaction, is especially prevalent in fill and water-saturated sediment, which tend to liquefy when shaken. Structures are tilted or toppled when liquefaction causes the material on which they are founded to flow.

Niigata, Japan, 1964
Wicander and Monroe (2002)

Liquefaction

1964 Earthquake

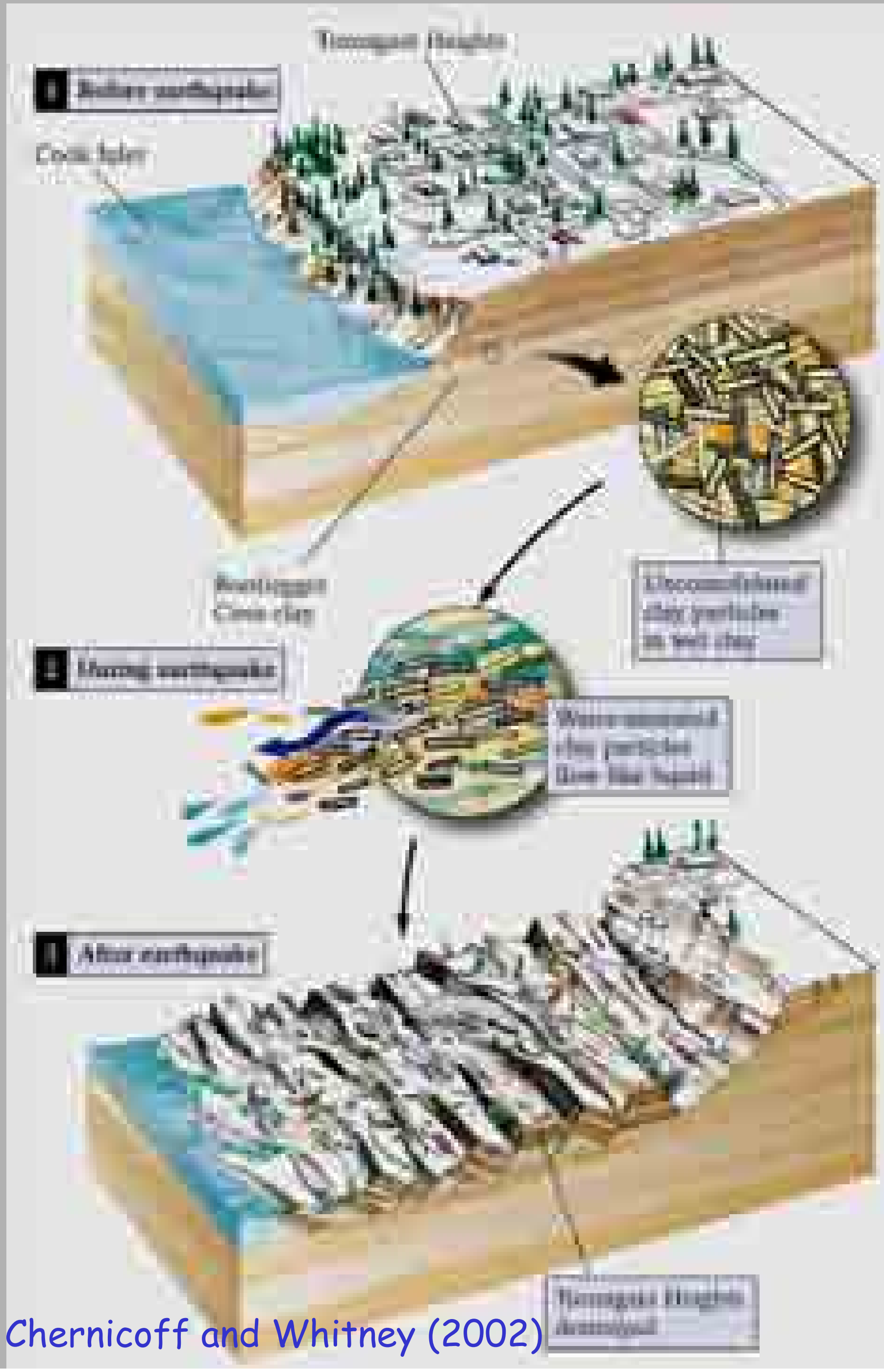
Anchorage, Alaska

Liquefaction caused widespread devastation of urban areas

Source: Dangerous Earth - Murck, Skinner & Porter, 1997

Liquefaction

Turnagain Heights, Alaska,
Pipkin and Trent (1997)



Chernicoff and Whitney (2002)

Liquefaction - sand boils

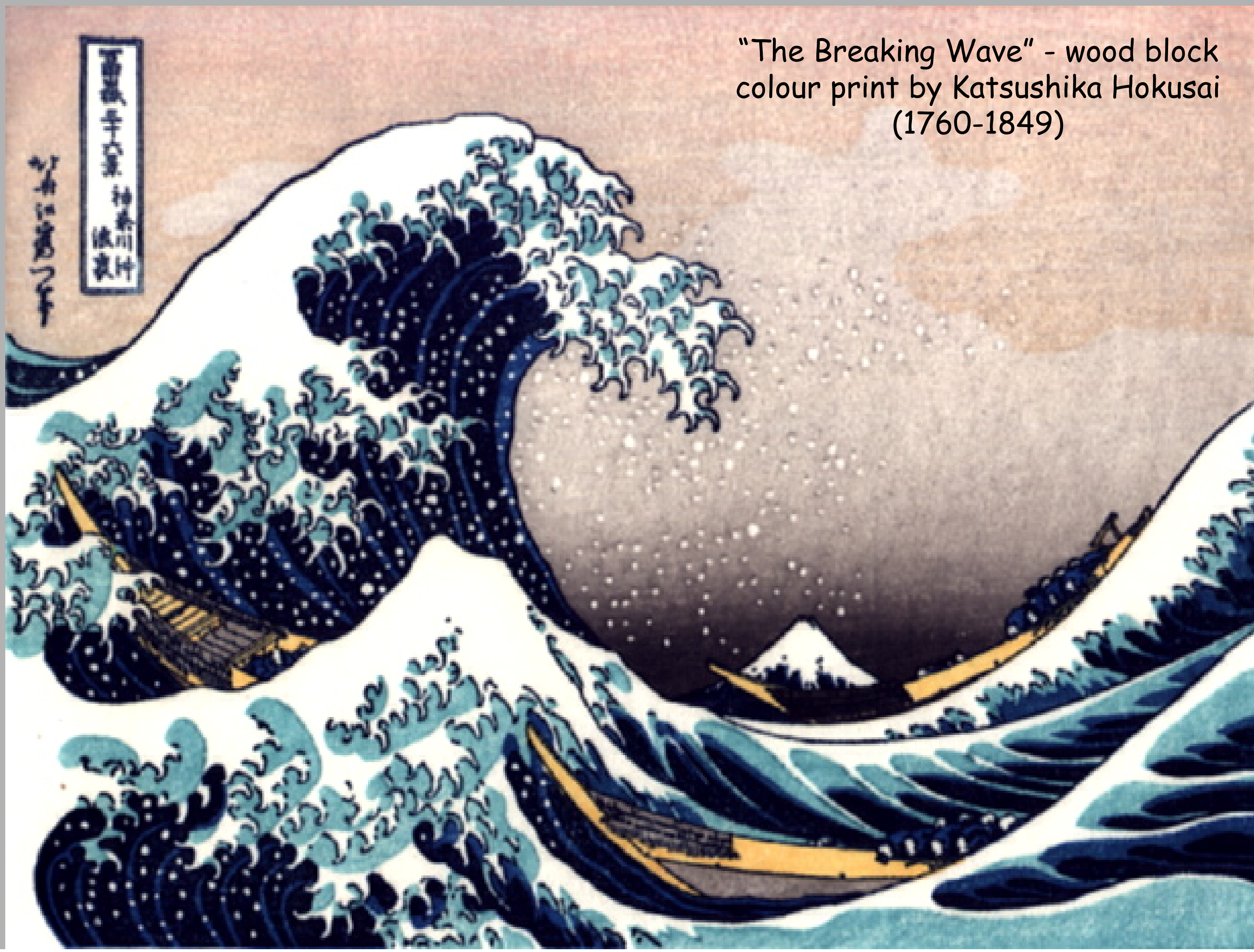
Sand boils, California, Montgomery (2001)

Fire

In urban areas fires sparked by severed electrical and gas lines pose a great hazard. Fire caused 90% of the damage in the San Francisco earthquake of 1902. In 1923 an earthquake caused fire that destroyed 75% of all the houses (most of which were wood) in Tokyo and practically all of the houses in Yokohama, Japan. In 1989 the Loma Prieta earthquake caused a large fire in San Francisco.

San Francisco, Calif., 1989
Wicander and Monroe (2002)

Tsunami



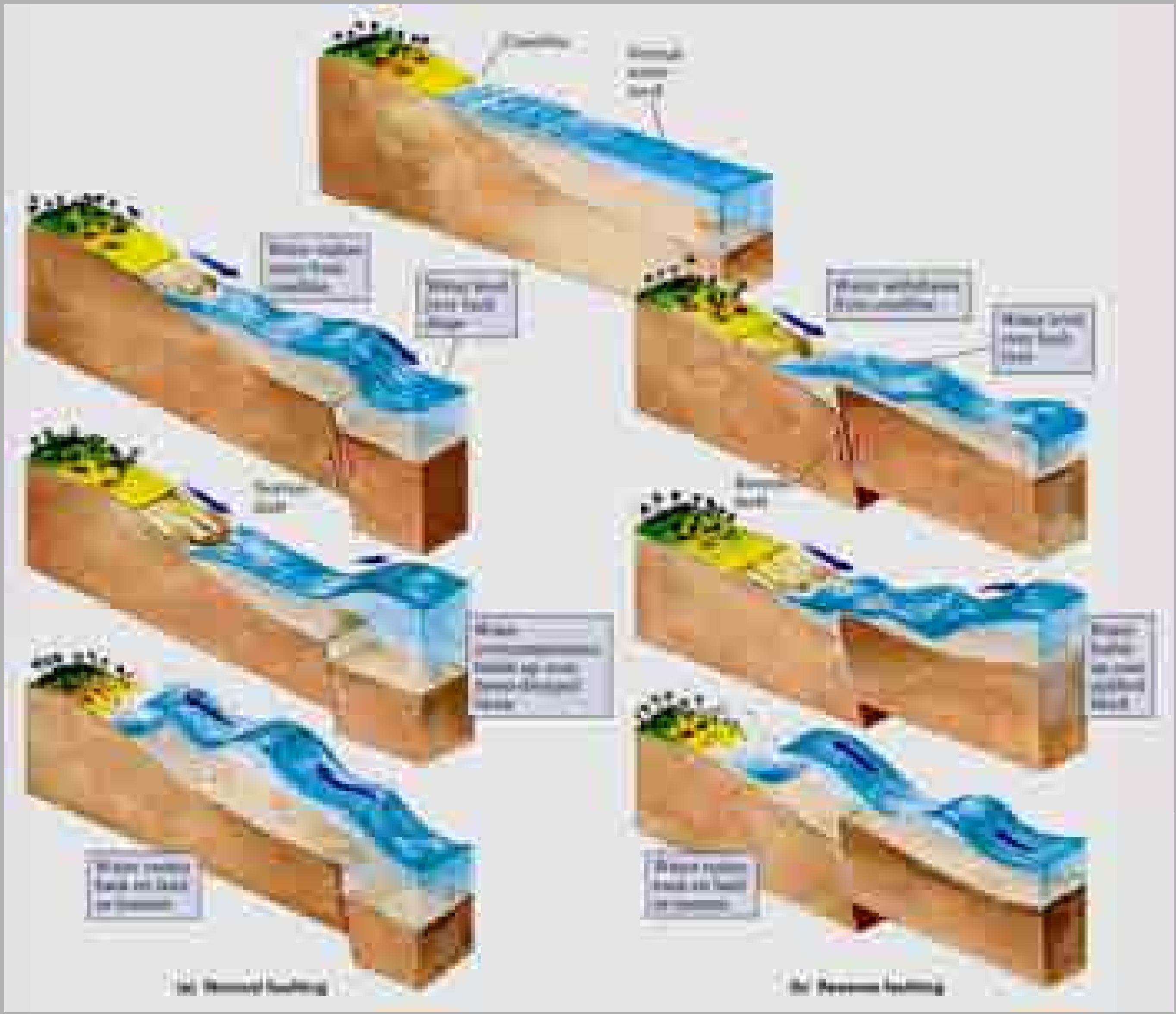
"The Breaking Wave" - wood block colour print by Katsushika Hokusai (1760-1849)

Killer Waves - Tsunami

The "tidal wave," or more correctly, tsunami, is an ocean wave produced by an earthquake. In the open ocean, tsunami are less than 1 m high, but can rise to 30 m or more as they enter the shallow water of coastal areas. Tsunami cross the oceans traveling at several hundred kilometers/hour and can devastate low-lying coastal areas thousands of miles from their source. Following the tsunami that struck Hilo, Hawaii, in 1946, the U.S. developed an early warning system to predict the arrival of tsunami to coastal areas of the Pacific Ocean.

Montgomery (2001)

Generation of a tsunami



Chernicoff and Whitney (2002)

Tsunami

Sequential photographs of the 1957 tsunami at Laie Point, Oahu. 57 deaths and $300,000 damage, Pipkin and Trent (1997)

Tsunami

- Tsunamis are impulsively generated waves that are produced when the sea floor is disrupted by faulting or landslides.
- Waves with wavelengths in excess of 160km and velocities of ~800kmh move out from the source in all directions.
- In the open ocean the waves are only a few feet high but as the wave moves into shallow water the velocity and wavelength decrease while the height increases
- M>7 quakes can generate tsunami 15m high that travel at 50kmh on land. There can be multiple waves separated by ~20 minutes.

1960 tsunami, Hilo, Pipkin and Trent (1997)

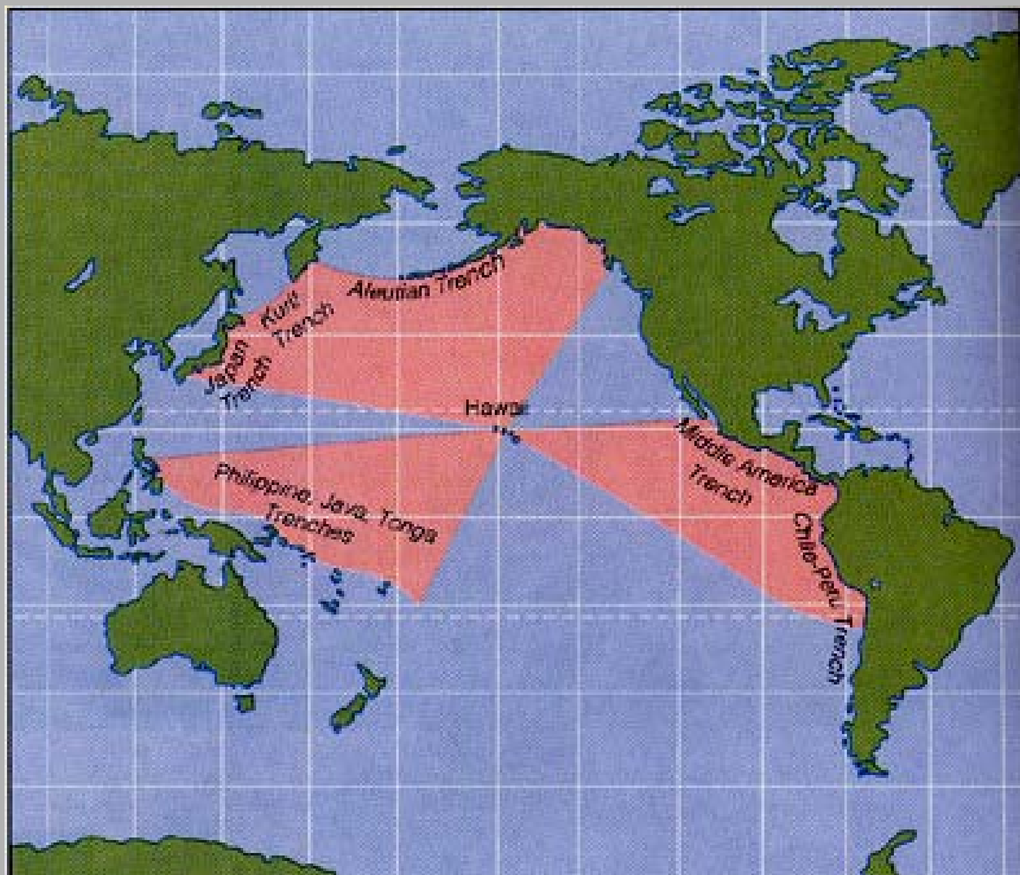
Tsunami

- In 1755 in Lisbon, Portugal 60,000 people were killed by a tsunami. They fled from buildings during the earthquake and gathered on the shoreline where they were killed by the tsunami

- The risk from tsunamis depends on the source mechanism, the distance to the shoreline and the configuration of the coastline

Tsunami

- **Hawaii has been struck by 85 damaging tsunami in the last 85 years**



Tsunami sources and travel paths, Pipkin and Trent (1997)

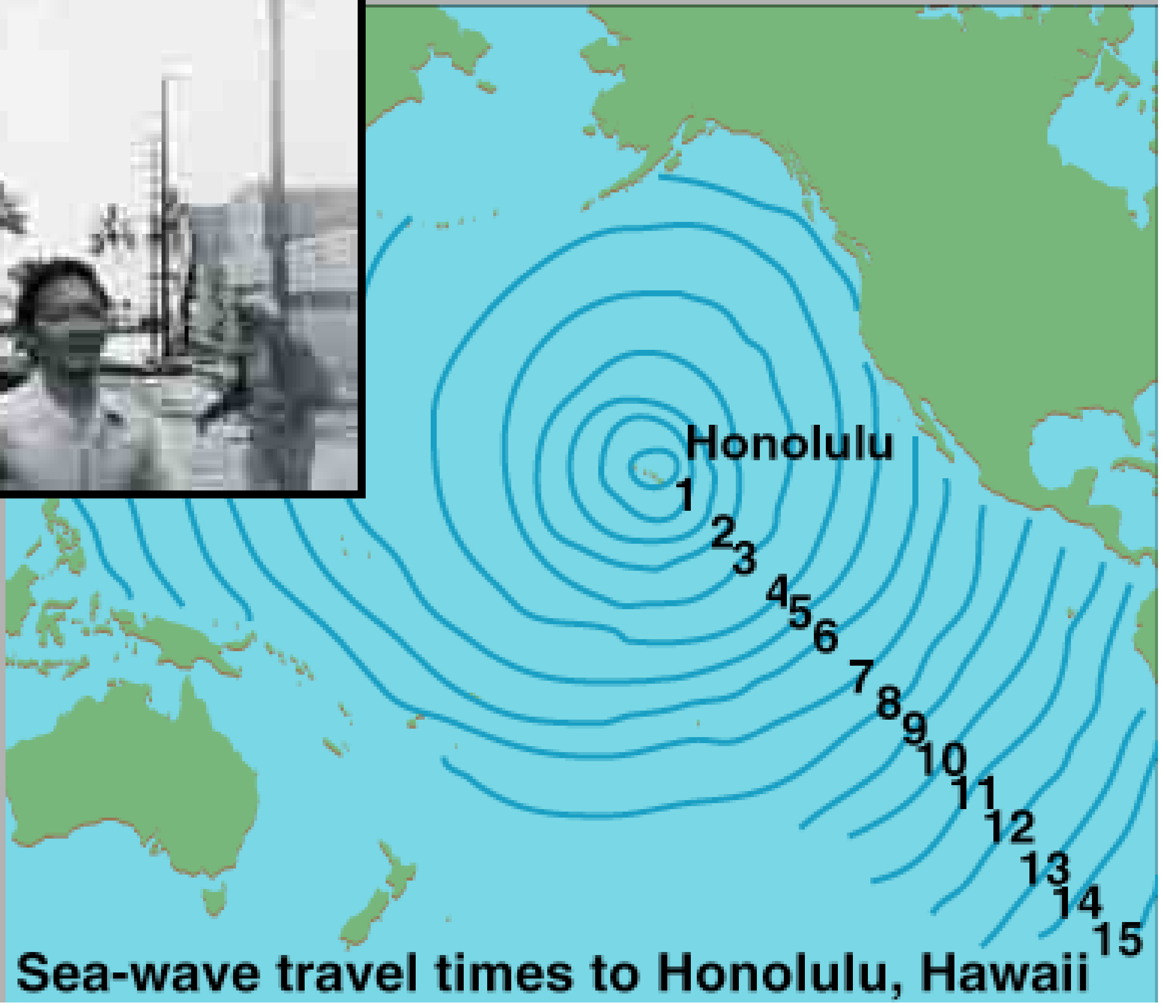
Tsunami

- **In general a flat coastal plain is at greater risk than a steep-cliffed shore line**
- **The best defence is an effective early warning system such as that set up around Hawaii after the 1946 tsunami that killed 146 in Hilo.**
- **In addition buildings are constructed with their narrowest dimension oriented towards the wave. Also lower levels of waterfront buildings comprise open parking to allow water to flow through**

Forecast tsunami heights, Pipkin and Trent (1997)

Tsunami

Hilo, Hawaii, 1946
Wicander and Monroe (2002)



Montgomery (2001)

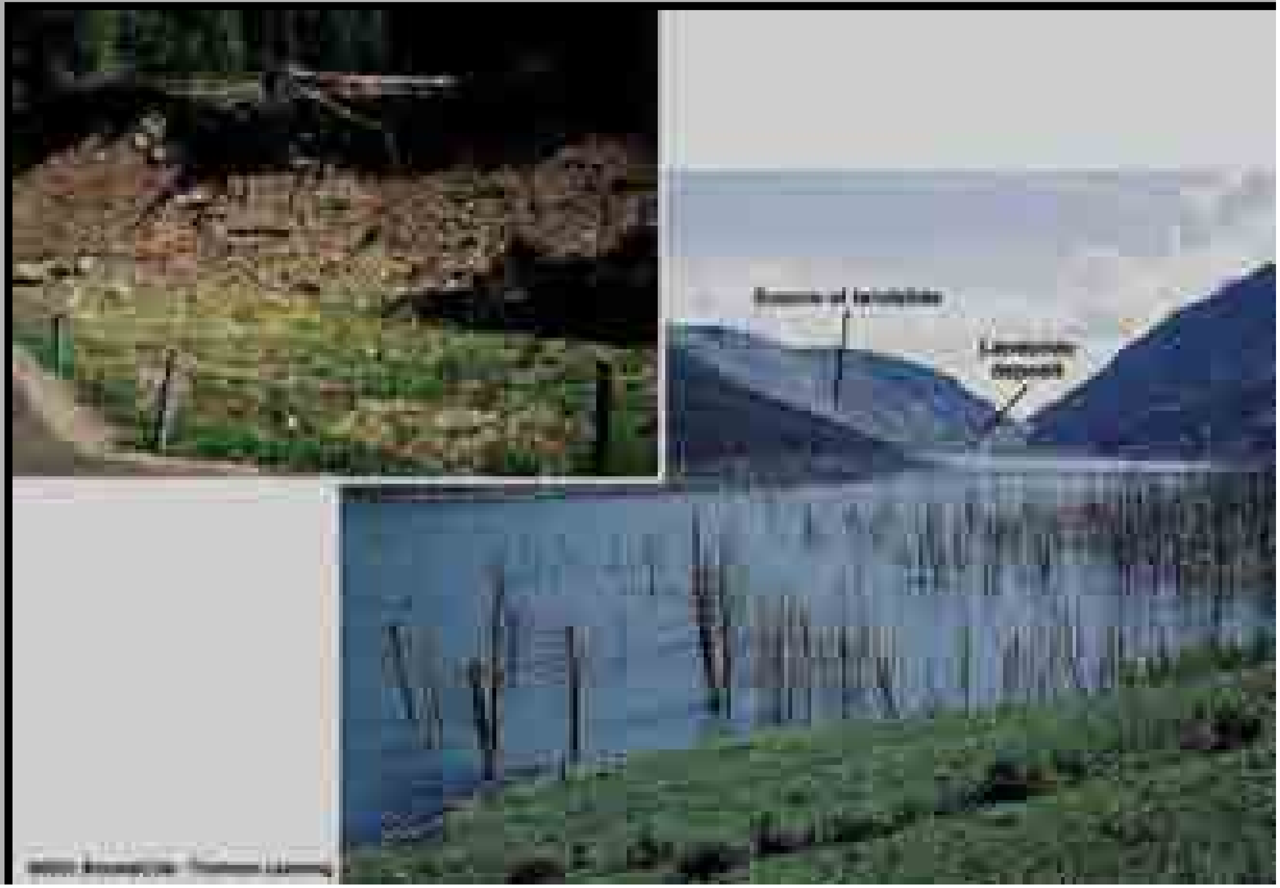
Ground Failure - landslides

- **In mountainous areas, earthquake-triggered landslides are a particular hazard and have caused much destruction and many deaths.**
- **Of the 100,000 killed in the earthquake of 1920 in Ganso, China, most died when cliffs of wind-laid silt collapsed. In 1970, an earthquake-induced avalanche killed 66,000 in Peru.**

Mount Huascaran, Murck and Skinner (1999)

Ground Failure - landslides

The 1959 Montana earthquake formed a fault scarp of several meters and caused a large rock slide that dammed the Madison River.

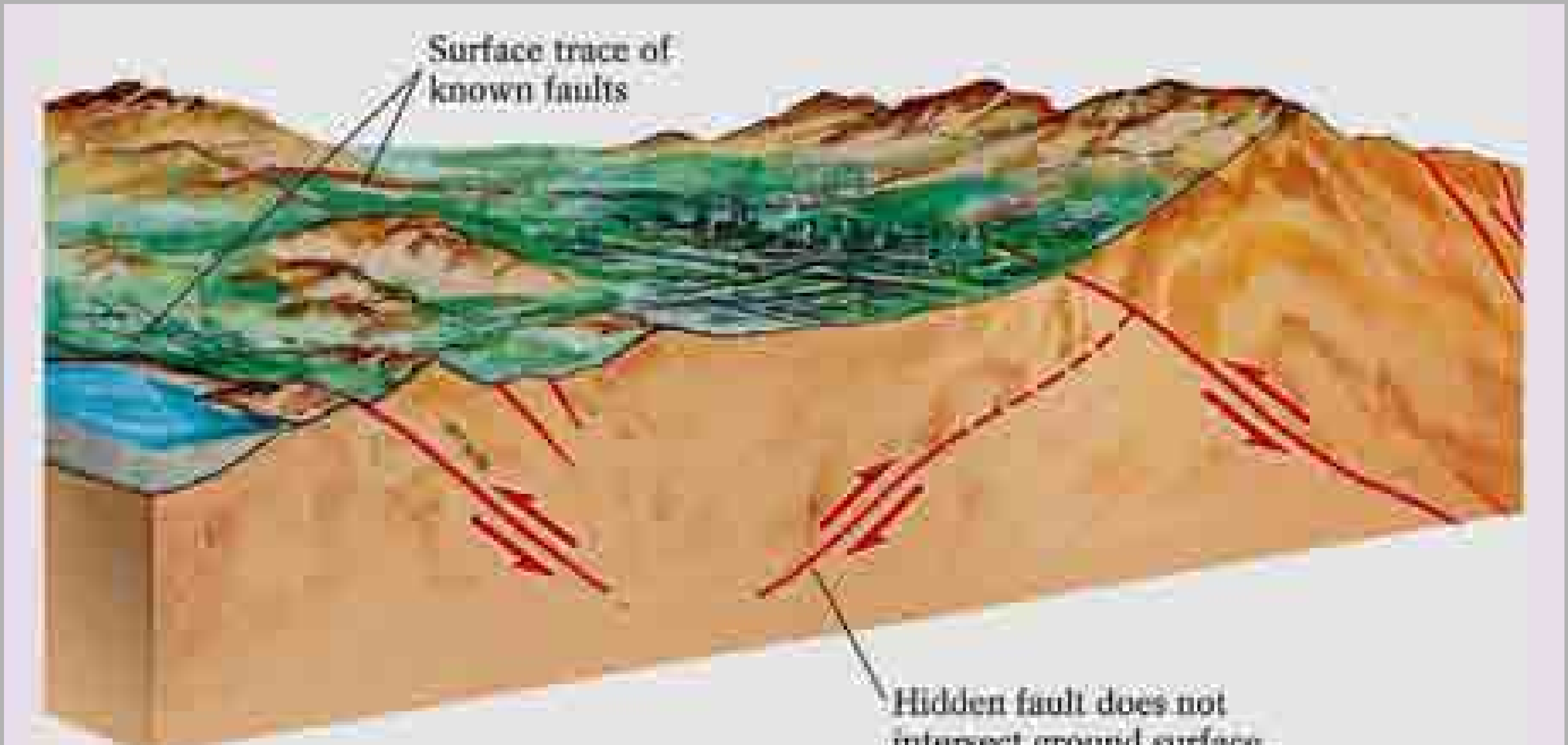


Montana, 1959
Wicander and Monroe (2002)

Northridge – the most expensive quake in the US

- At 4.30 AM, 17 Jan ’94, a previously unrecognised fault beneath the San Fernando Valley ruptured in a M = 6.7 quake.
- The overlying block of a thrust fault moved upwards 2.0m producing violent ground motions in the immediate vicinity destroying or damaging several thousand one- and two-story structures
- Ground accelerations of 0.3g are considered dangerous, values of 1.8g were recorded at Northridge. These high accelerations were responsible for much of the damage and were strongest in a N-S direction

Hidden faults



Chernicoff and Whitney (2002)

Northridge

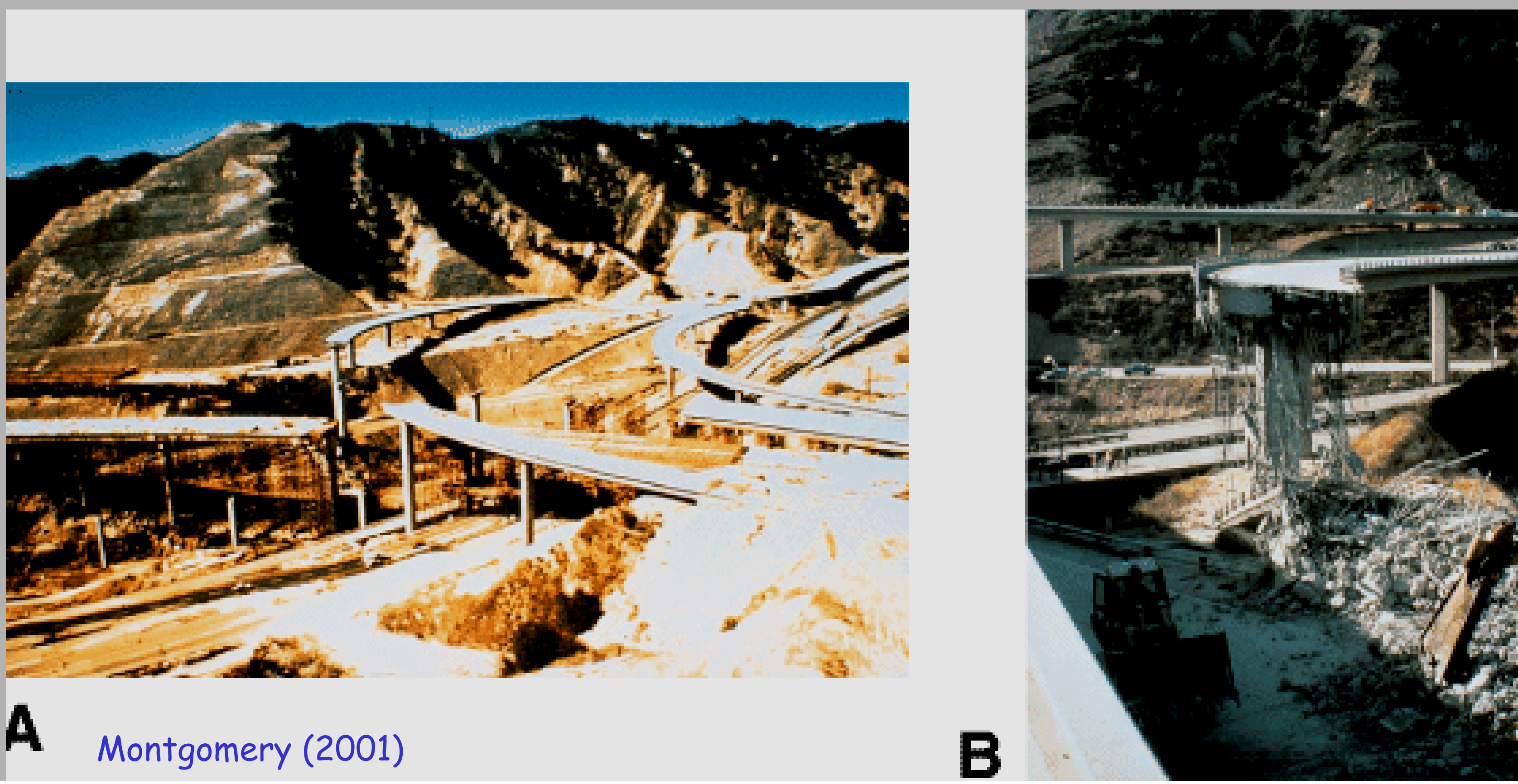
- 60 people were killed and estimates of the costs range from US$13-20 billion. 13,000 buildings were damaged and 21,000 homes had to be evacuated. Selective damage was reported up to 10km away
- The low death toll reflects the early hour of the quake as most highways and commercial buildings were empty
- The building codes also played a role. A similar magnitude quake in Armenia killed 25,000
- 17,000 landslides caused 166 cases of “valley fever” when *Coccidioides immitis* released

Northridge, 1997

Unreinforced masonry buildings are liable to collapse during strong earthquakes

Freeway damage

Damage from the 1971 San Fernando quake repeated in 1994 Northridge quake. Freeway rebuilt but did not account for atypical ground motion in second quake



Montgomery (2001)

Kobe, Japan

- At 5.46 AM, 17 Jan ’95 a magnitude 6.9 earthquake struck Kobe a city of 1.5 million people.
- A 50km rupture on the Nojima fault passed directly under the city. Ground rupture of 1.7m was found nearby
- 5,378 people were killed,
- 152,000 buildings damaged or destroyed
- 6,913 buildings destroyed by fire
- Damage estimated to cost $100 billion

1995 Earthquake - Kobe, Japan
Murck, Skinner & Porter, 1997

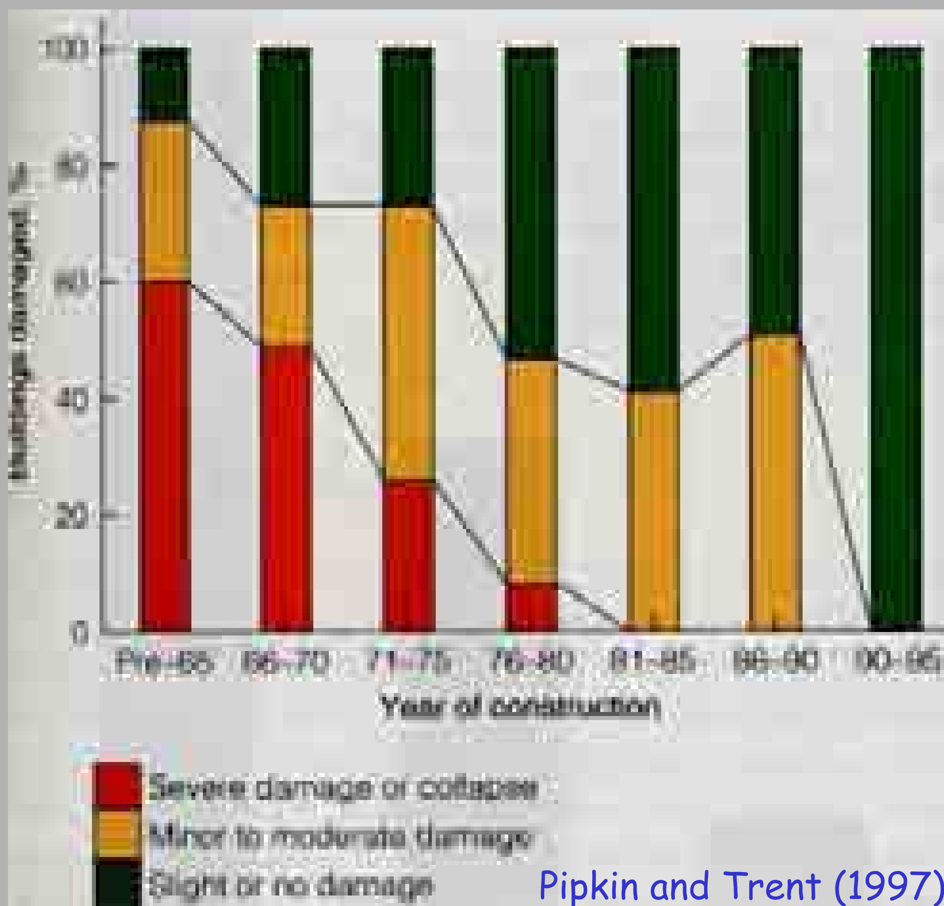
Kobe, Japan

- **Much of Kobe was built on reclaimed land so it is not surprising that the 10-15 seconds of ground shaking at 0.5g caused extensive liquefaction.**
- **90% of fatalities were associated with the collapse of older wood-frame houses. These traditional structures comprise lightly braced vertical posts supporting a heavy tile roof**

Pipkin and Trent (1997)

Kobe, Japan

- **Most of the damage was done to buildings constructed prior to changes in the building codes in 1980**



Pipkin and Trent (1997)

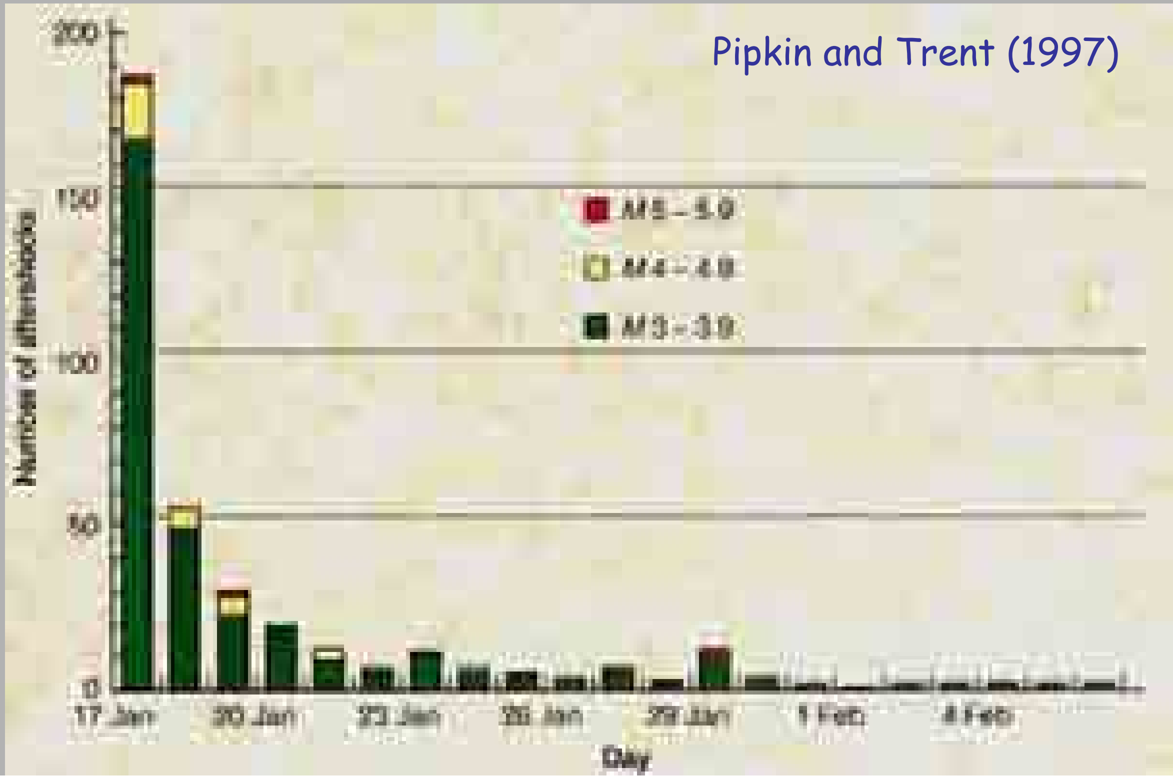
Kobe, Japan

- **Residential areas - Osaka vs Oakland**

Pipkin and Trent (1997)

Aftershocks

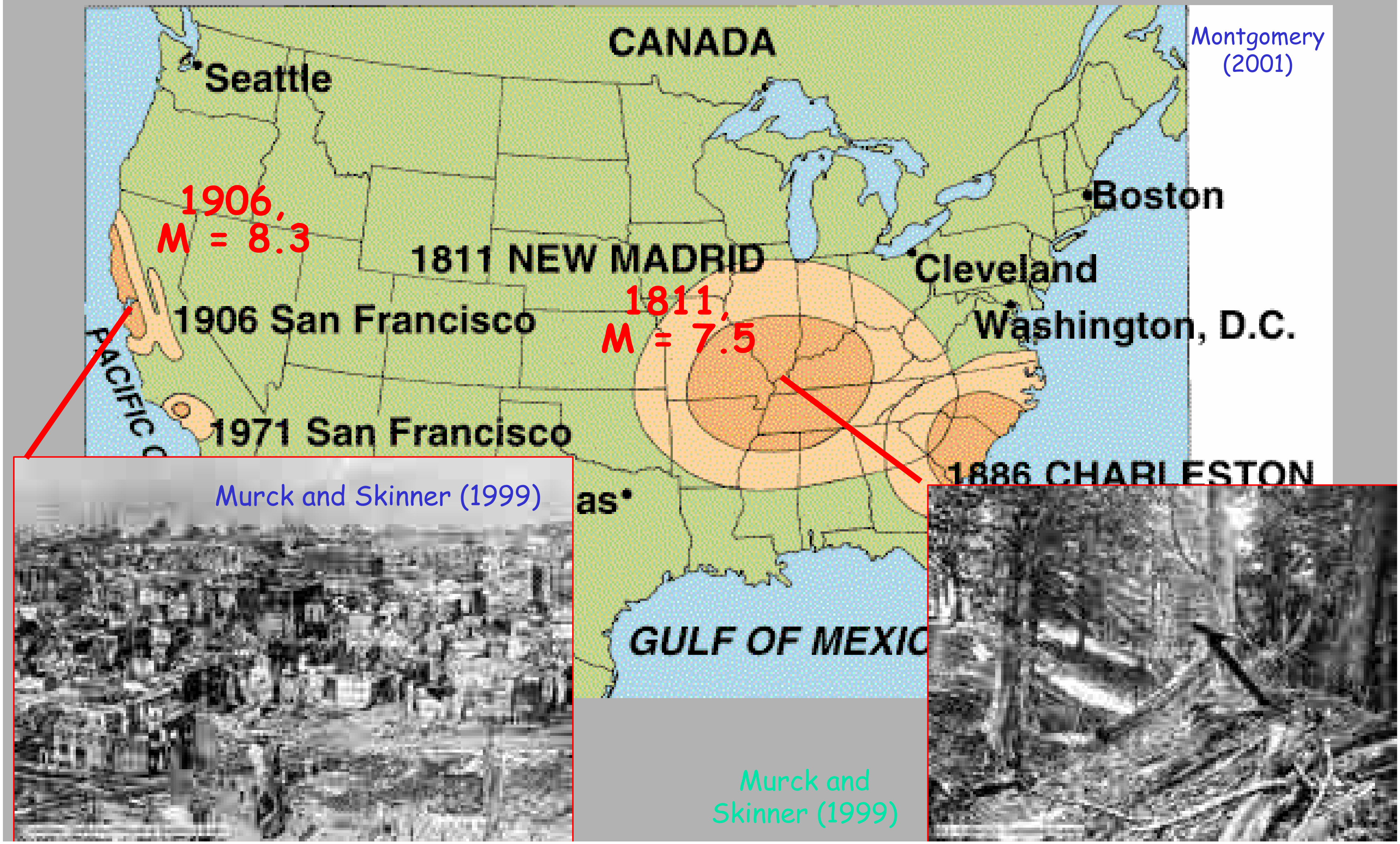
- **Aftershocks can be a major problems as structures are already weakened**
- **2500 after Northridge, 3 > M5**



Intraplate earthquakes

- The New Madrid, Missouri quakes of 1811 and 1812 were felt over much of the east coast, yet the epicentre is far from a plate boundary
- Intraplate quakes share a number of characteristics:
  - The faults are deeply buried and do not break the surface
  - The rocks of the continental interior are stronger and transmit the seismic waves of greater distances
  - Intraplate quakes are concentrated in areas of failed continental rifts
- The New Madrid quakes destroyed towns, drained lakes, created new ones and destroyed ~150,000 acres of timberland.

Intraplate quakes



New Madrid

- 3 quakes over 2 months in 1811-1812, M > 8
- 1,874 aftershocks in the following year and continued for 10 years
- 12 million people now live in the region

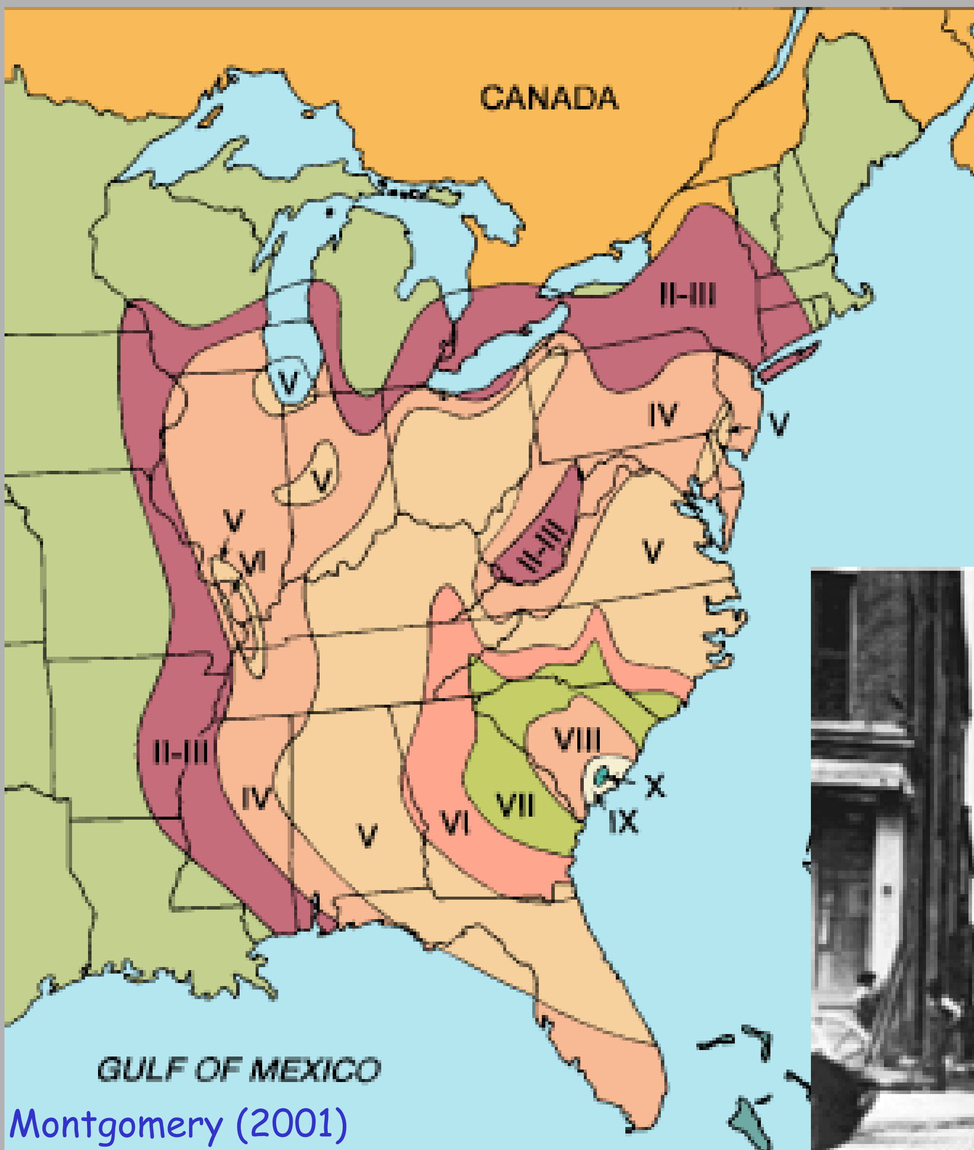
Chernicoff and Whitney (2002)

Modern intraplate quakes

- Bhuj, India
- Jan 26, 2001 a 7.7 Mw Quake felt over 2000km
- No surface expression of the fault but close to a failed rift system

EOS v 82, #32, August 7, 2001

Charleston, 1886



Magnitude >7.1
Loma Prieta quake

Can Earthquakes Be Predicted?

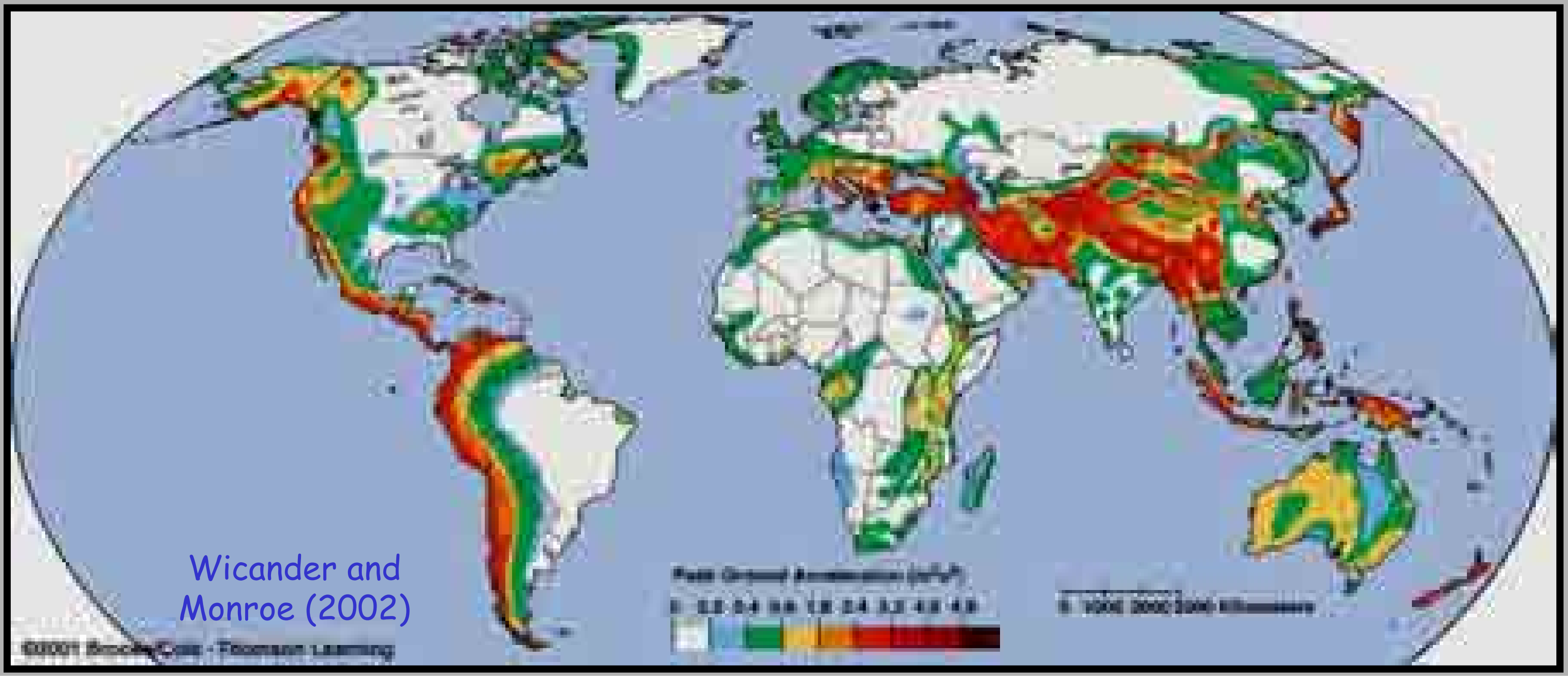
- Successful earthquake prediction includes the location, strength, and time frame for occurrence of the quake. Successful predictions remain rare.
- Only three quakes have been predicted since the 70’s
    - Haicheng, 1975
    - Songpan-Pingwu, 1976
    - Longling, 1976
- At Haicheng a rapid increase in ground tilt and microearthquakes led to the evacuation of several million people. 9 hours later a major earthquake destroyed many buildings, but killed no one.
- In contrast at Tangshen they could only say that an earthquake would occur in the next couple of months, no evacuation took place and the M = 8 quake killed 250,000

Can Earthquakes Be Predicted?

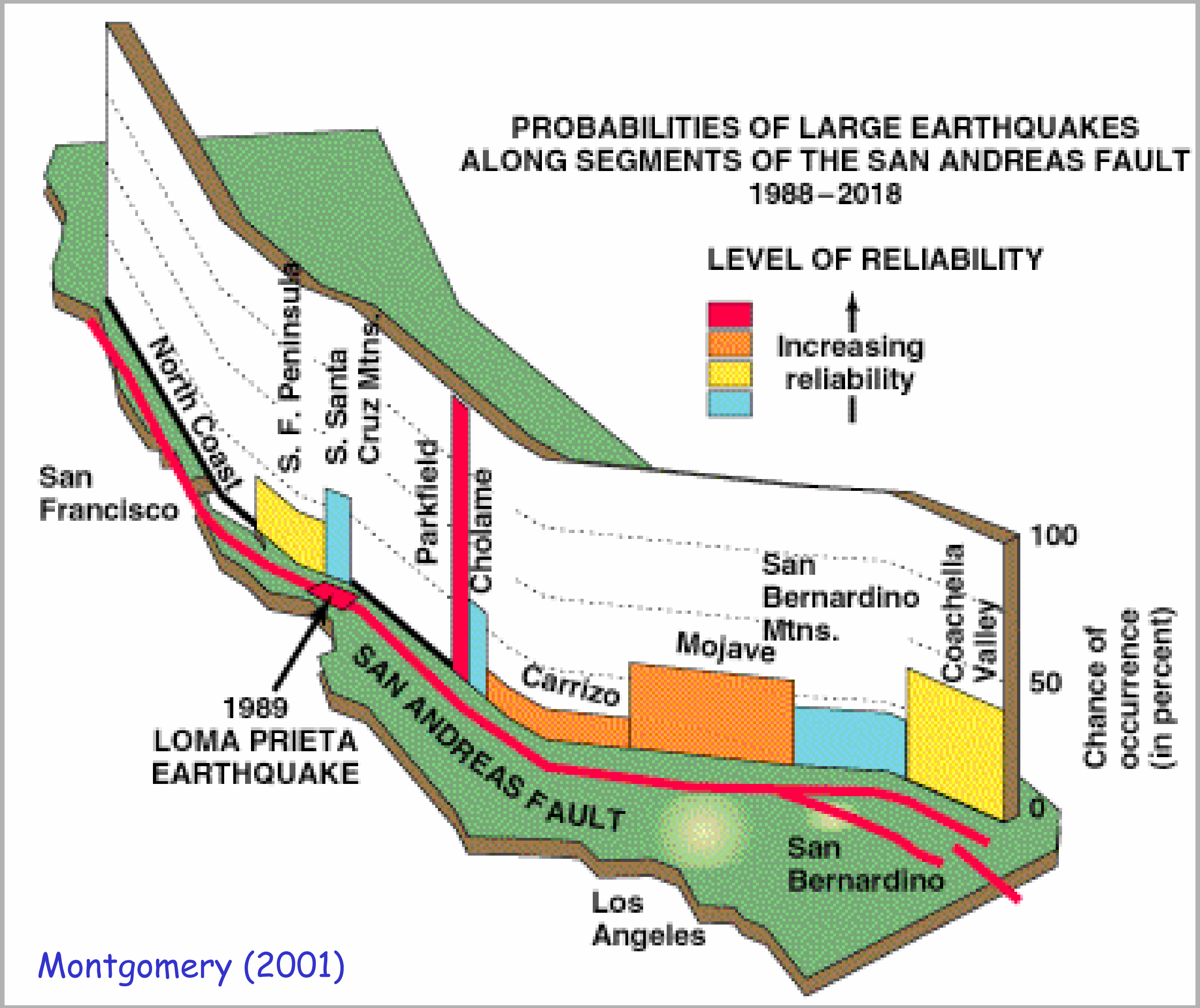
- Three methods can be applied to earthquake prediction
  - Statistical
  - Geophysical
  - Geological

Statistical

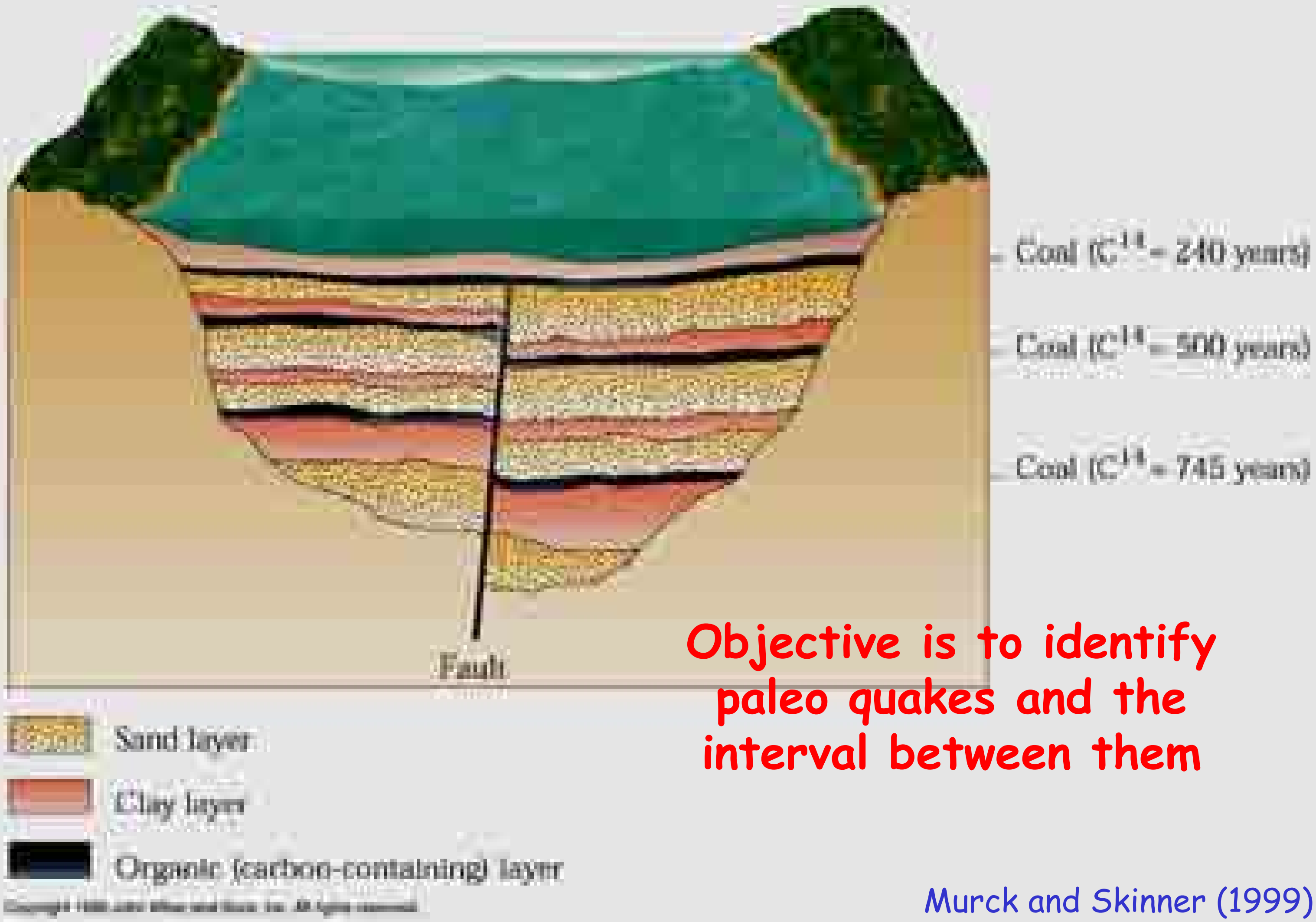
Seismic risk maps, constructed based on historic records and the distribution of known faults, can be used to assess the potential severity and likelihood of future earthquakes



Probabilities of Large Quakes along the San Andreas Fault



Paleoseismology



Objective is to identify paleo quakes and the interval between them

Murck and Skinner (1999)

Earthquake Precursors

- Short- and long-term changes within Earth in advance of earthquakes are known as precursors. They include:
  - Ground tilt
  - Earth magnetism
  - Conductivity
  - Radon levels
  - P wave velocity
- All of these are related to the concept of dilatancy

Dilatancy of highly stressed rocks

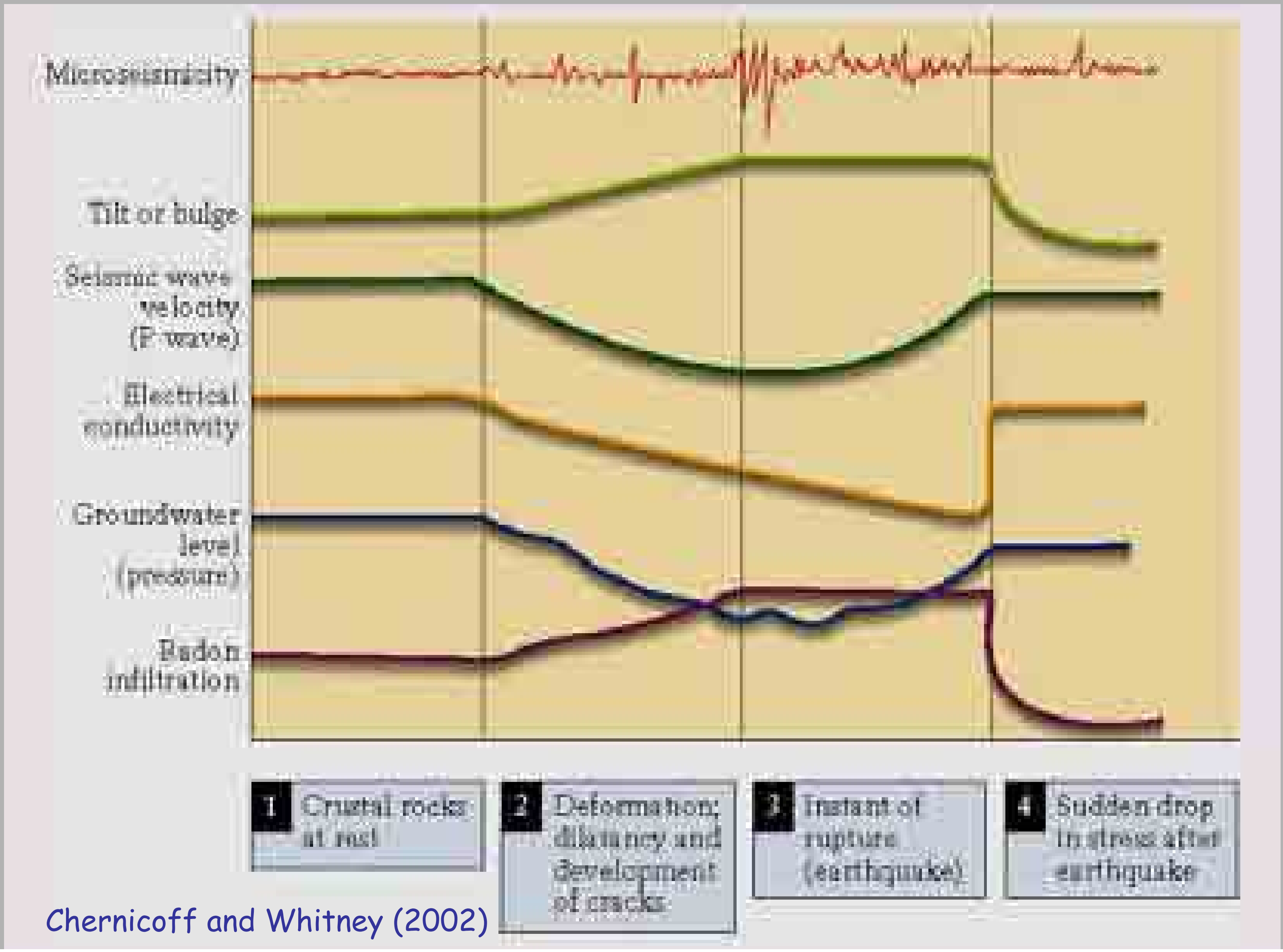
Rock dilatancy occurs when increased stress causes microfractures in the rocks increasing the volume. This can account for a number of earthquake precursors such as increased radon levels, decreased electrical resistivity and increased water levels in wells

Chernicoff and Whitney (2002)

Dilatancy

- One of the most important predictive tools is the change in P-wave velocity. The fracturing associated with dilatancy slows the P-waves, but as water occupies the cracks the P-waves speed up again. Consequently a quake may occur a day after the P-wave velocities return to normal. Generally the longer the period of reduced velocities the larger the subsequent quake

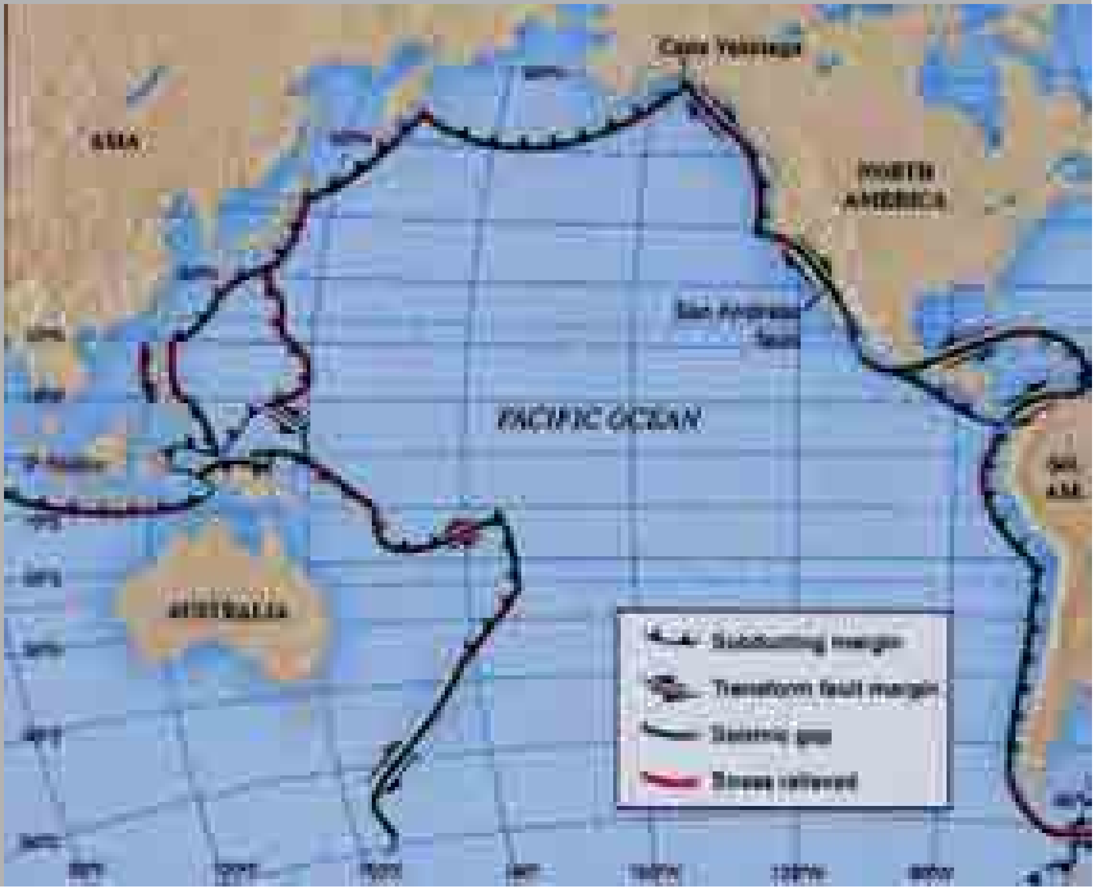
Dilatancy of highly stressed rocks.



Chernicoff and Whitney (2002)

Seismic gaps

- **Delineation of seismic gaps may prove useful for long-term predictions. Seismic gaps are locked areas along fault zones. Locked areas are not releasing energy and so there is long-term danger that continued accumulation of pressure could lead to major earthquakes in the future.**



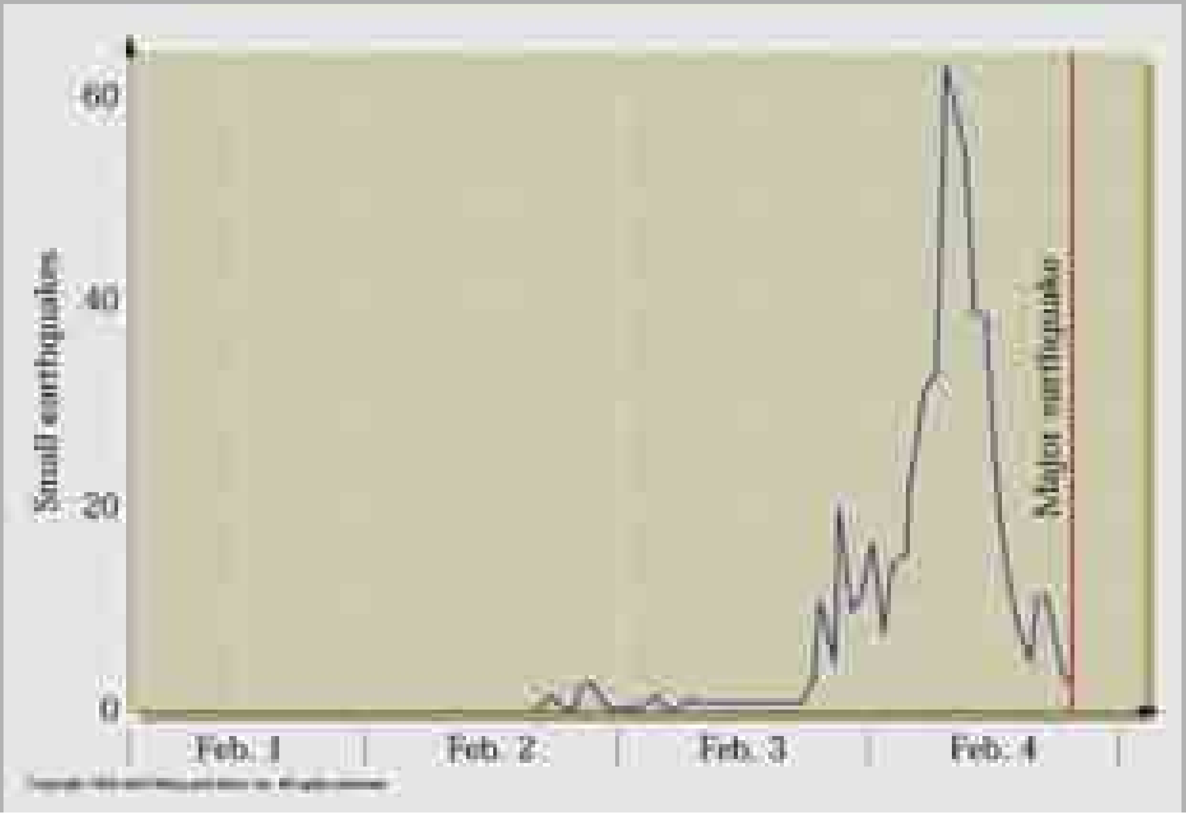
Chernicoff and Whitney (2002)

Seismic gaps

Chernicoff and Whitney (2002)

Foreshocks

At Haisheng, China the foreshocks peaked in frequency before the 1975 M = 7.3 quake



Murck and Skinner (1999)

Animals as predictors?

- Some animals have behaved abnormally prior to earthquakes
  - Tientsin Zoo, China, 1969. Depressed tiger and restless turtle 2 hours before M 7.4
  - Haicheng, China, 1975. 6 wks before M 7.3 snakes came out of hibernation, 1-2 days before pigs would not eat, 20 minutes before turtles climbed out of water and cried

Animals as predictors?

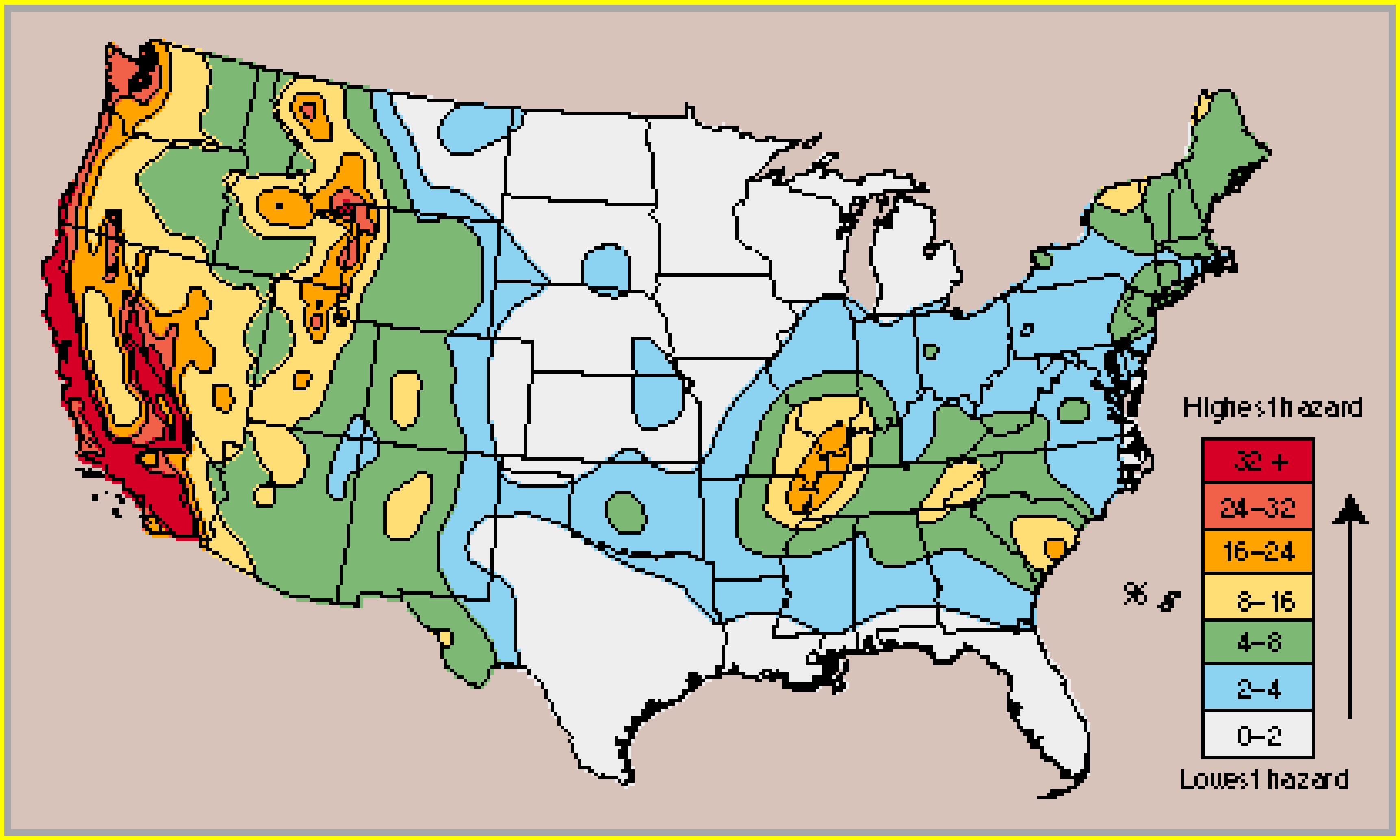
- Some animals have behaved abnormally prior to earthquakes
  - Tokyo, 1855. 1 day before M 6.9 rats disappeared
  - Concepcion, Chile, 1835. 1 hr before quake flock of sea birds flew inland and dogs left the city
  - San Francisco, 1906
  - Dogs barked all
  - night before M 8.3
  - quake
- Unreliable and unpredictable

Pipkin and Trent (1997)

Earthquake Prediction Programs

- The United States, Russia, Japan, and China are the only nations that have government-funded earthquake prediction programs.
- The Chinese have the most ambitious prediction program and emphasize precursors that can be observed or heard without sophisticated instruments.
- Earthquake prediction is progressing, but unsuccessful short-term predictions may lead to skepticism and disregard as is sometimes the case with hurricane, tornado, and tsunami warnings.

US High risk areas



Earthquake hazard map of USA, showing regions that are statistically most likely to have a damaging earthquake over the next 50 years

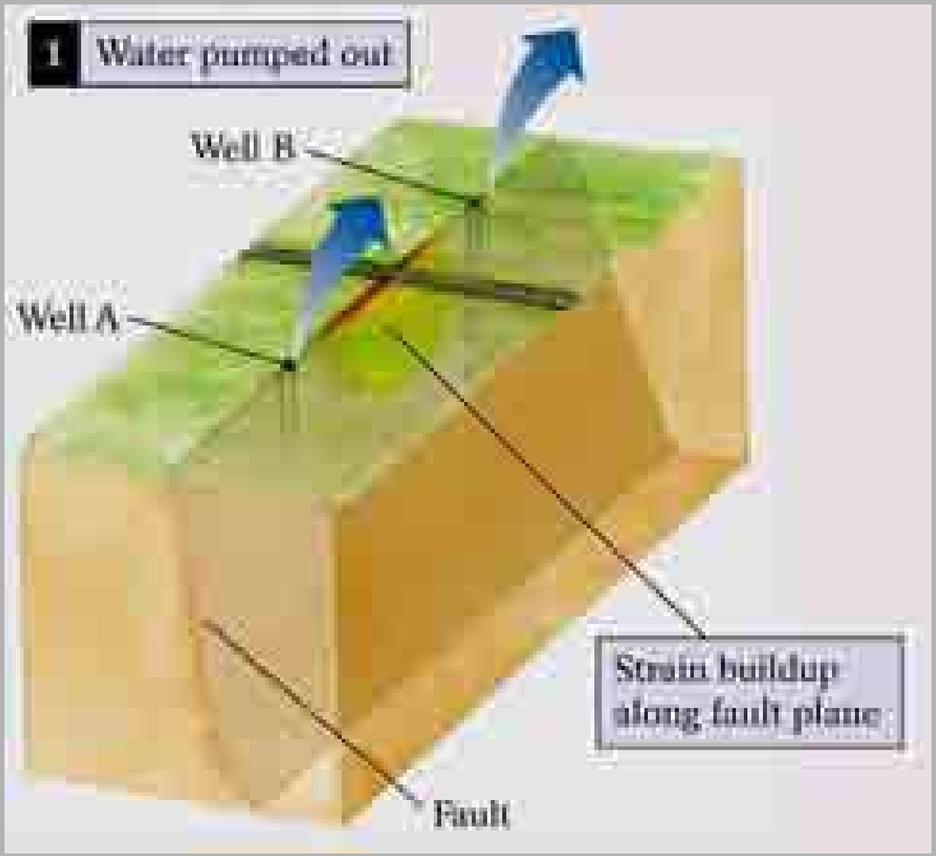
Controlling earthquakes

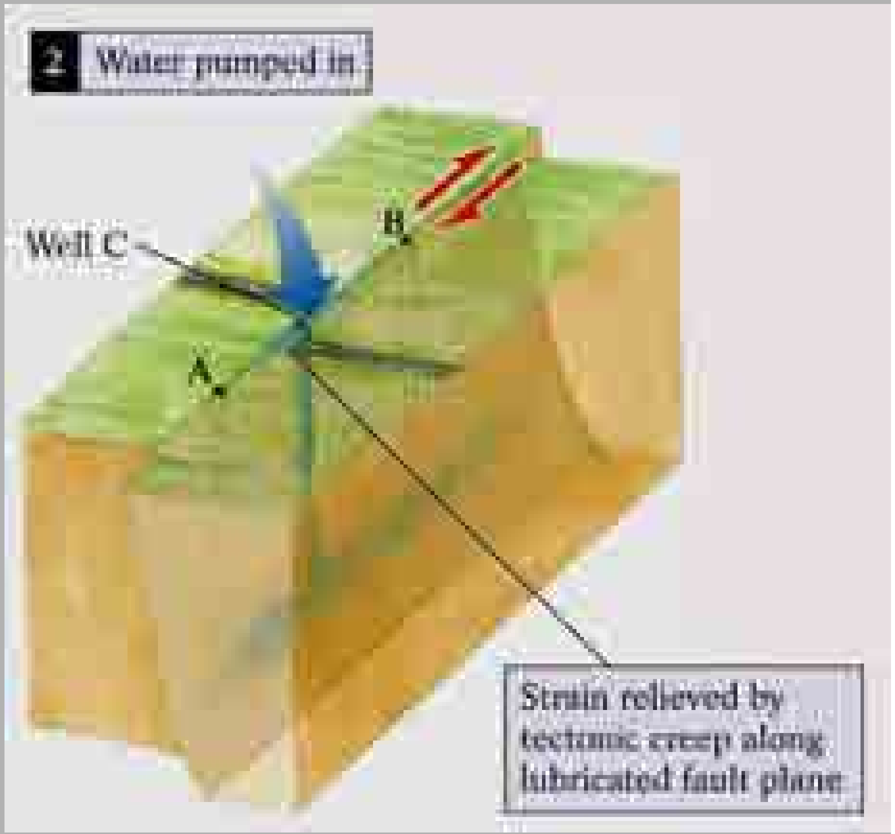
- It was once suggested that detonating nuclear bombs in the vicinity of major faults would be a good method of reducing the risk of earthquakes
- Earthquakes in Denver in the mid ‘60s have been associated with an Army liquid waste disposal well. It seems that the liquid lubricated old faults causing them to slip
- This led to the suggestion that fluid injection could be used to relieve stress on major faults, however, it is not certain what the effect would be. It could result in either a gradual or a sudden release of the stress.
- As with earthquake prediction there are numerous potential problems with these methods, particularly in the US where litigation is very common

Can Earthquakes Be Controlled?

- Experiments in an abandoned oil field near Rangely, Colorado, established a relationship between pore-water pressure and earthquakes.
- As pore-water pressure increases, rock strength decreases such that rocks with higher pore-water pressures will fail more easily.
- It has been proposed that large earthquakes might be avoided by manipulating pore-water pressure in rocks along locked faults so as to release pressure gradually in a series of small earthquakes.
- More research needs to be completed before this technique can be tested.
- For now, the best defense against earthquakes remains careful planning and preparation.

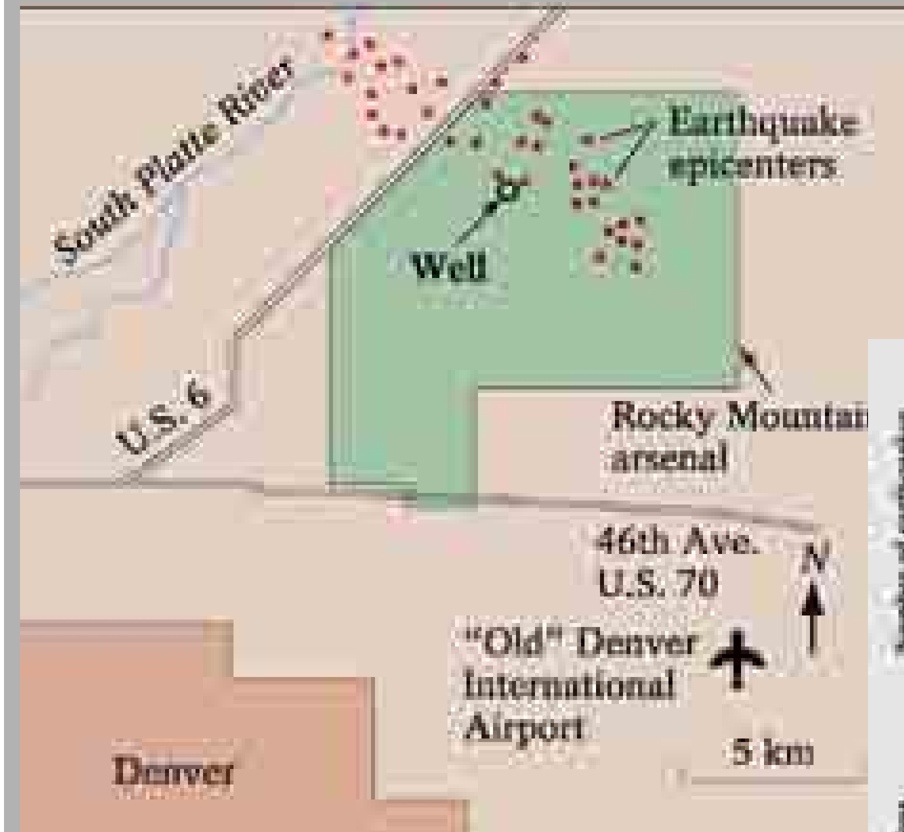
US Geological Survey plan

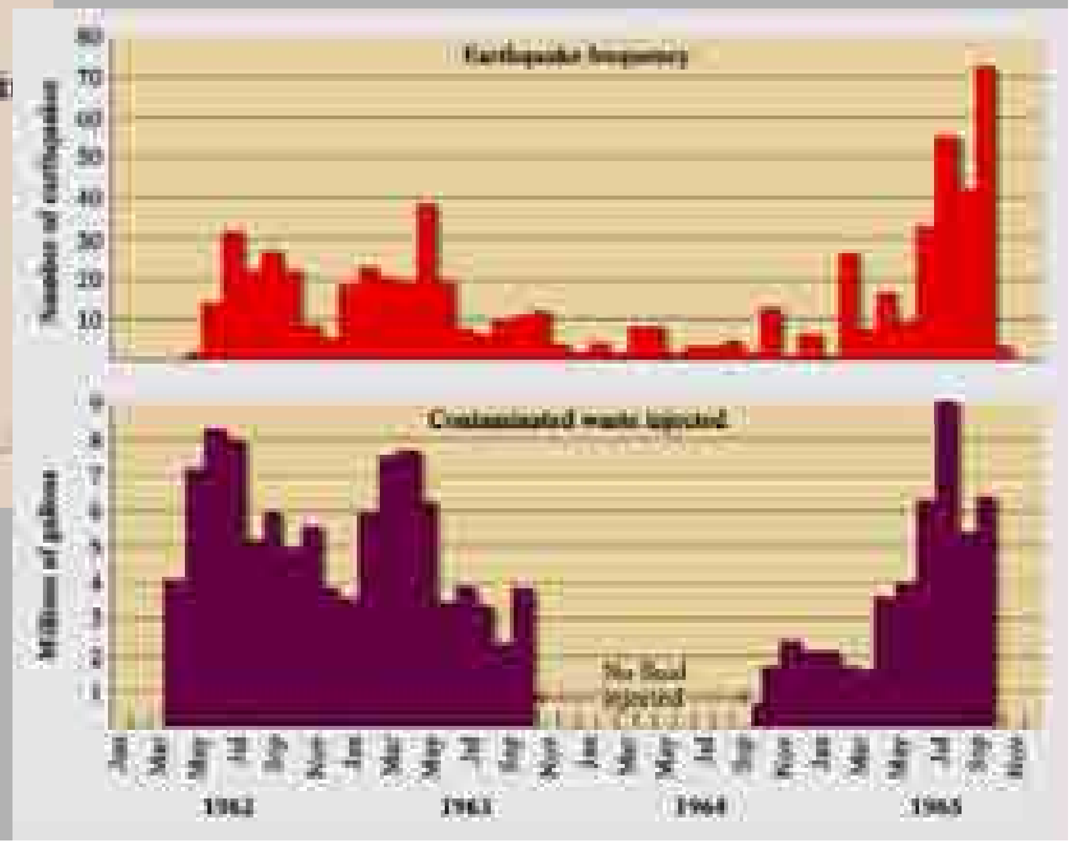




Chernicoff and Whitney (2002)

Denver earthquakes.





Chernicoff and Whitney (2002)

Mitigation

- By studying the effects of earthquakes engineers have developed building codes in order to construct “earthquake-resistant” buildings. While this has likely saved lives in many recent quakes there are limitations
- The epicentre of the Northridge quake was very close to that of the 71 San Fernando quake. The buildings damaged in ’71 were rebuilt to be resistant to predominantly horizontal ground motion. Unfortunately the Northridge quake included a large vertical component
- A concrete building designed to withstand a 1 minute quake will not necessarily survive a 3 minute quake
- It would be extremely expensive to build new buildings to be resistant to almost any imaginable earthquake. Let alone redesign existing buildings

Summary

- Factors affecting the impact on humans
  - Magnitude of the earthquake
  - Density of the population
  - Degree of preparedness
  - Timing of the earthquake