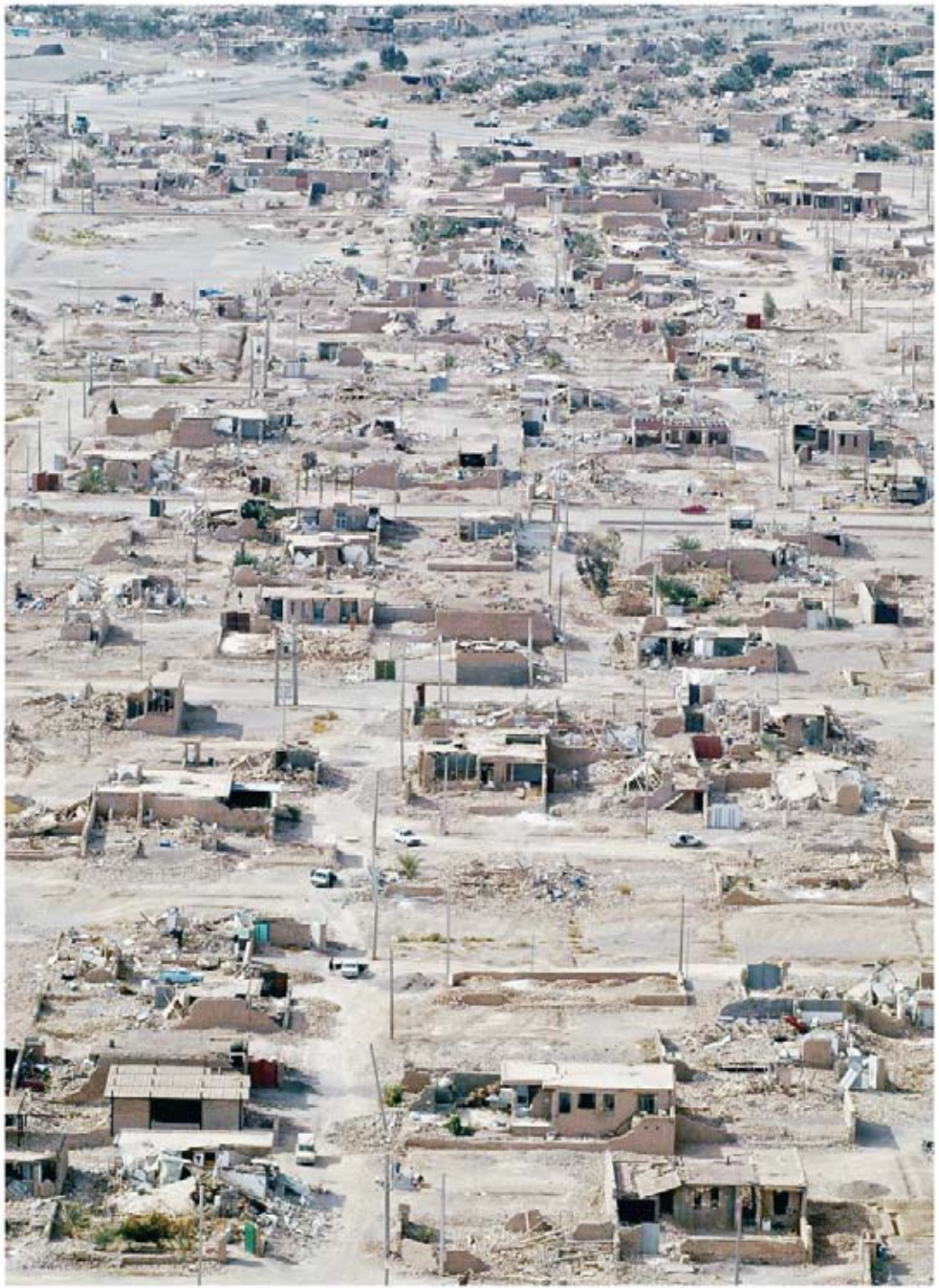
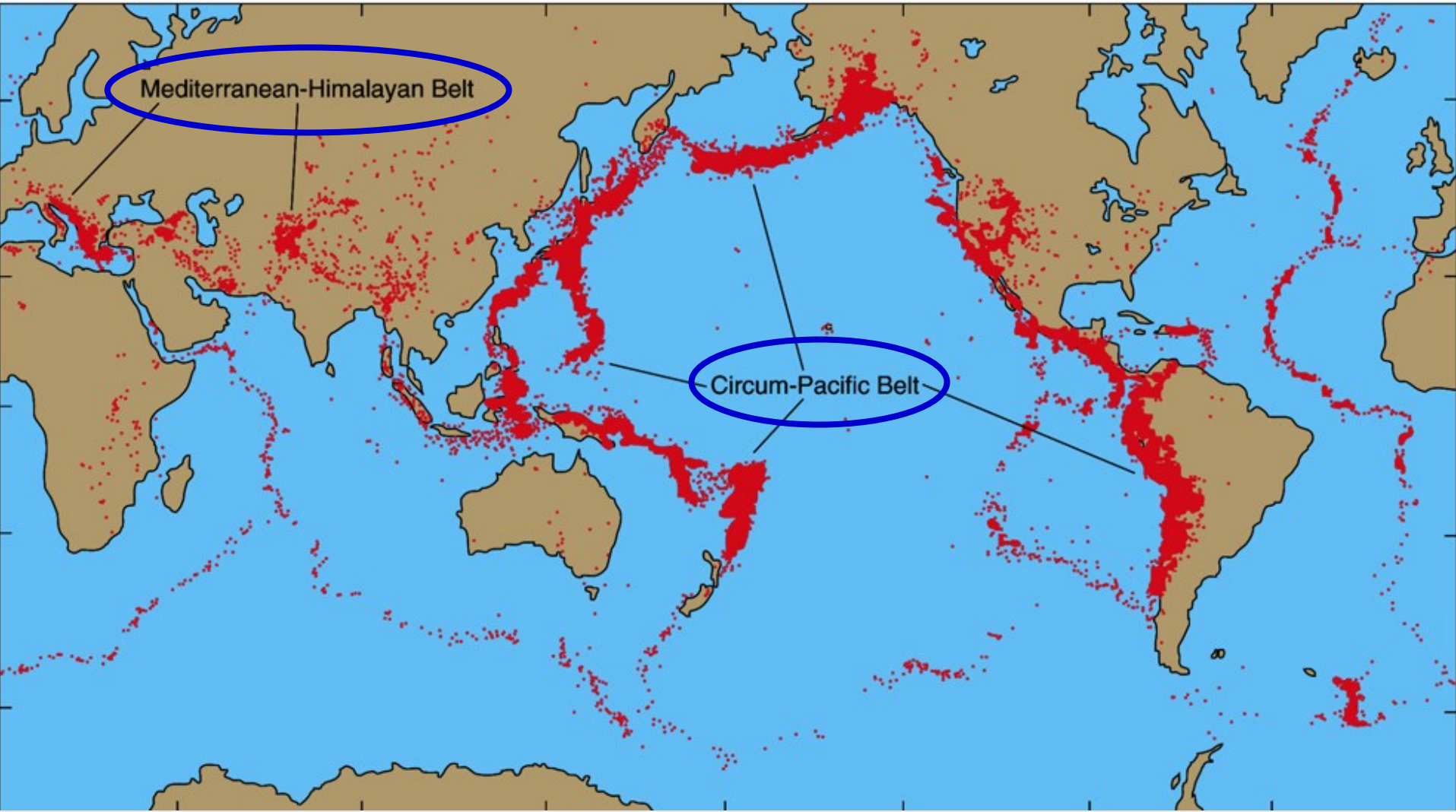
# Chapter 2
# Earthquakes



# Earthquakes destroy buildings, buildings kill people

# Earthquakes related to plate tectonics

## Primary earthquake belts or zones



# Fault activity

***Active*** – moved during past 10,000 years

***Potentially Active*** – moved during the past 2 million years

***Inactive*** – has NOT moved during the past 2 million years

# Earthquake magnitude and frequency

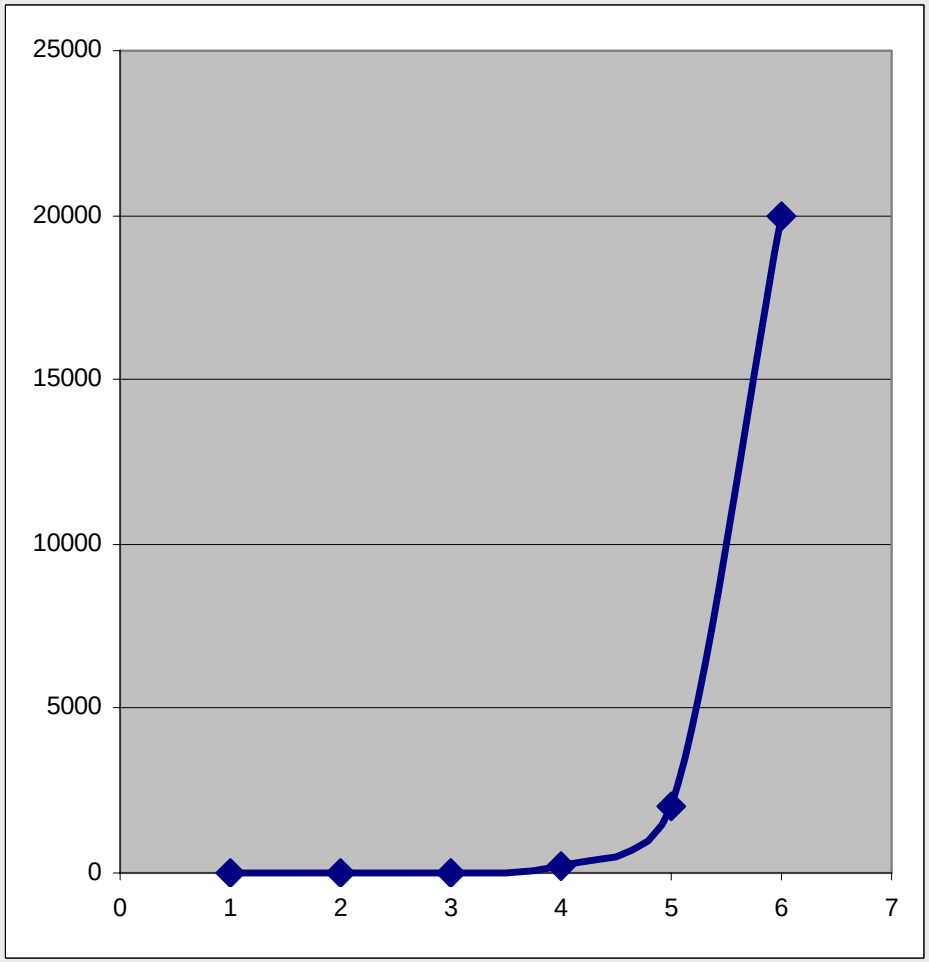
**TABLE 2.2 Frequency of Earthquakes by Descriptor Classification**

| Descriptor | Average Annual Magnitude | Number of Events |
|---|---|---|
| Great | 8 and higher | 1 |
| Major | 7–7.9 | 17 |
| Strong | 6–6.9 | 134 |
| Moderate | 5–5.9 | 1319 |
| Light | 4–4.9 | 13,000 (estimated) |
| Minor | 3–3.9 | 130,000 (estimated) |
| Very Minor | 2–2.9 | 1,300,000 (estimated) (approx. 150 per hour) |

*Source: U.S. Geological Survey. 2007.* Earthquakes facts and statistics. *http://neic.usgs.gov/neis/eqlists/eqstats.html. Accessed 6/12/07.*

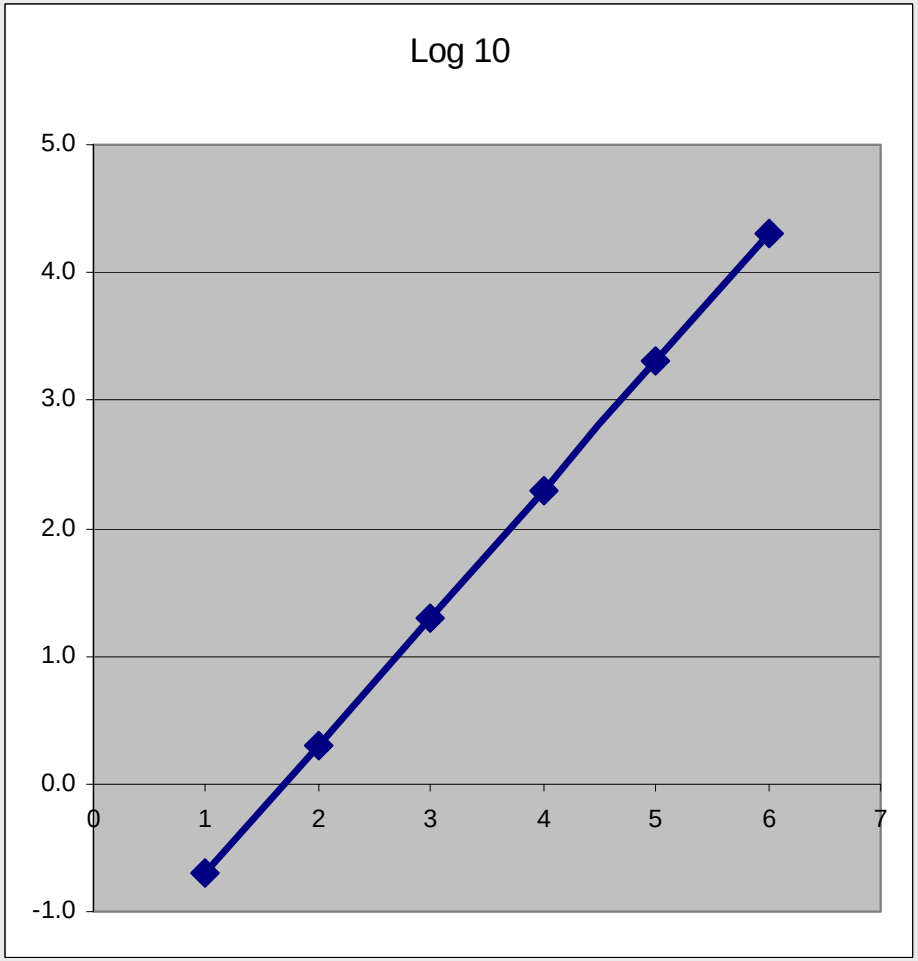
# A logarithmic or exponential increase

| x | Linear |
|---|---|
| 1 | 0.2 |
| 2 | 2 |
| 3 | 20 |
| 4 | 200 |
| 5 | 2000 |
| 6 | 20000 |



# A logarithmic or exponential increase

| x | Linear | Log 10 |
|---|---|---|
| 1 | 0.2 | -0.7 |
| 2 | 2 | 0.3 |
| 3 | 20 | 1.3 |
| 4 | 200 | 2.3 |
| 5 | 2000 | 3.3 |
| 6 | 20000 | 4.3 |

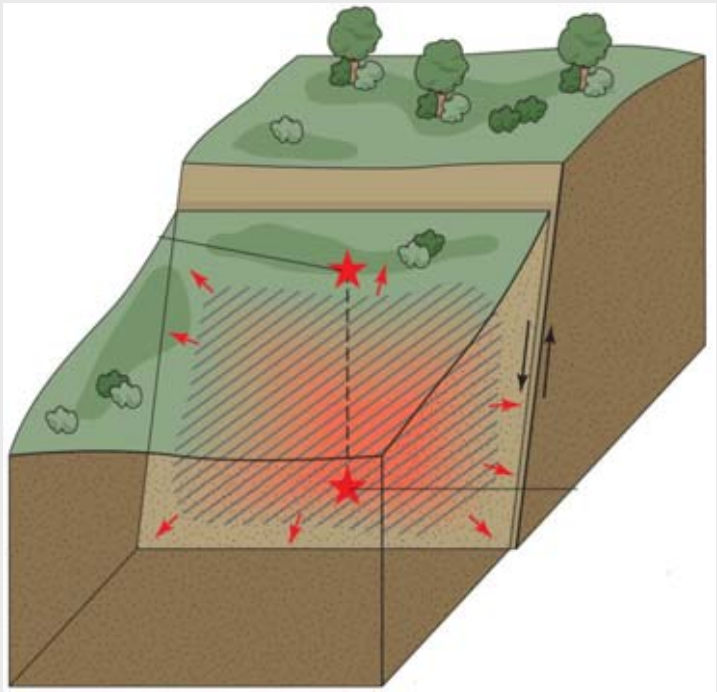


# Earthquake magnitude

The Richter Scale – no longer used

**Moment Magnitude** – currently used

estimate of the area that ruptured along a fault plane during the quake



Related measure:
total energy released by the earthquake

# Earthquake magnitude

**TABLE 2.3 Change in Ground Motion and Energy Released from an Incremental Change in Earthquake Magnitude**

| Units of Magnitude Change | Ground Motion Change[1] | Change in Amount of Energy Released |
|---|---|---|
| 1 | 10 times | About 32 times |
| 0.5 | 3.2 times | About 5.5 times |
| 0.3 | 2 times | About 3 times |
| 0.1 | 1.3 times | About 1.4 times |

[1] As reflected in the maximum amplitude of seismic waves on a standard seismograph. Amplitude is the distance that a seismic wave is displaced from a baseline (zero line) that is established when no seismic waves are detected.

*Source: U.S. Geological Survey. 2007.* Earthquakes, facts and statistics. http://neic.usgs.gov/neis/eqlists/eqstats.html. *Accessed 6/12/07.*

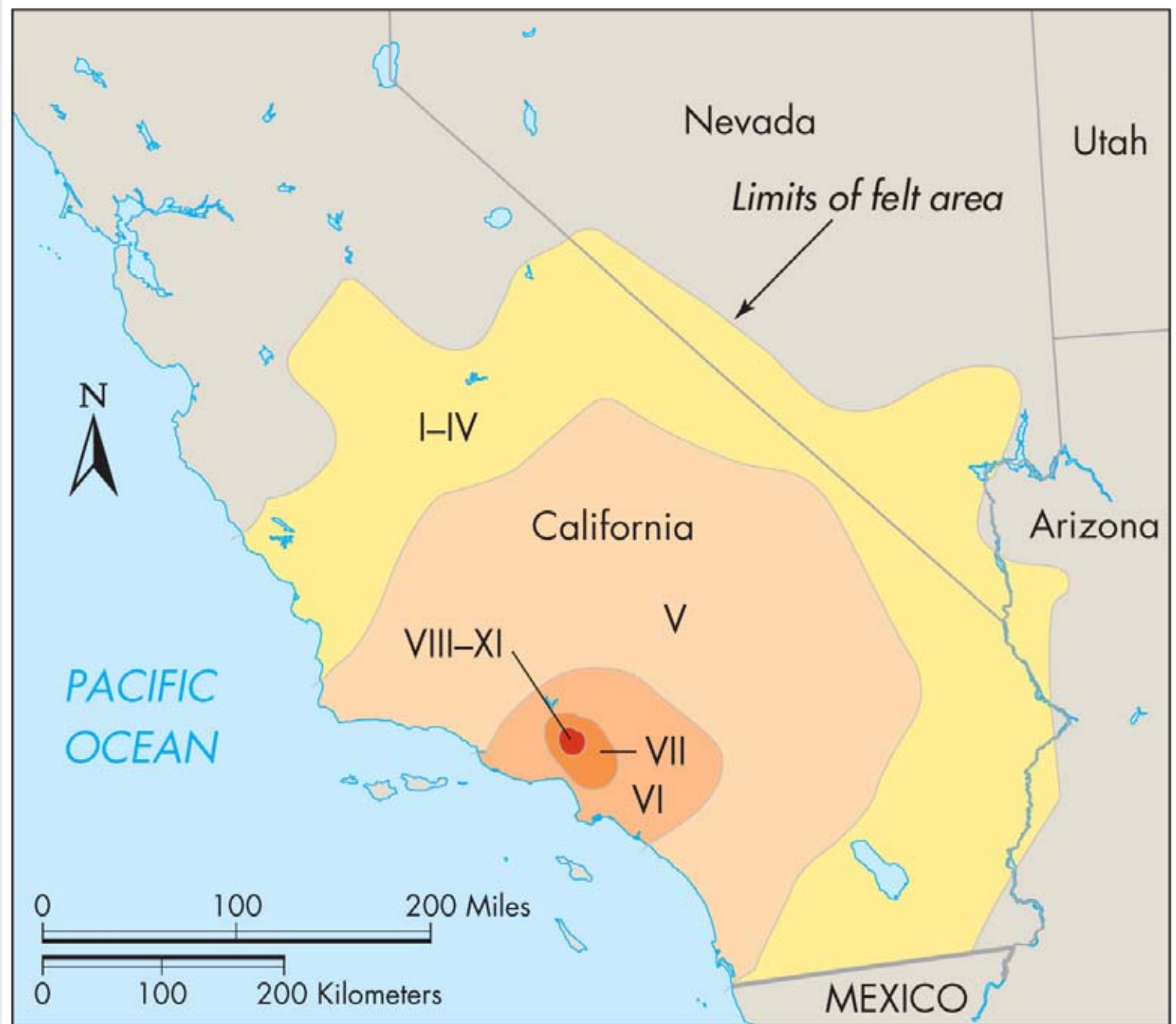
# Intensity: Modified Mercalli scale

**TABLE 2.4 Abbreviated Modified Mercalli Intensity Scale**

| Intensity | Effects |
|---|---|
| I | Felt by very few people under especially favorable conditions. |
| II | Felt by only a few persons at rest, especially on upper floors of buildings. |
| III | III Felt indoors May not recognize as an earthquake. ot recognize it as an earthquake. |
| 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 vehicles rock noticeably. |
| V | Felt by nearly everyone; many awakened. Some dishes and windows broken. Unstable objects overturned. |
| VI | Felt by all; many frightened. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. |
| VII | VII Moderate damage to ordinary structures o moderate in well-built ordinary structures; s broken. Noticed by vehicle drivers. |
| 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, and walls. Heavy furniture overturned. Disturbs vehicle drivers. |
| IX | IX Masonry and frame structures destroyed, train rails bent of plumb. Damage great es broken. |
| X | Some well-built wooden structures are destroyed; most masonry and frame structures with foundations destroyed; train rails bent. |
| XI | Few, if any masonry structures remain standing. Bridges destroyed. Underground pipelines taken out of service. Train rails bent greatly. |
| XII | XII Damage total ground surfaces. Lines of sight and level are distorted. Objects thrown into the air. |

*Source: Modified after U.S. Geological Survey Earthquake Hazards Program http://earthquake.usgs.gov/learning/topics/mercalli.php. Accessed 6/12/07.*

# Modified Mercalli Intensity Map




Sylmar
California
1971

**M** 6.7

# Instrumental intensity

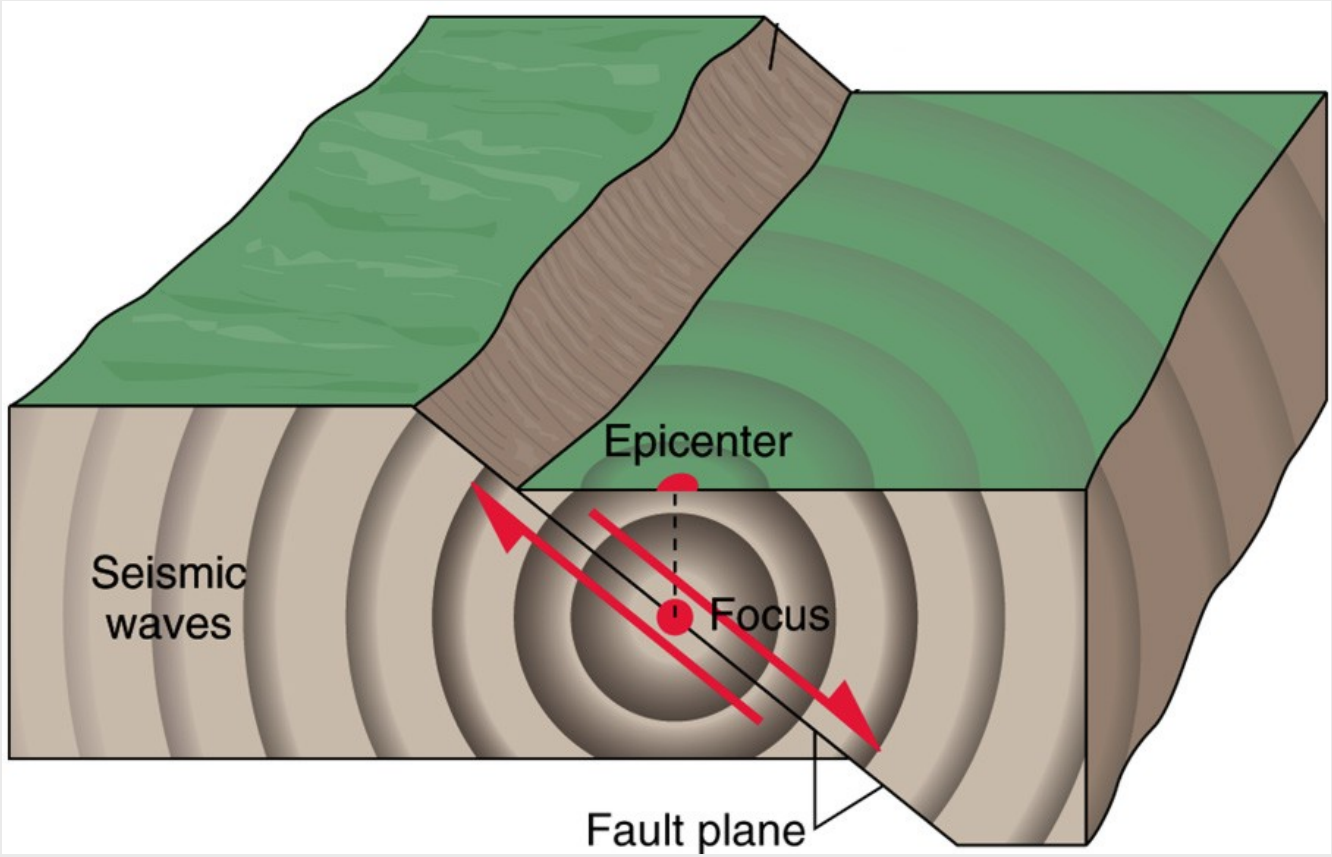

| Instrumental intensity | I | II-III | IV | V | VI | VII | VIII | IX | X+ |
|---|---|---|---|---|---|---|---|---|---|
| Shaking | not felt | weak | light | moderate | strong | very strong | severe | violent | extreme |
| Damage | none | none | none | very light | light | moderate | moderate/heavy | heavy | very heavy |

Northridge
California
1994

**M** 6.7

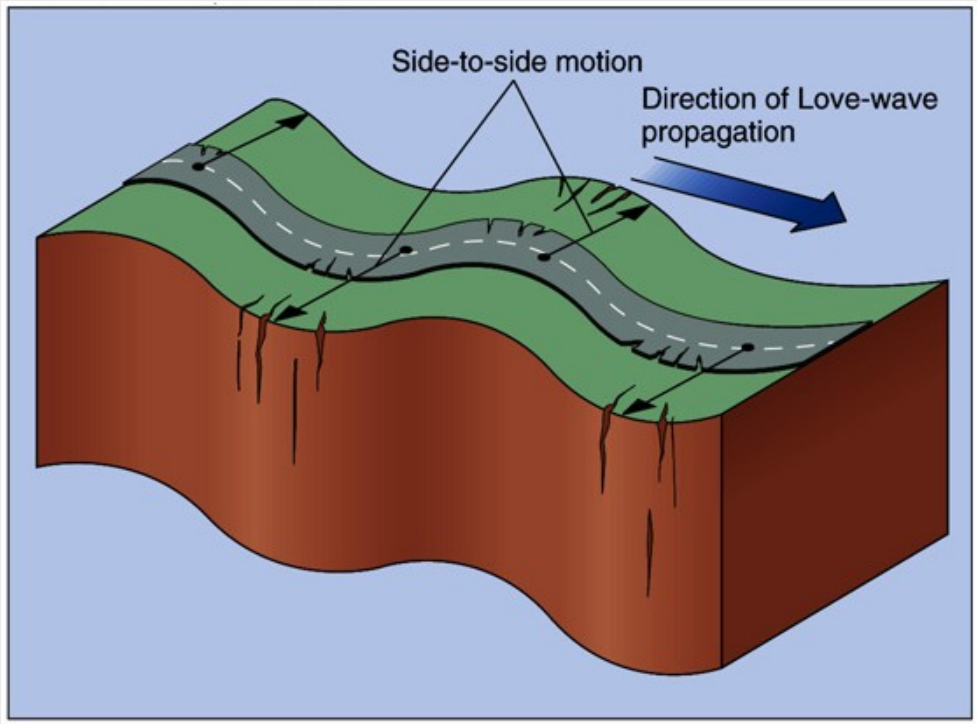
# Seismic waves produced by an earthquake

Body waves – spherical waves through the ***body*** of the Earth



# Seismic waves produced by an earthquake

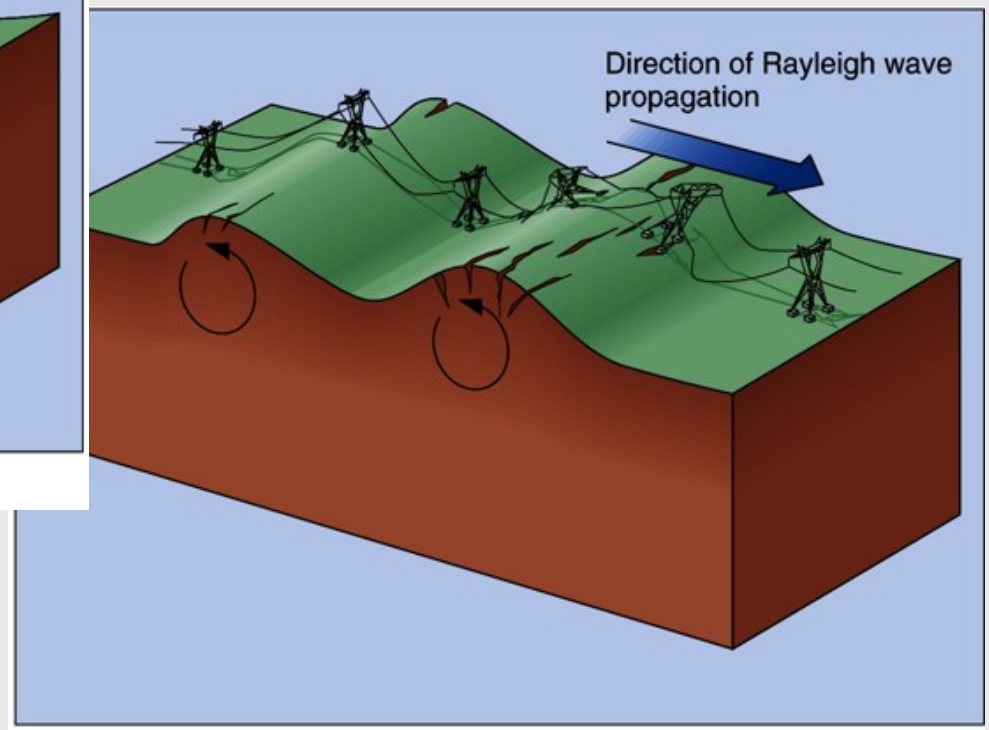
## Surface waves – responsible for most damage




C Love wave

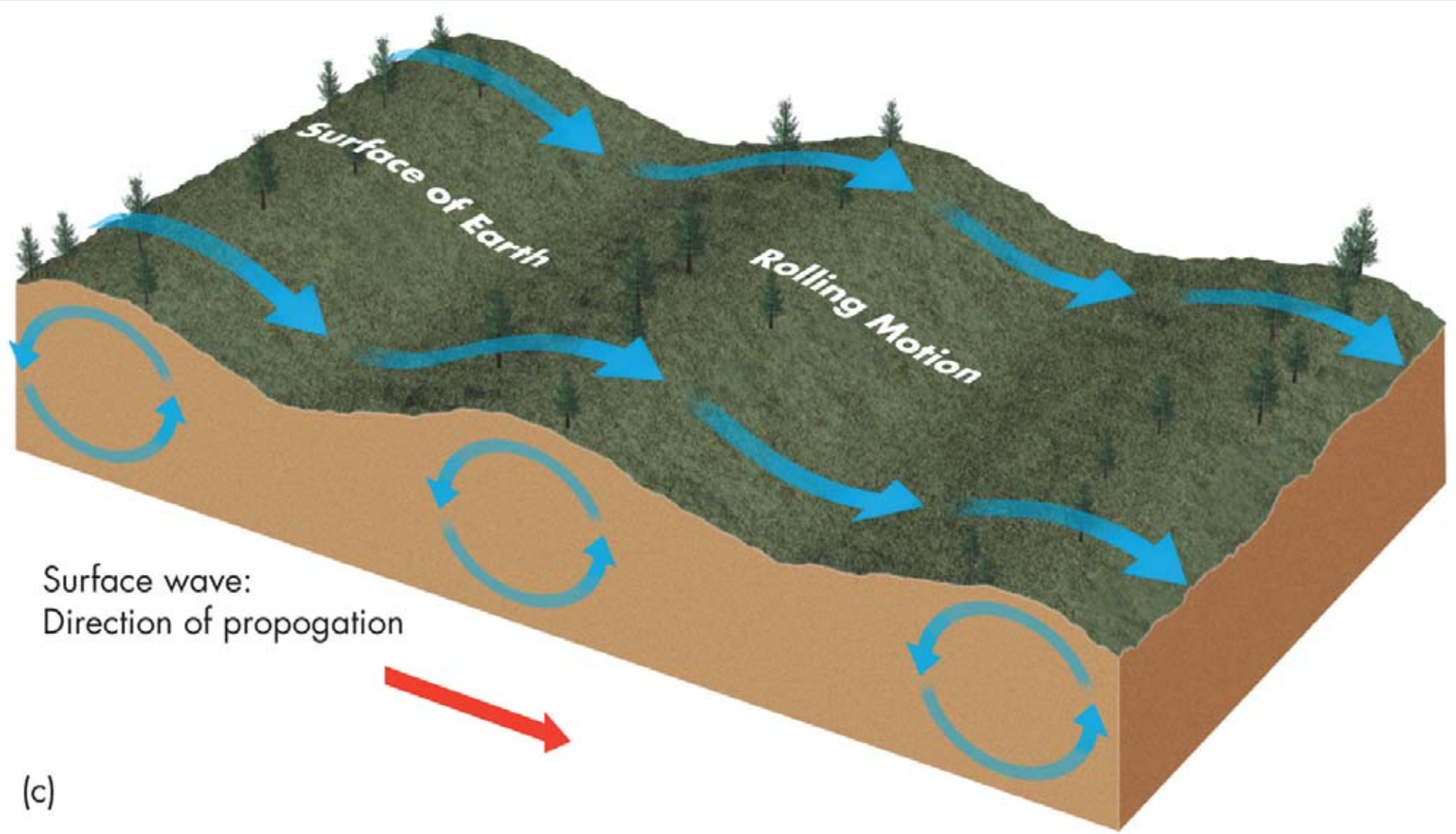
Love wave

Rayleigh wave




D Rayleigh wave

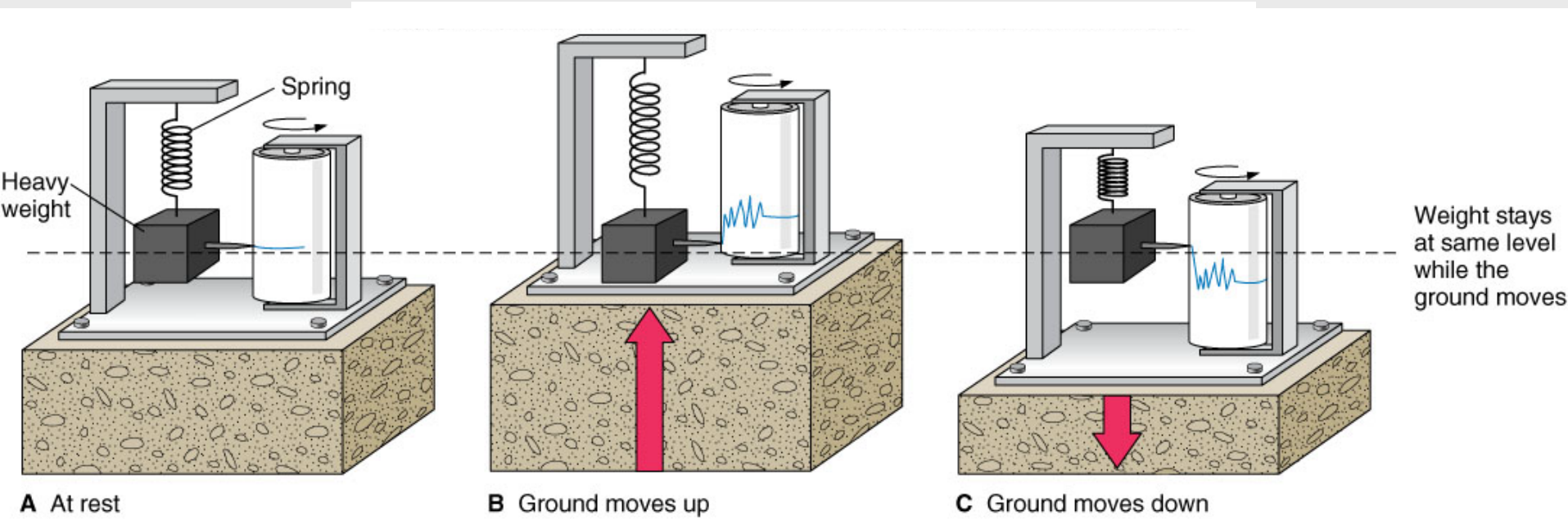
Figure 2.12c


Surface of Earth
Rolling Motion
Surface wave:
Direction of propogation
(c)

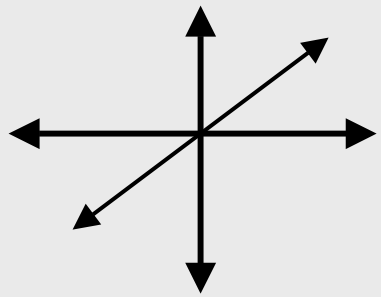
# ANIMATIONS OF
# PRIMARY & SECONDARY SEISMIC WAVES

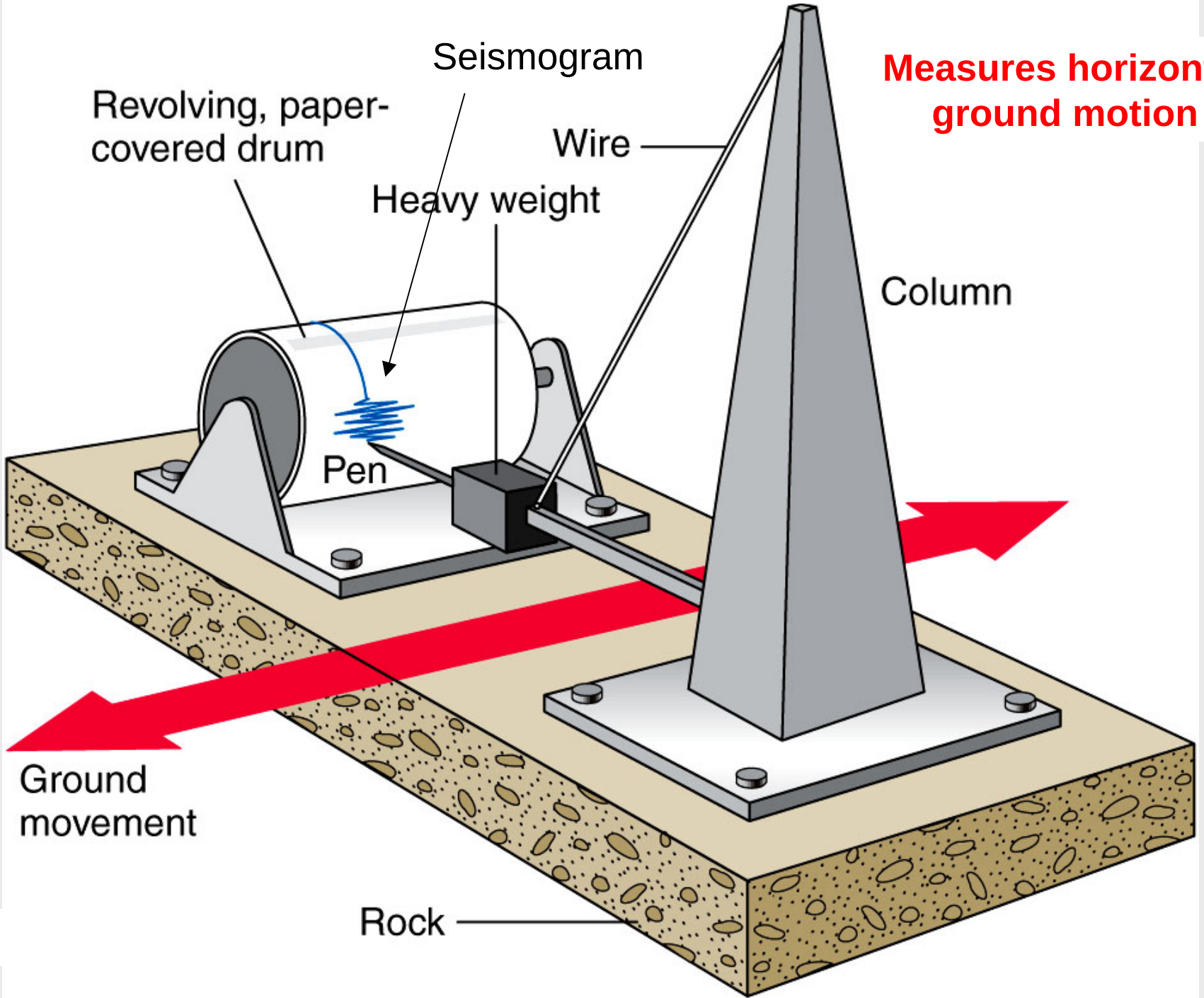
# ANIMATIONS OF SURFACE & BODY SEISMIC WAVES

# Seismograph – measures ground motion

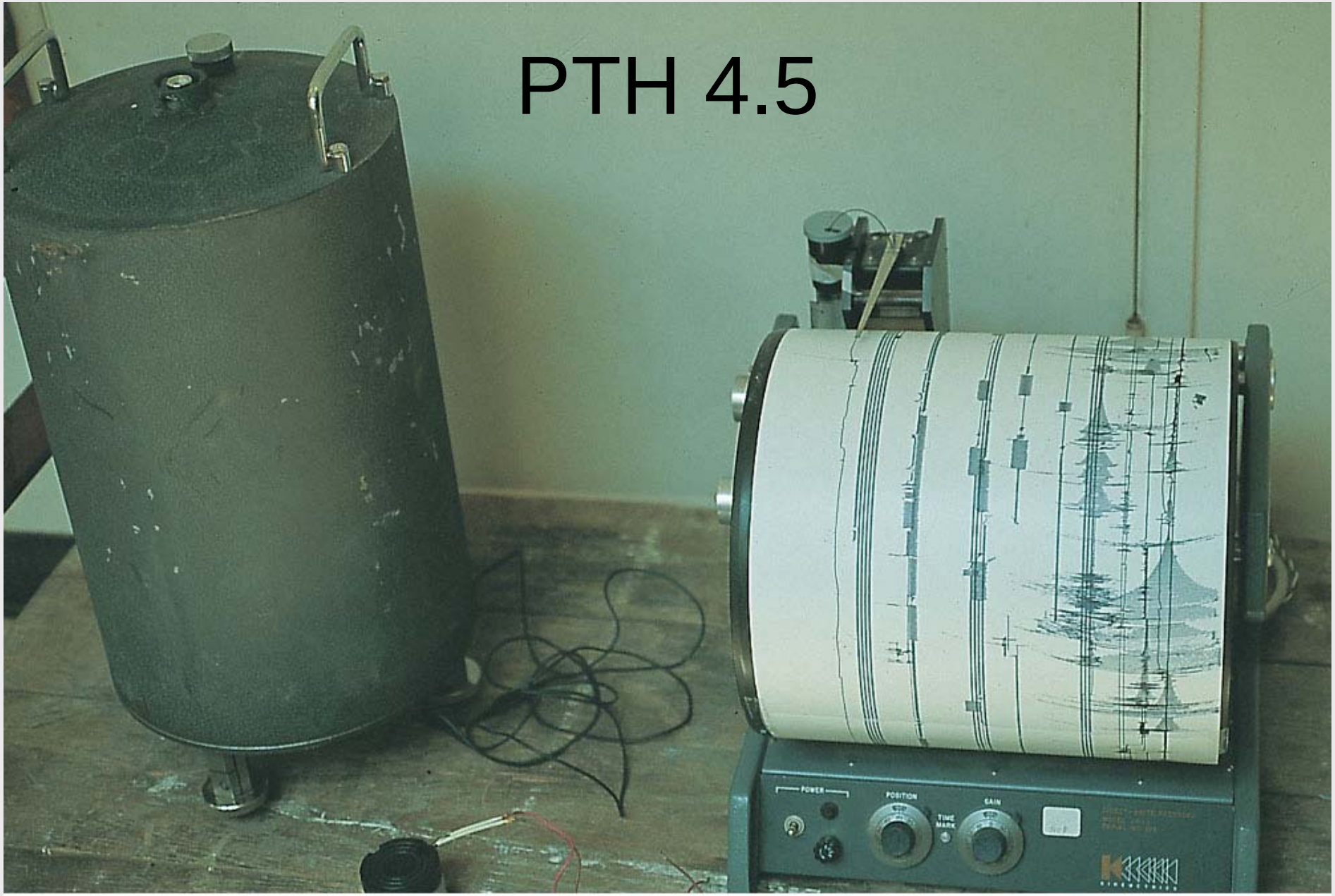



Motion in the three primary directions: X Y Z






**Measures horizontal ground motion**

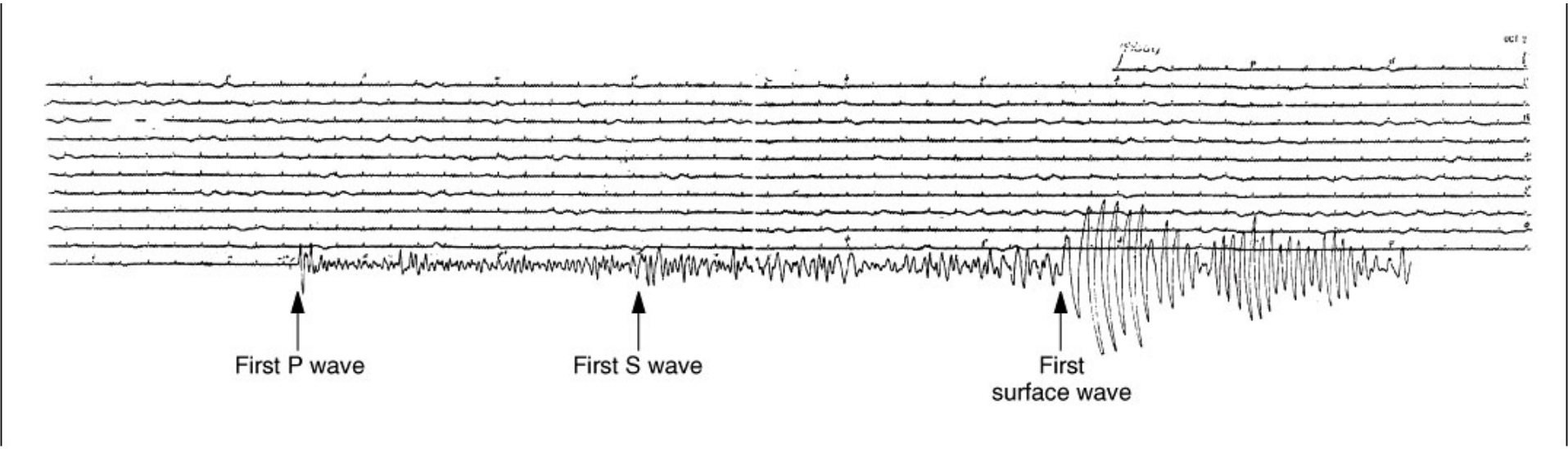



Inertial seismograph with a seismogram.

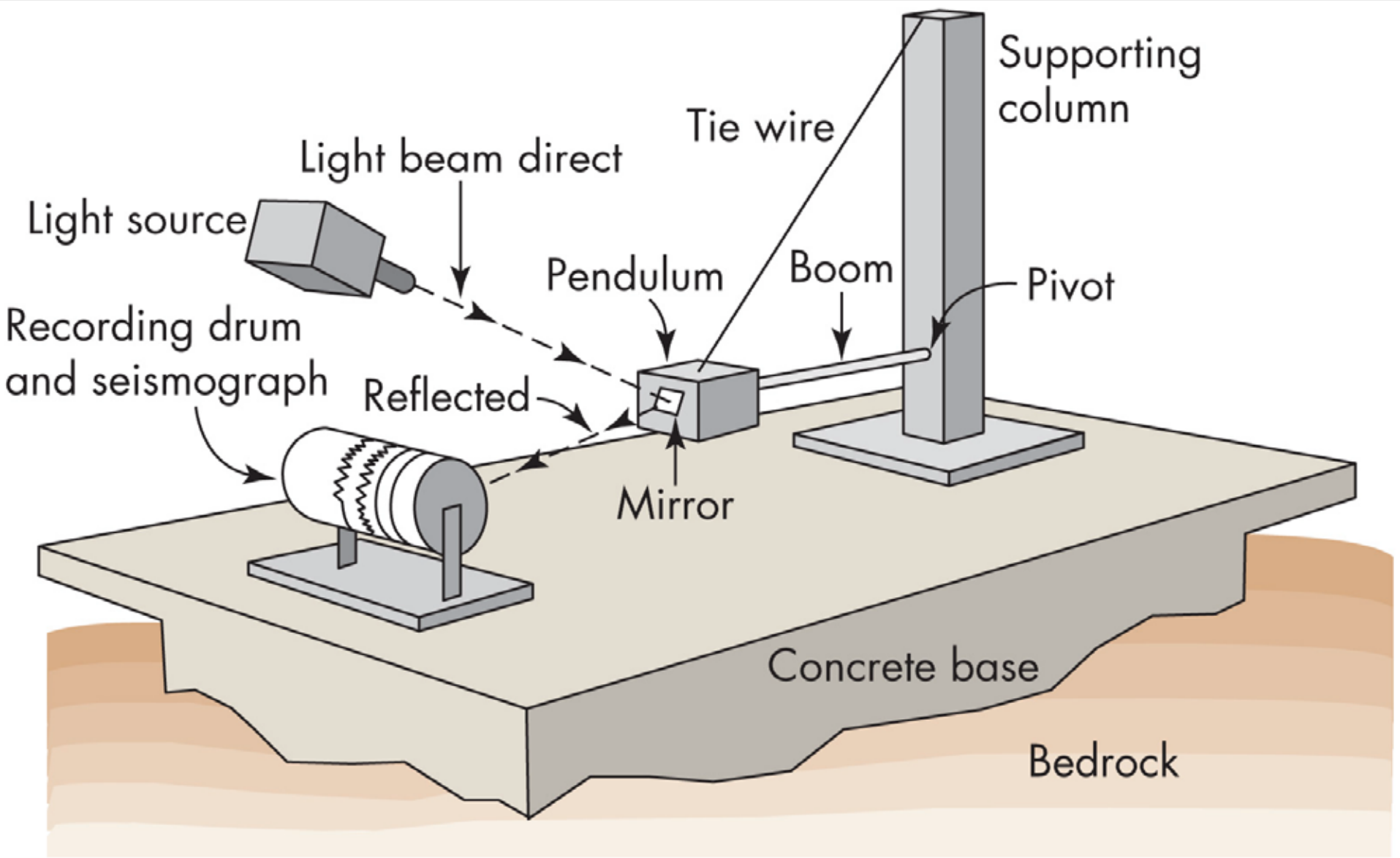
# ANIMATION OF A SEISMOGRAPH

# Seismogram: record of an earthquake

A ***seismogram*** is the recording of the earthquake ground motions made by a ***seismograph***.

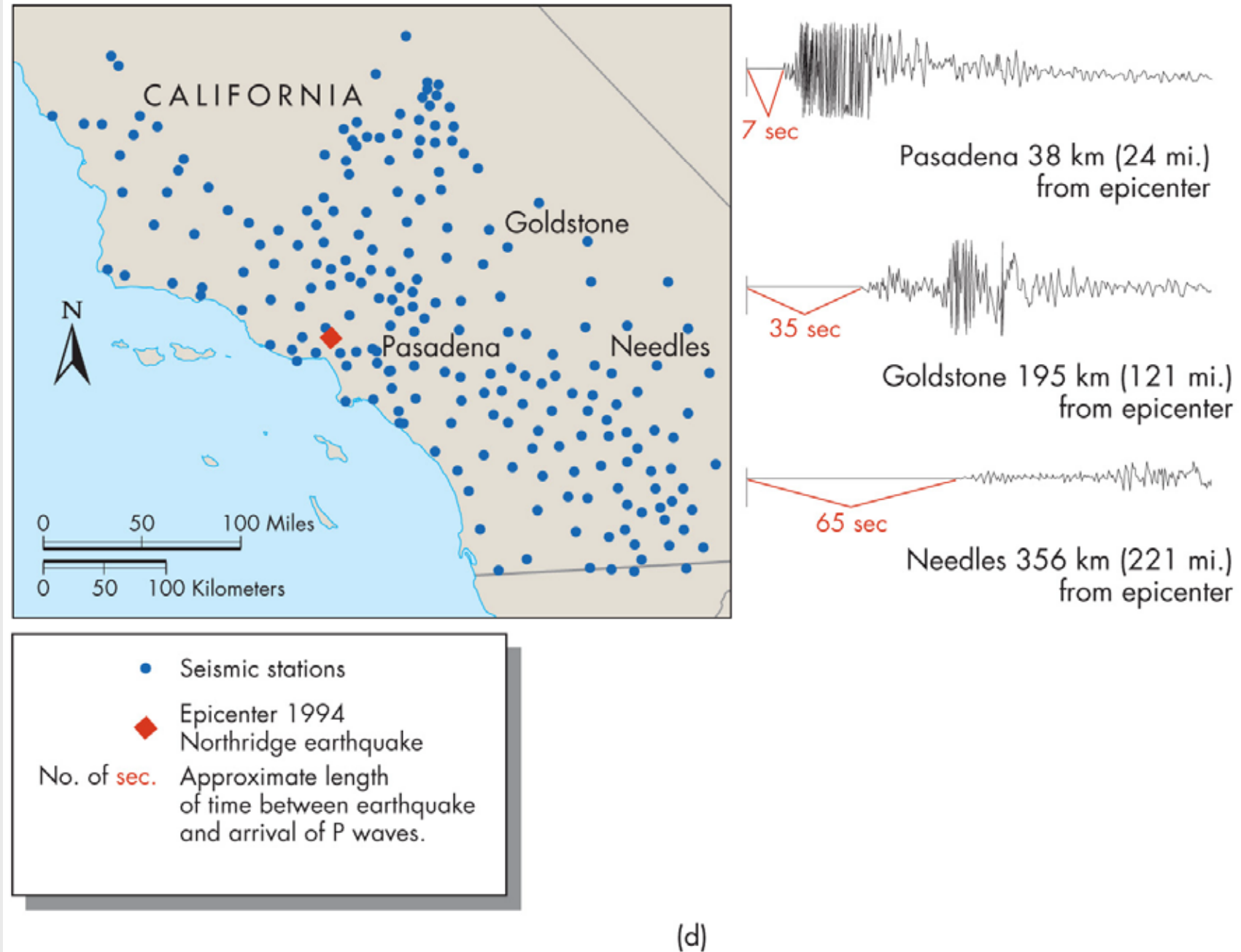


# Modern seismograph




(a)

# California seismic network



# Triangulating an earthquake epicenter


*******

NEED three seismic stations at a minimum

*******

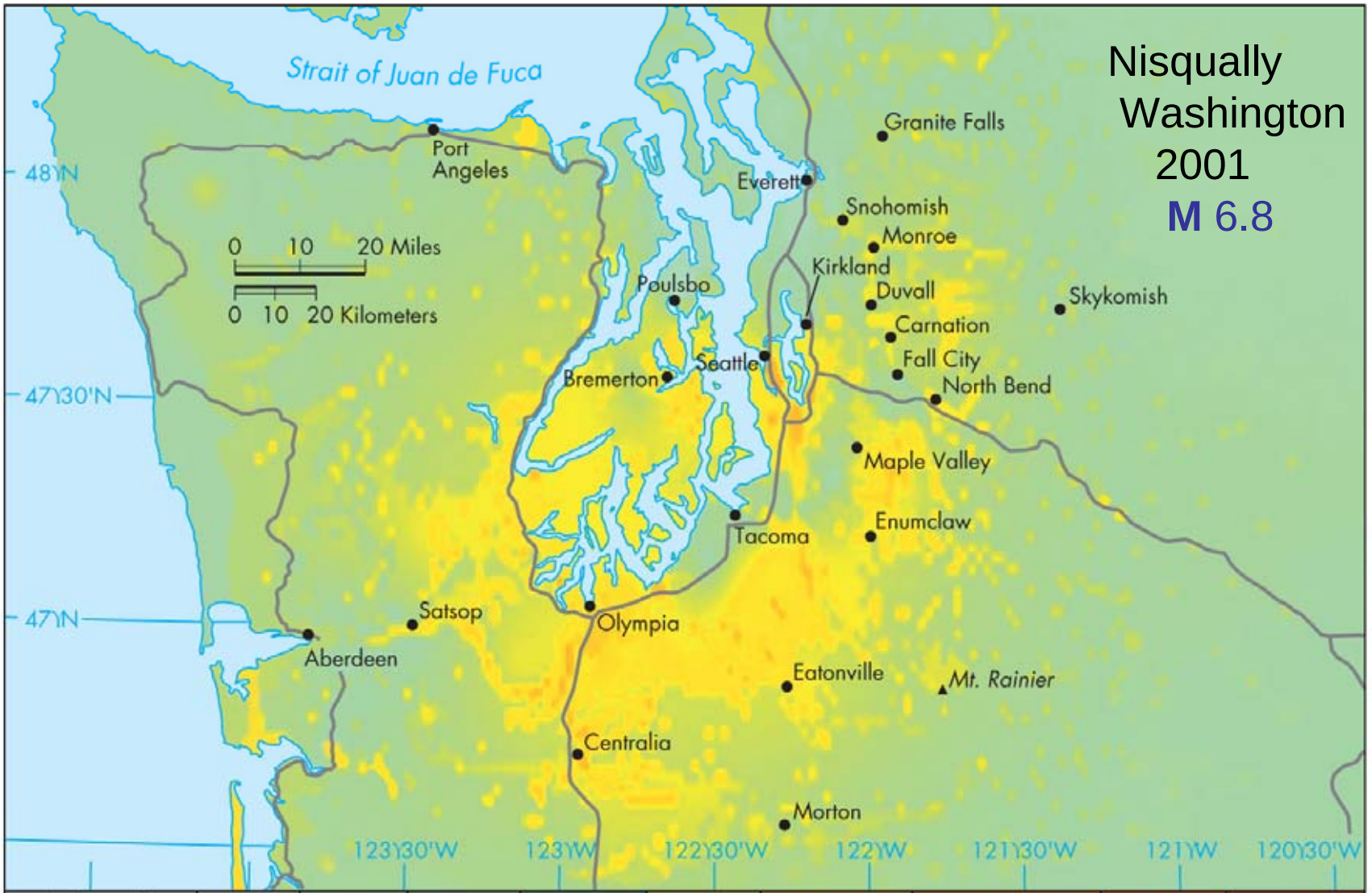
# Instrumental intensity


| Instrumental intensity | I | II-III | IV | V | VI | VII | VIII | IX | X+ |
|---|---|---|---|---|---|---|---|---|---|
| Shaking | not felt | weak | light | moderate | strong | very strong | severe | violent | extreme |
| Damage | none | none | none | very light | light | moderate | moderate/heavy | heavy | very heavy |

Northridge
California
1994

**M** 6.7

# Instrumental intensity




| Instrumental intensity | I | II-III | IV | V | VI | VII | VIII | IX | X+ |
|---|---|---|---|---|---|---|---|---|---|
| Shaking | not felt | weak | light | moderate | strong | very strong | severe | violent | extreme |
| Damage | none | none | none | very light | light | moderate | moderate/heavy | heavy | very heavy |

What's different?

# Factors that affect land-surface shaking

(1) Earthquake magnitude

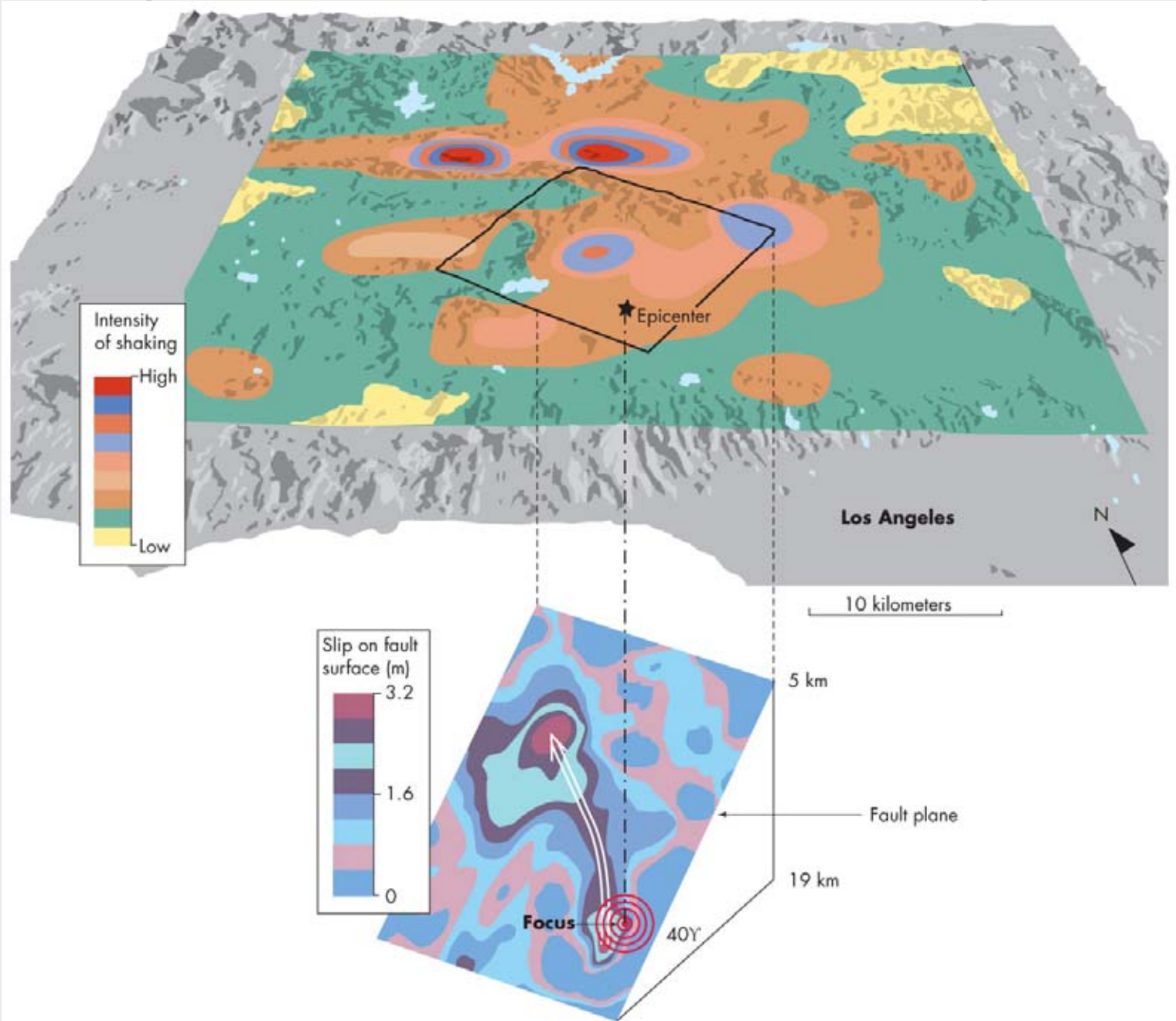
(2) Distance from epicenter

(3) Depth of focus

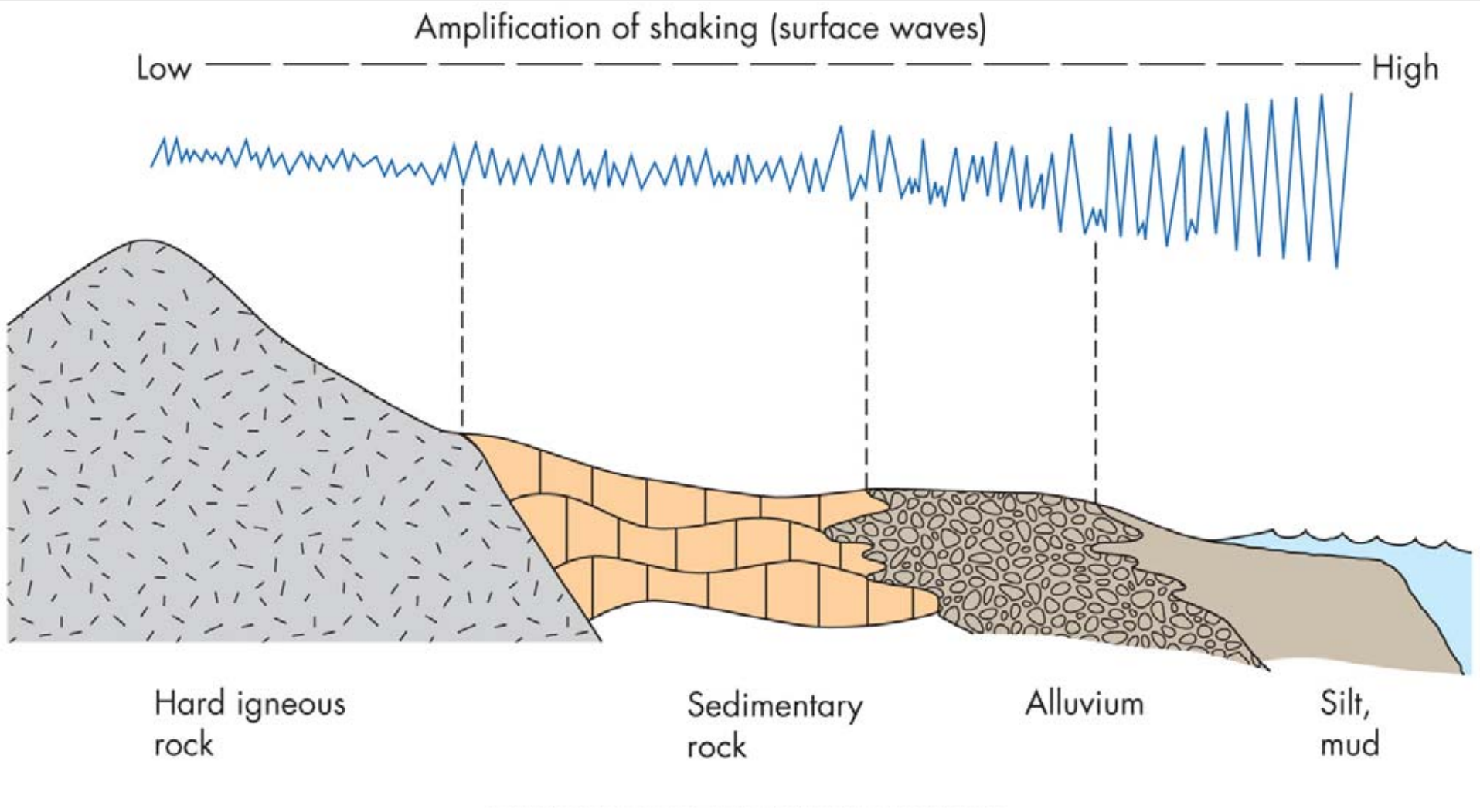
(4) Direction of rupture

(5) Bedrock and soil conditions

# Depth of focus & direction of rupture

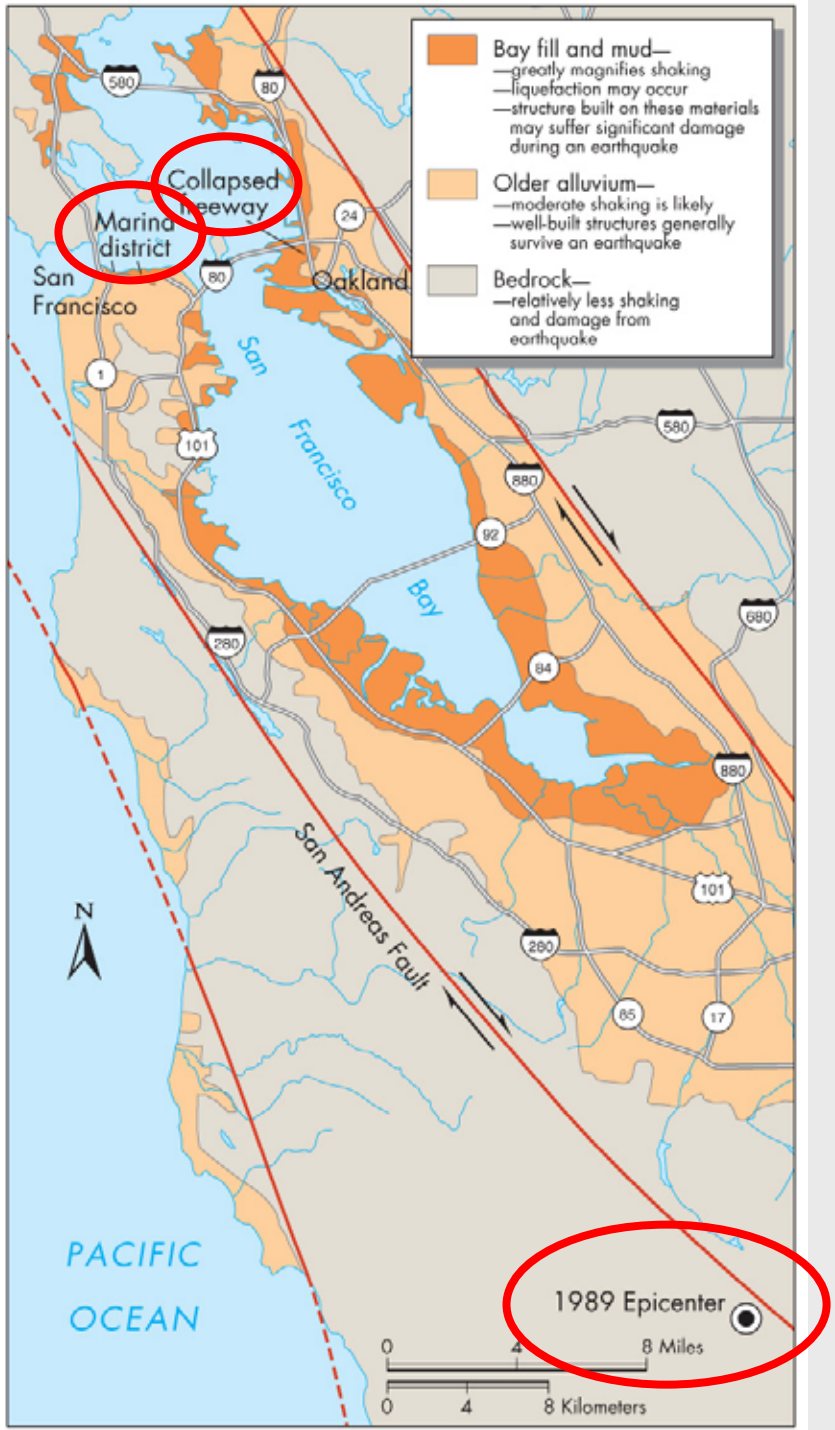


# Material amplification



Loma Prieta
California
1989

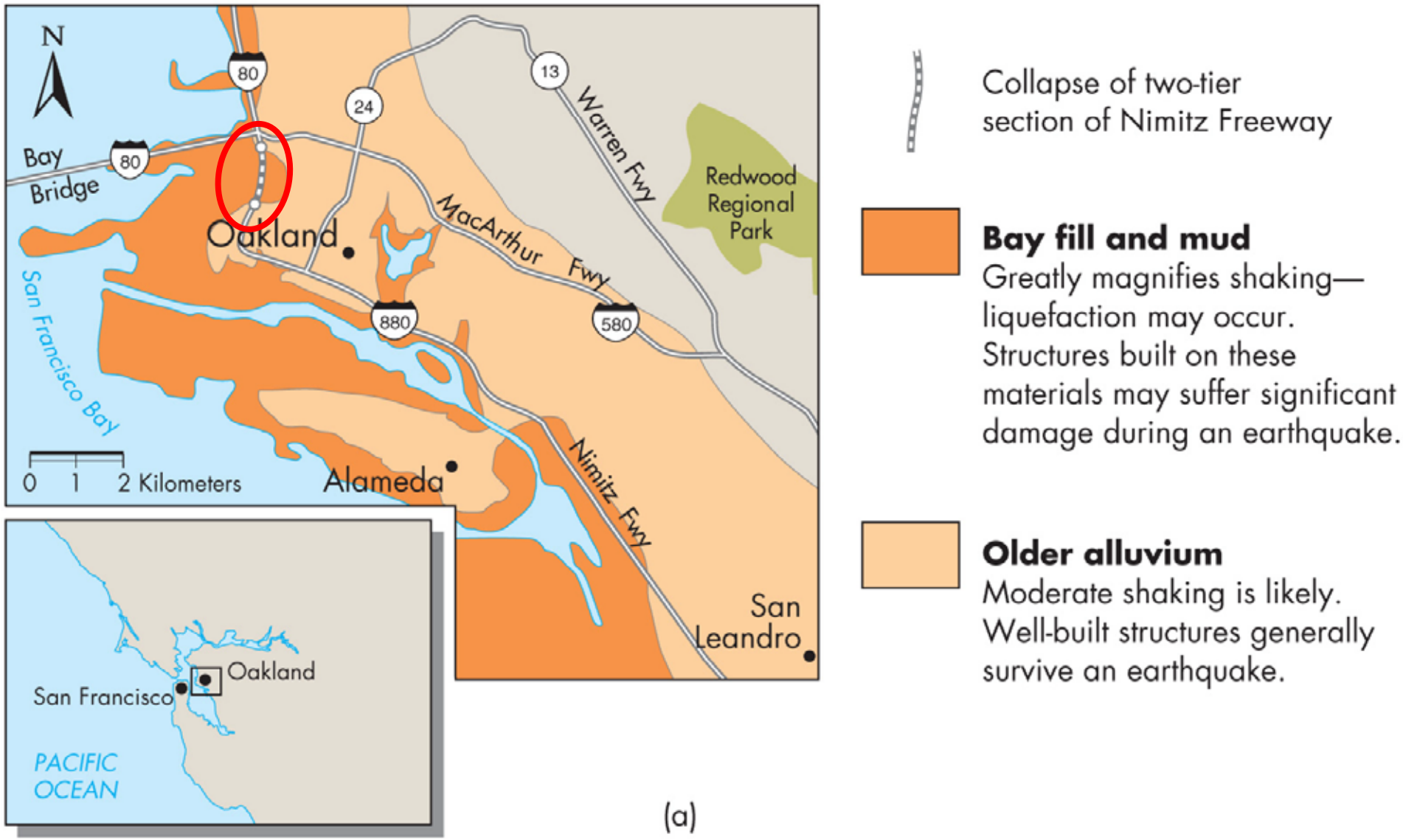
**M** 6.9




Fill & mud

Alluvium

Bedrock

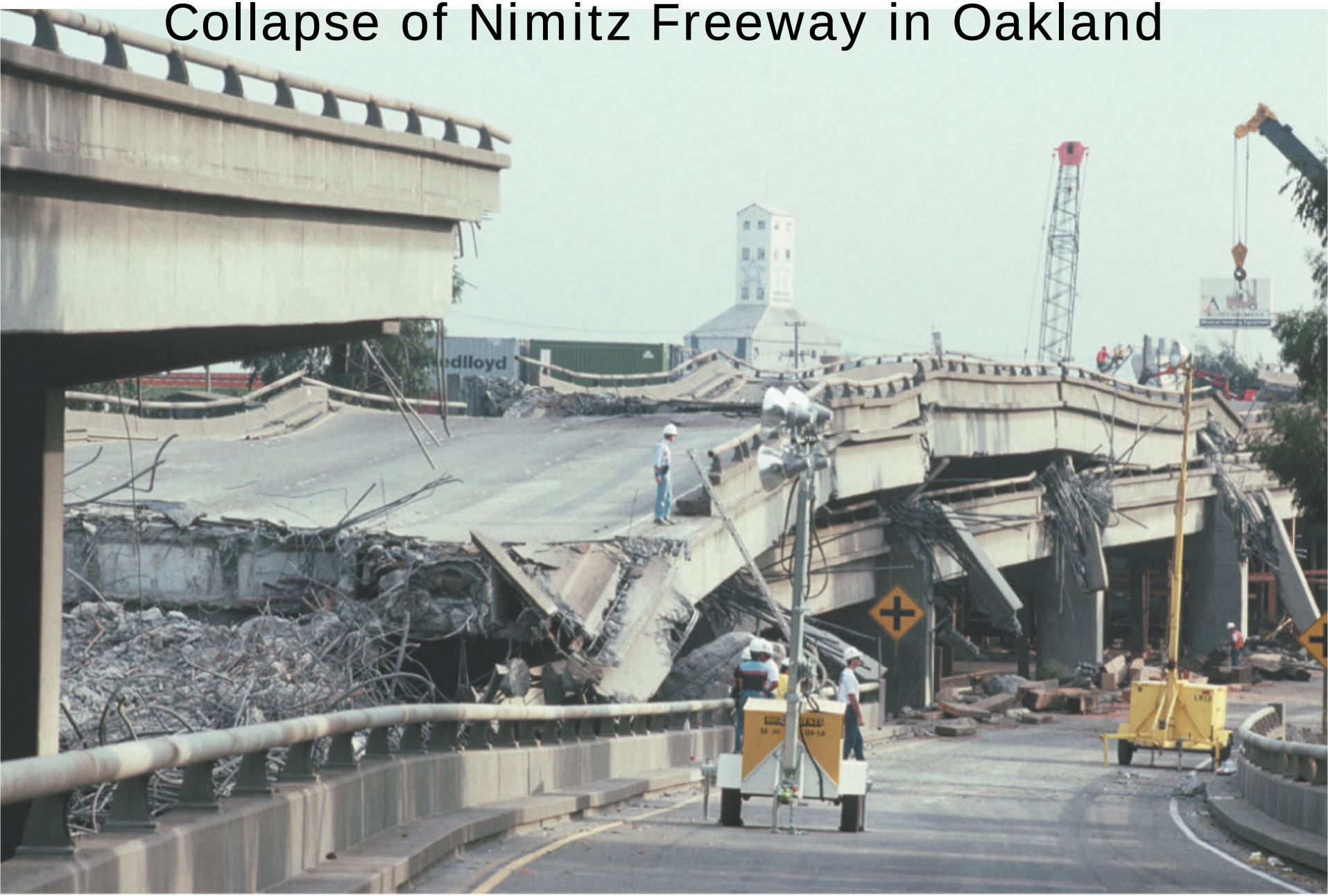

N
80
24
13
Warren Fwy
Bay
Bridge
80
Redwood
Regional
Park
Oakland
MacArthur Fwy
San Francisco Bay
880
580
0 1 2 Kilometers
Alameda
Nimitz Fwy
San
Leandro
Oakland
San Francisco
PACIFIC
OCEAN
Collapse of two-tier section of Nimitz Freeway
Bay fill and mud
Greatly magnifies shaking—liquefaction may occur. Structures built on these materials may suffer significant damage during an earthquake.
Older alluvium
Moderate shaking is likely. Well-built structures generally survive an earthquake.

(a)

# Collapse of Nimitz Freeway in Oakland

(b)

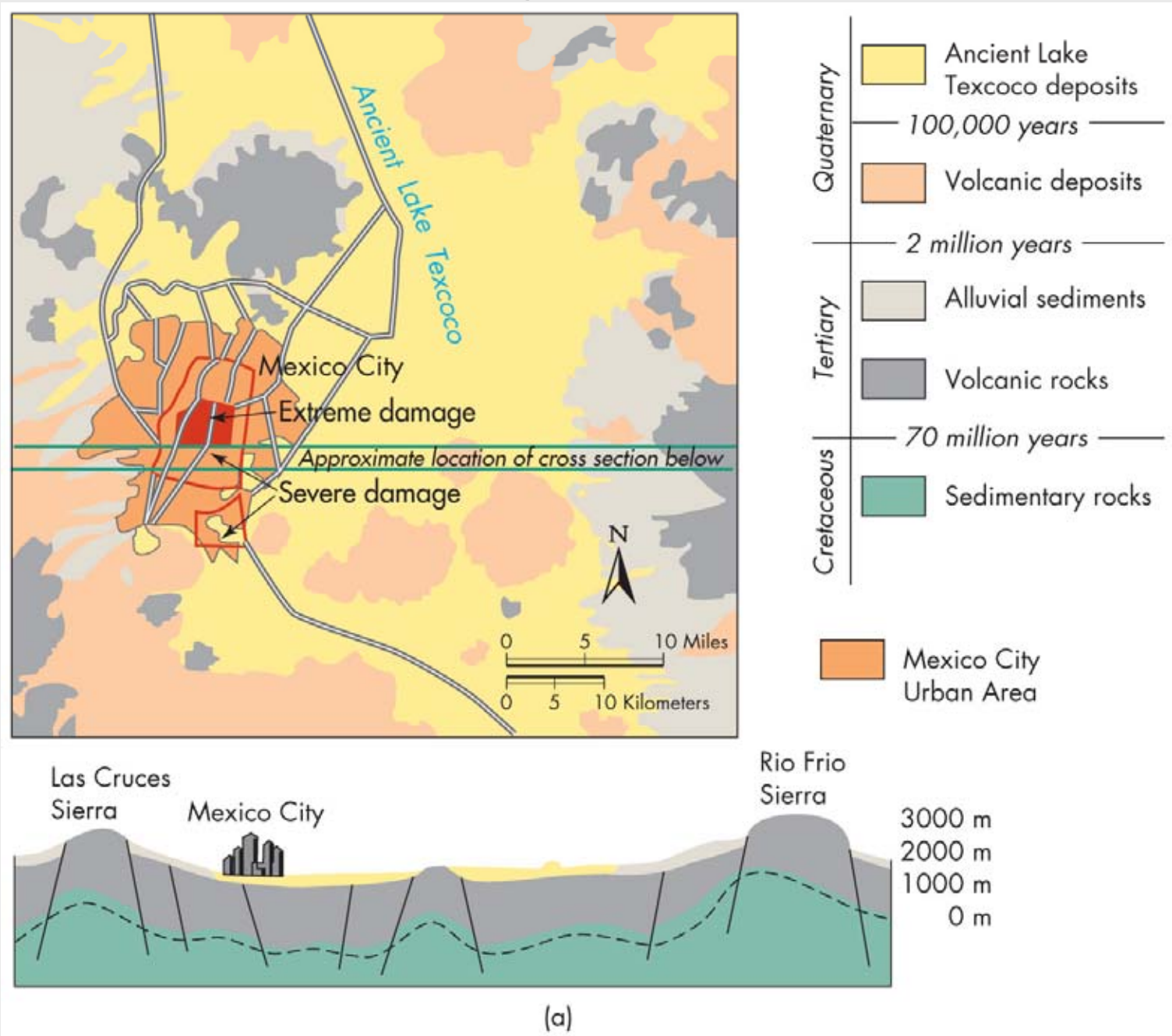
# Collapse of Nimitz Freeway in Oakland




**Collapse of the Cypress St. Viaduct during the 1989 Loma Prieta Earthquake (M 6.9).**

# Marina District, San Francisco

# Mexico City 1985 **M** 8.0

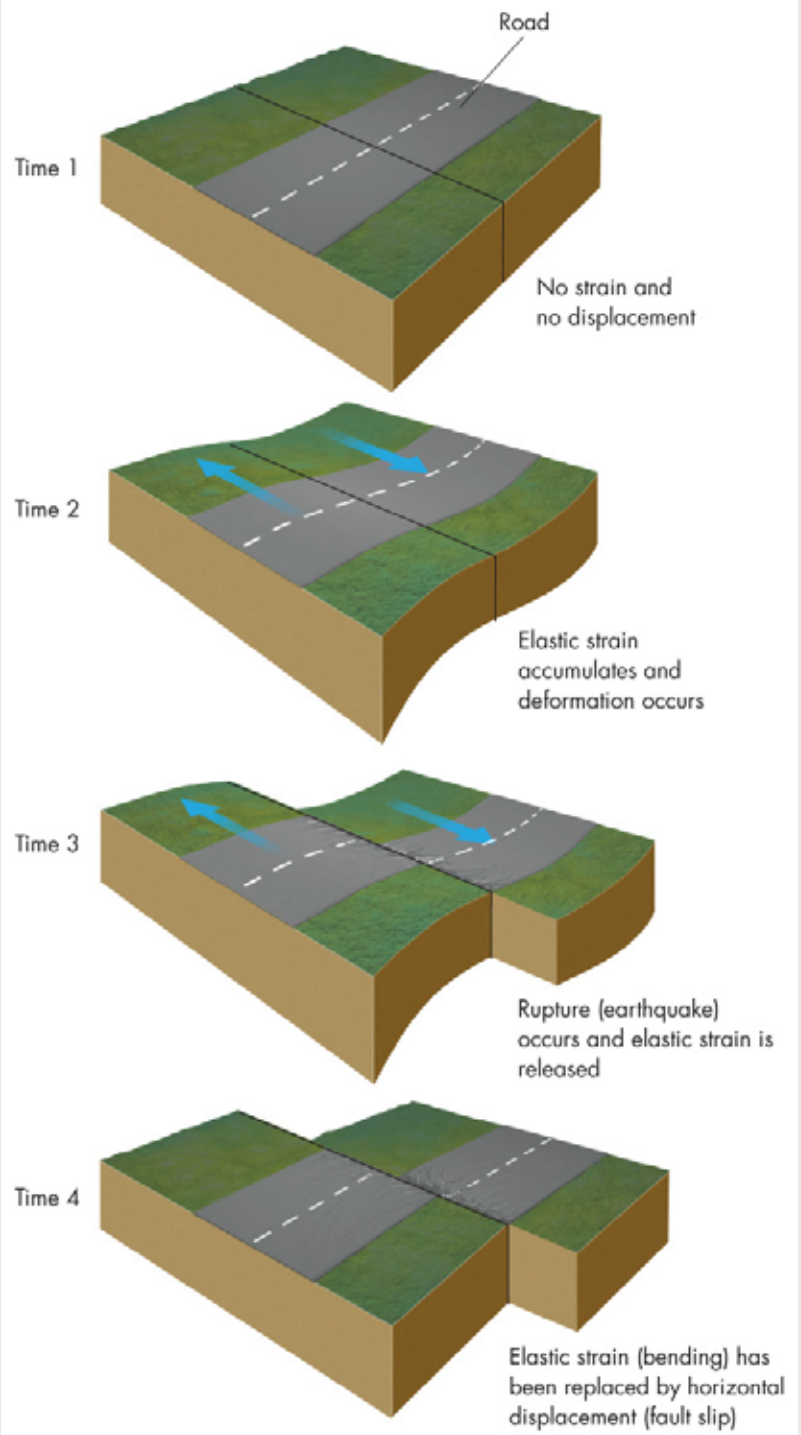


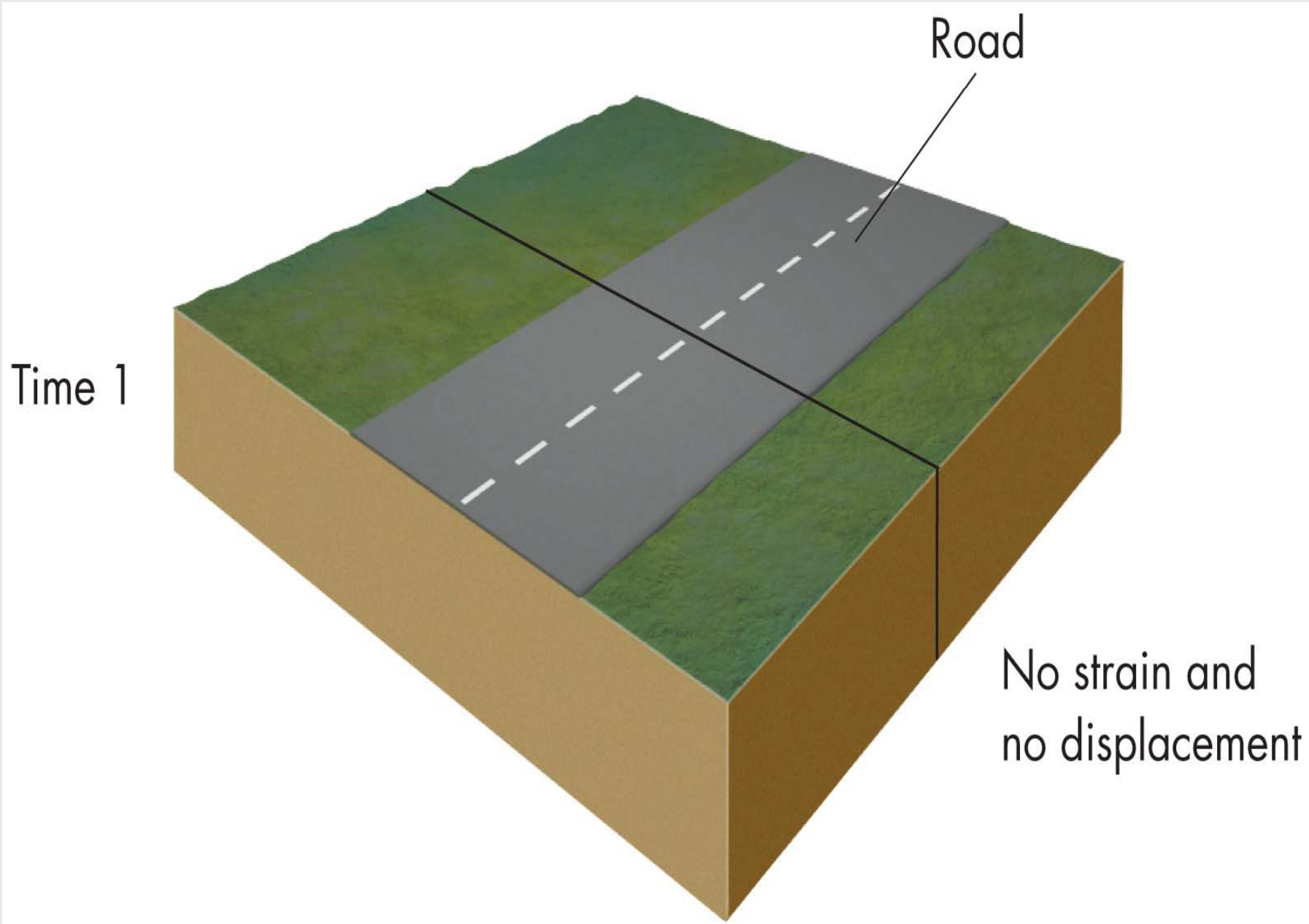
# Collapse of a hospital

(b)

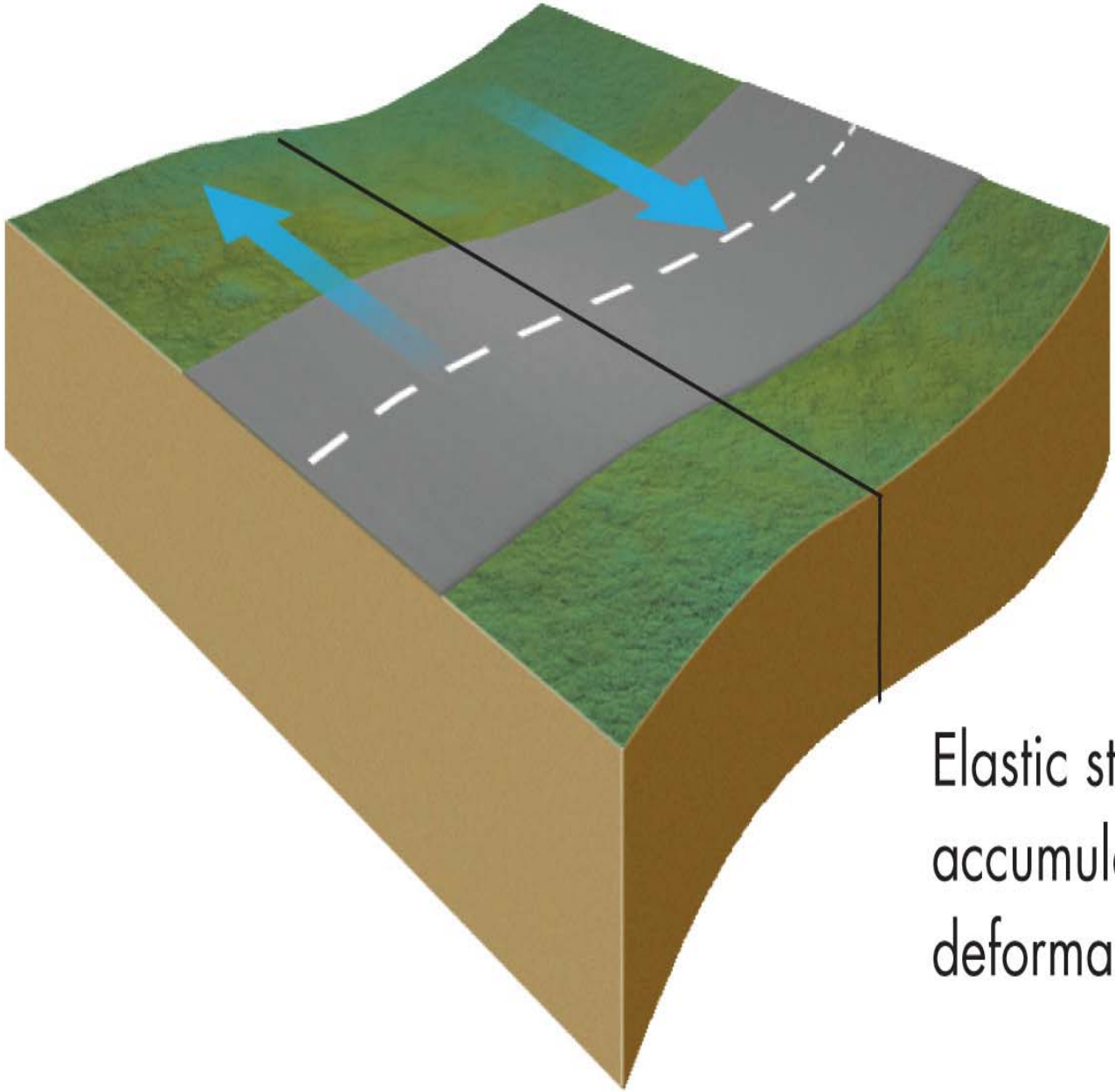
# The Earthquake Cycle

Elastic rebound hypothesis



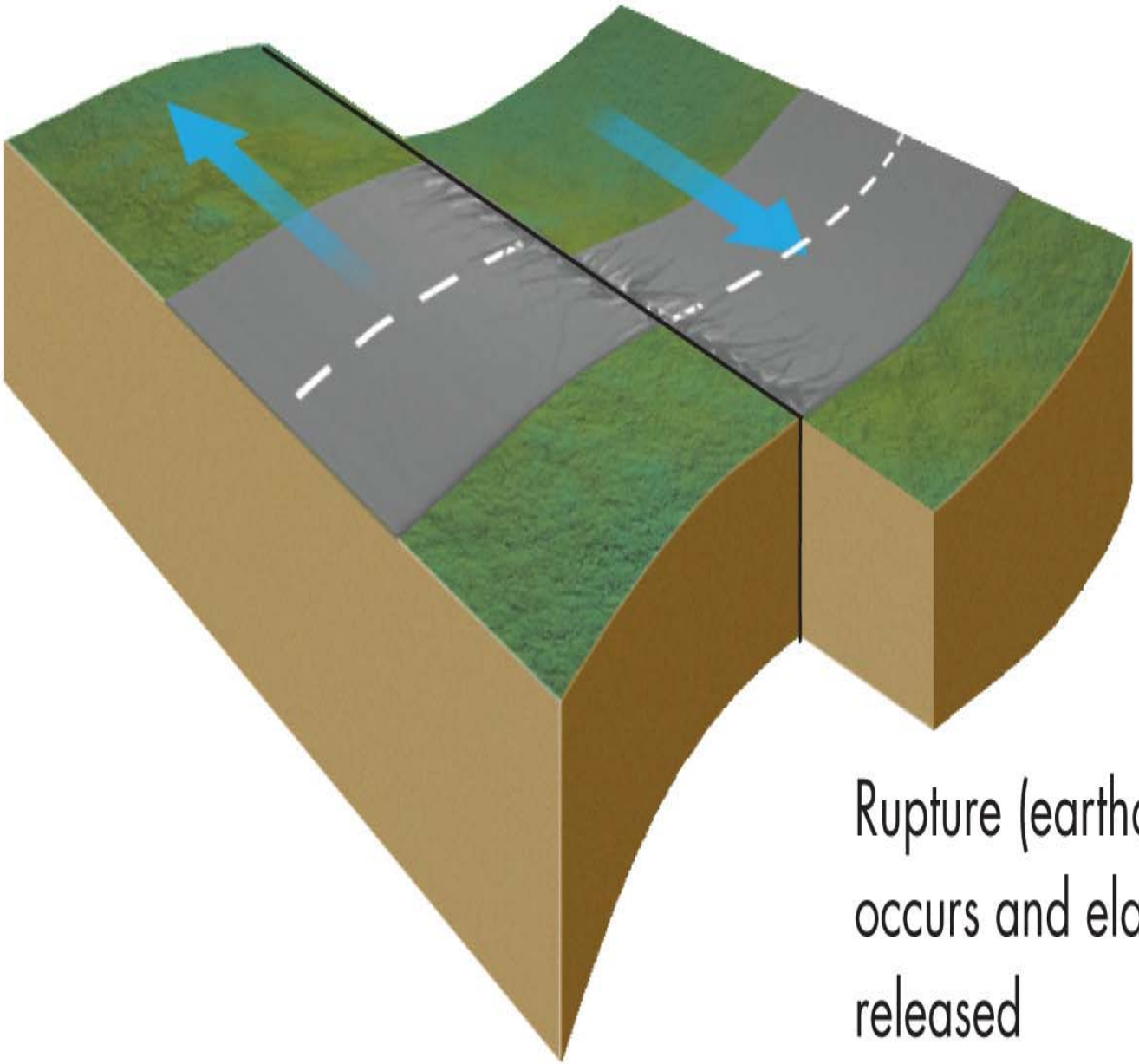

Road
Time 1
No strain and
no displacement

Time 2



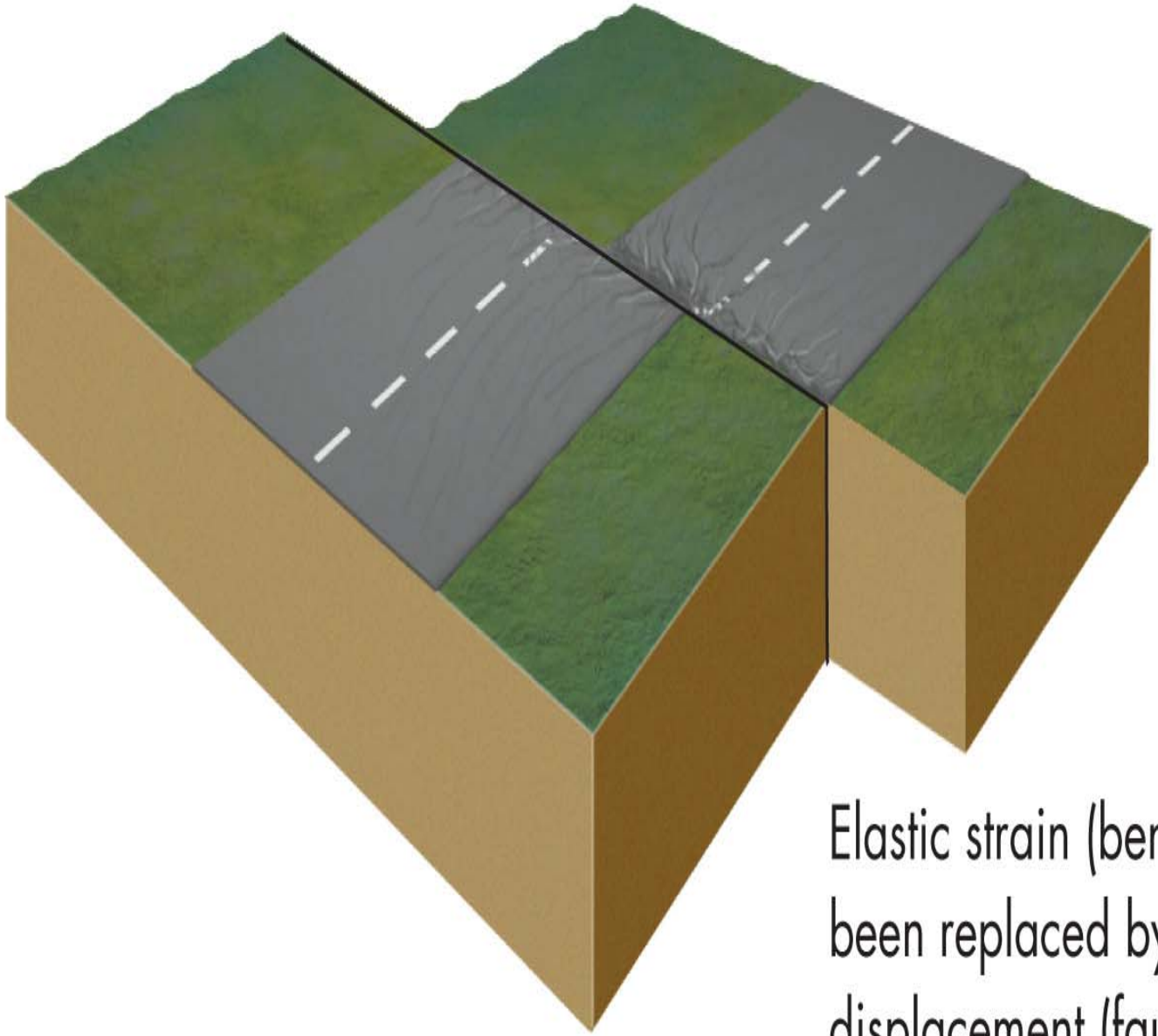
Elastic strain accumulates and deformation occurs

Time 3



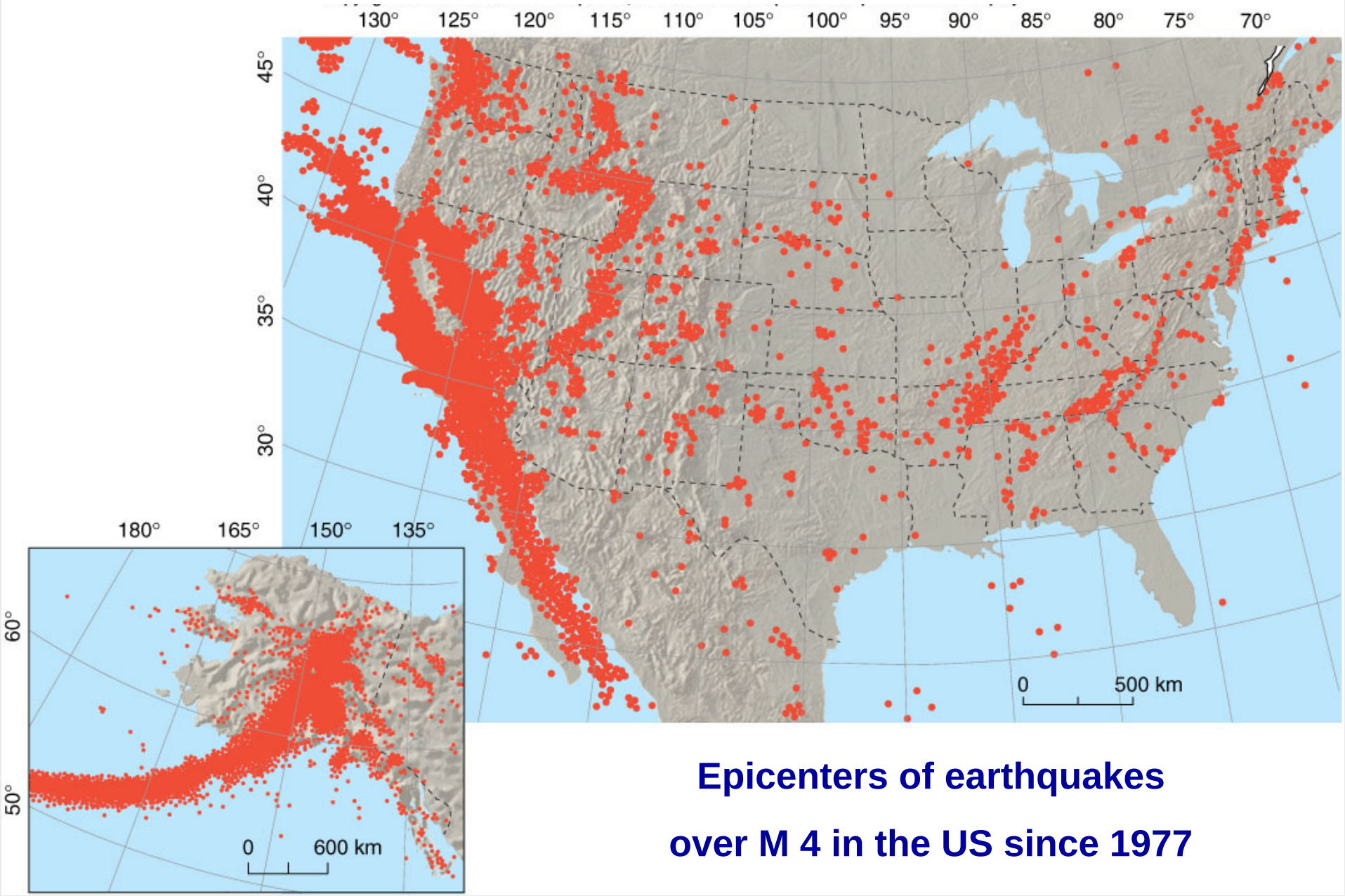
Rupture (earthquake) occurs and elastic strain is released

Time 4



Elastic strain (bending) has been replaced by horizontal displacement (fault slip)

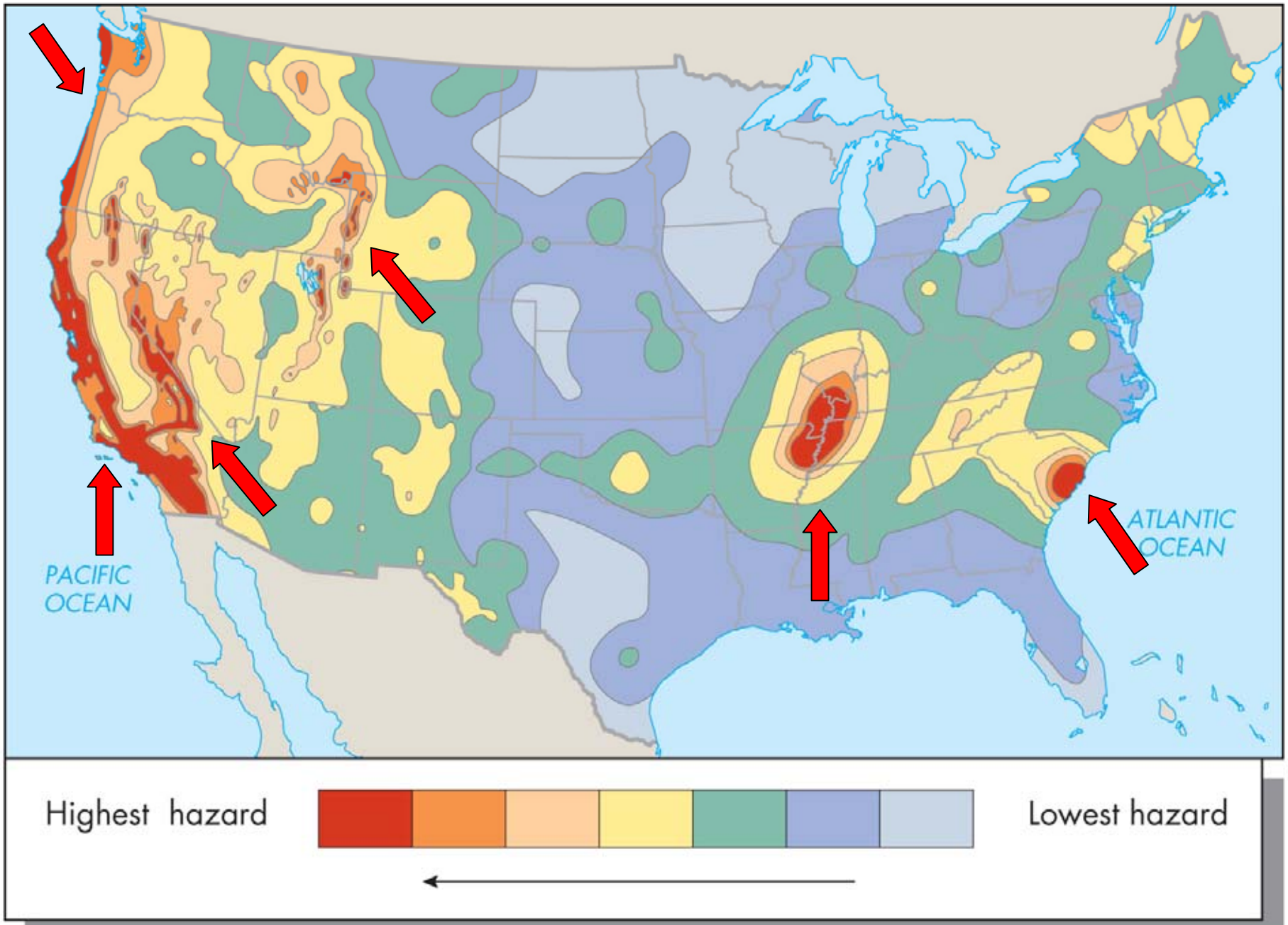
# ANIMATION OF ELASTIC REBOUND ALONG A FAULT




**Epicenters of earthquakes**

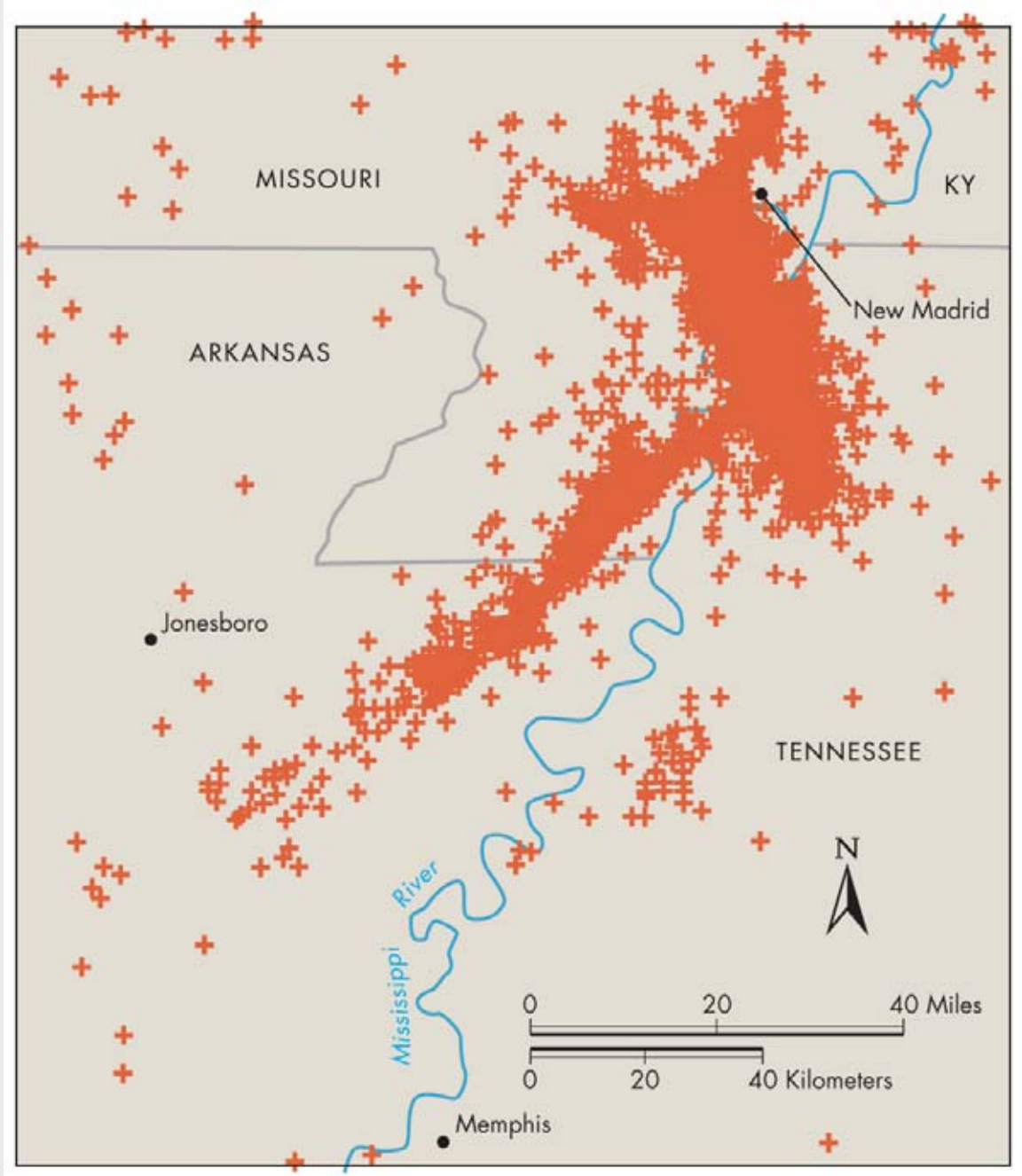
**over M 4 in the US since 1977**

# Earthquake Hazard Map



# The North American Plate

# New Madrid Fault Zone

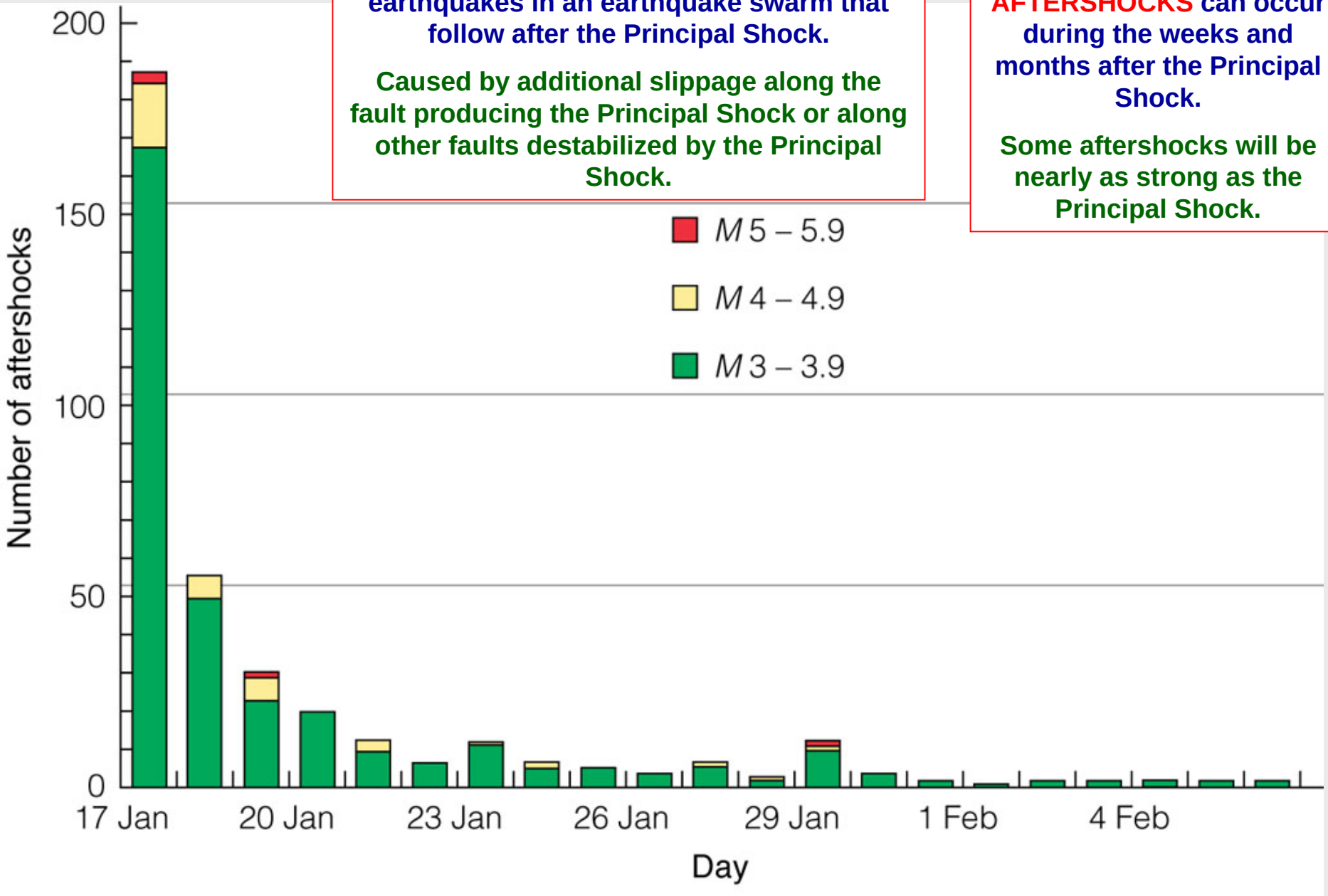


**AFTERSHOCKS = small to large, common earthquakes in an earthquake swarm that follow after the Principal Shock.**

**Caused by additional slippage along the fault producing the Principal Shock or along other faults destabilized by the Principal Shock.**

**Hundreds of AFTERSHOCKS can occur during the weeks and months after the Principal Shock.**

**Some aftershocks will be nearly as strong as the Principal Shock.**




**Aftershocks from the 1994 Northridge, CA earthquake**

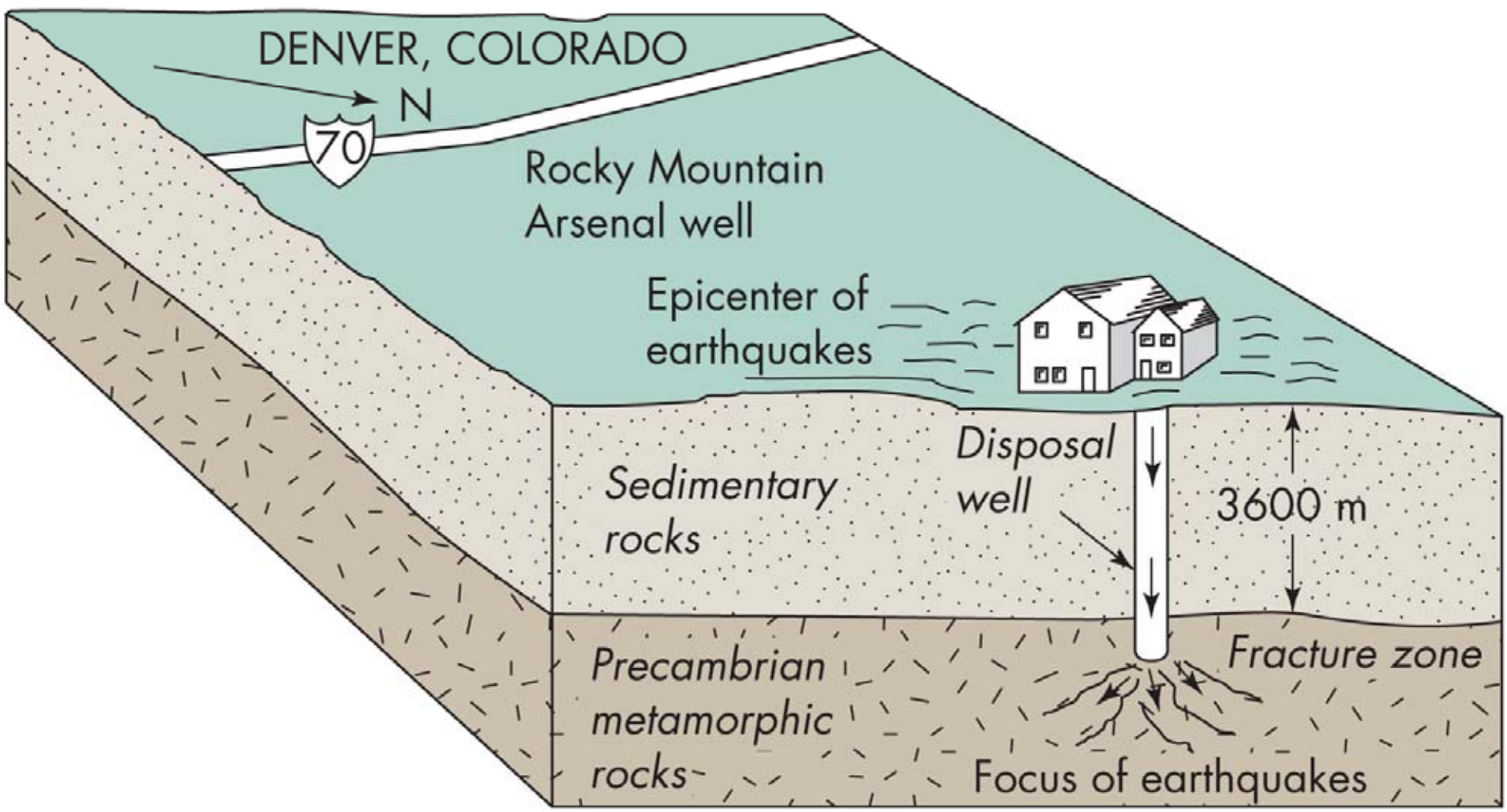
# Secondary effects – sediment liquifaction

# Secondary effects – fires (... cause?)

# Secondary effects – landslides

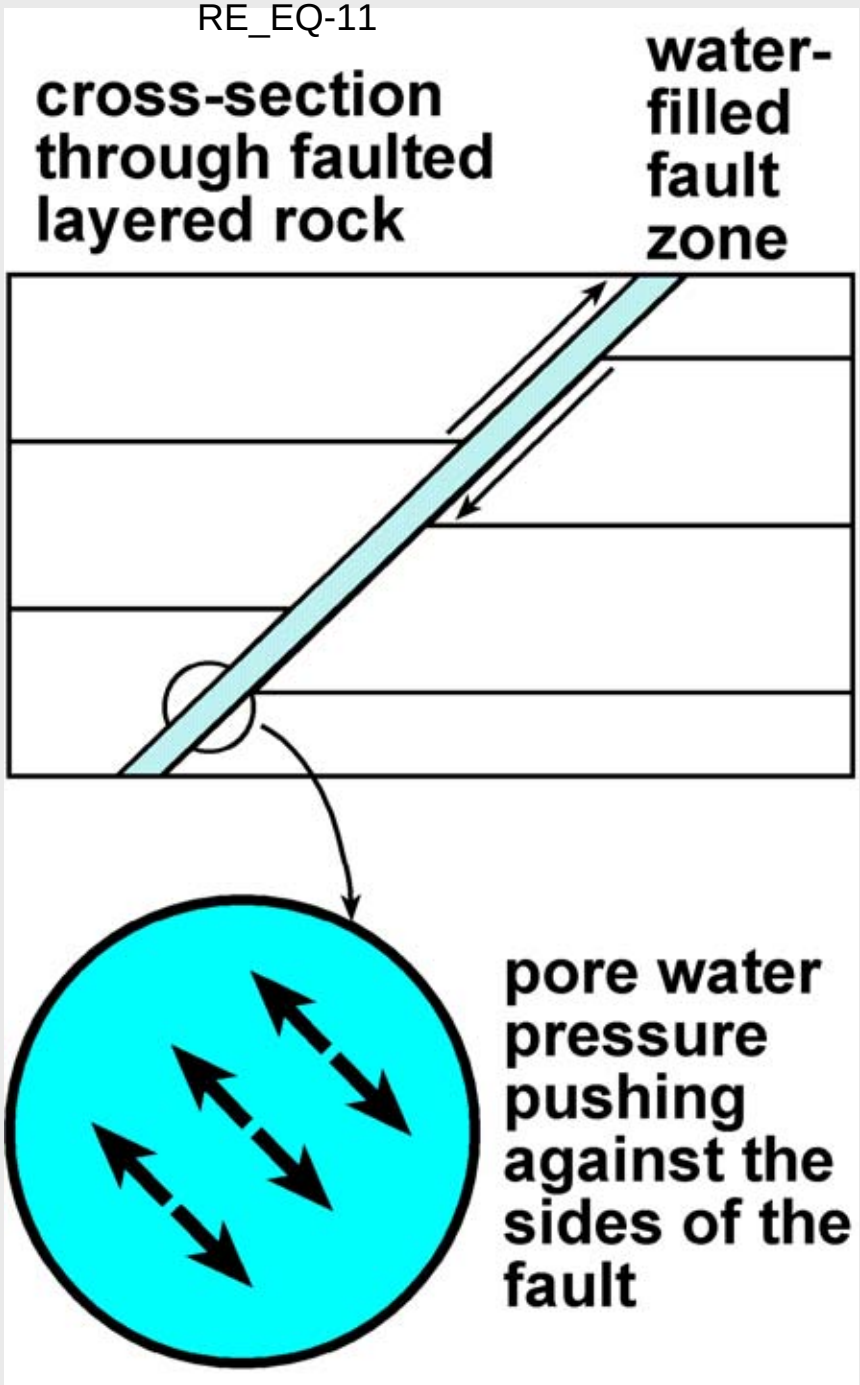
# Secondary effects – building construction

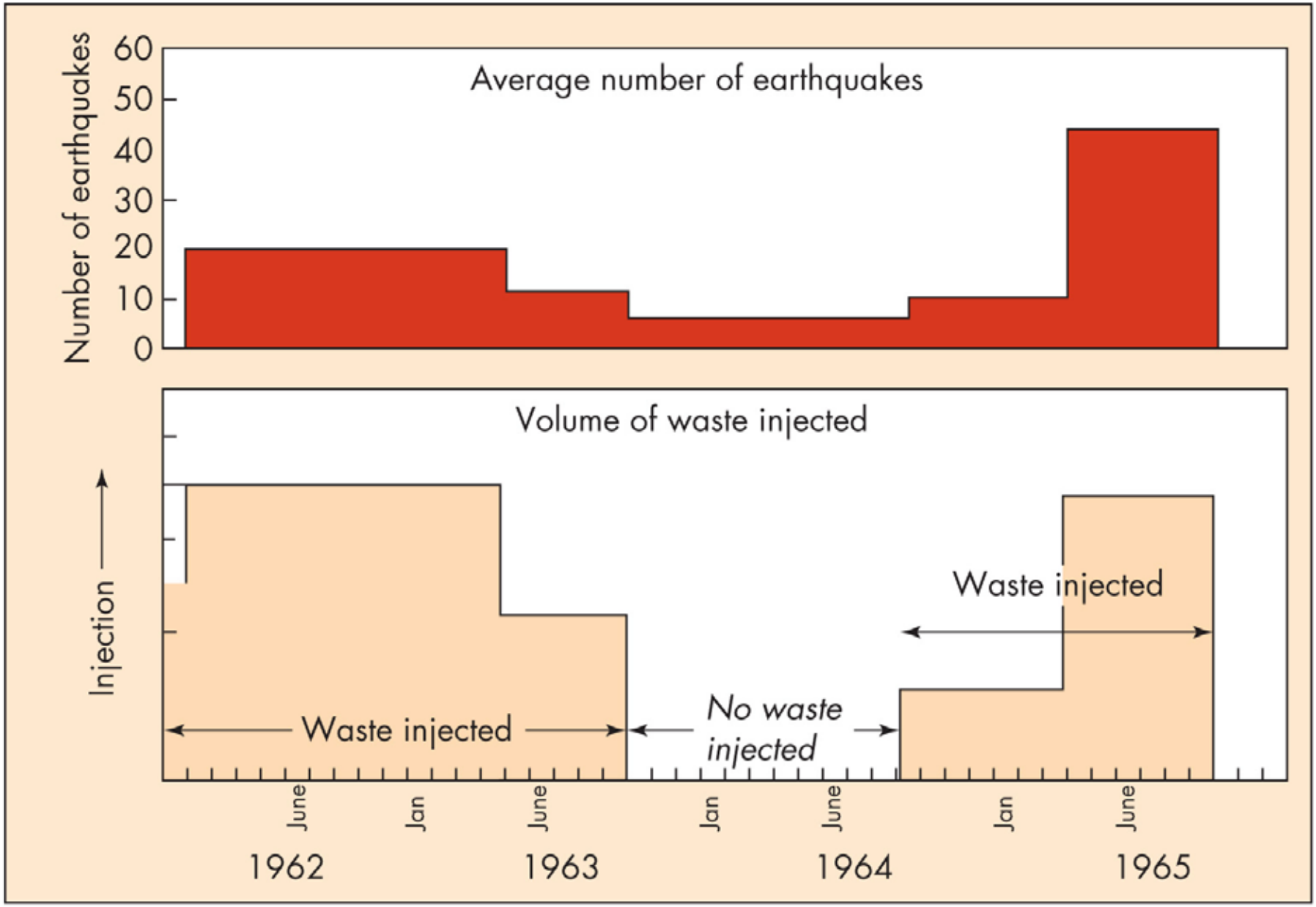
# Retrofitting buildings




(a)

**Groundwater along a fault exerts an extensional stress on the rock walls and thereby reduces the frictional resistance that keeps the fault locked.**






(b)