Lecture # 7

Engineering Geology and Seismology

Structural Geology

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Structural Geology

- The branch of geology that deals with:
  - Form, arrangement and internal architecture of rocks
  - Description, representation, and analysis of structures from the small to moderate scale
  - Reconstruction of the motions of rocks

- Structural geology provides information about the conditions during regional deformation using structures

Structural Geology

- Structural geologists are concerned with why parts of the Earth have been bent into folds and others have been broken by faults.
- Mapping of these structures provides important information to land managers and mineral exploration.
- Understanding of these features help us understand the dynamic Earth.

Sub-disciplines of Structural Geology

- **Field Relations**
  - Make accurate geologic maps
  - Measure orientations of small structures to inform us of the shape of larger structures
  - Study the sequence of development and superposition of different kinds of structures
- **Rock Mechanics** – the application of physics to the study of rock materials.
- **Tectonic and Regional Structural Geology** – Study of mountain ranges, parts of entire continents, trenches and island arcs, oceanic ridges

Definitions

- **Tectonics**: Study of the **origin and geologic evolution** (history of motion and deformation) of large areas (regional to global) **of the Earth's lithosphere** (e.g., origin of continents; building of mountain belts; formation of ocean floor)

- **Structural Geology**: **Study of deformation in rocks at scales ranging from submicroscopic to regional (micro-, meso-, and macro-scale)**

Structural Geologist

- A geologist who:
  - Studies deformation of rock and Earth’s crust
  - Identifies and interprets geological structures and their tectonic implications

Field Tectonic Studies

- Many tectonic problems are approached by studying structures at outcrop scale, and smaller (microscopic) or larger (100's to 1000's of km) scales

- Systematically observe/record the patterns of rock structures (e.g., fault, fold, foliation, fracture). This gives the geometry of the structures.

Tectonics vs. Structural Geology

- Both are concerned with the reconstruction of the motions that shape the outer layers of earth
- Both deal with motion and deformation in the Earth's crust and upper mantle
- Tectonic events at all scales produce deformation structures
- These two disciplines are closely related and interdependent

Applications of Structural Geology

- Engineering Issues
  - Bridges
  - Dams
  - Power Plants
  - Highway Cuts
  - Large Buildings
  - Airports

Applications of Structural Geology

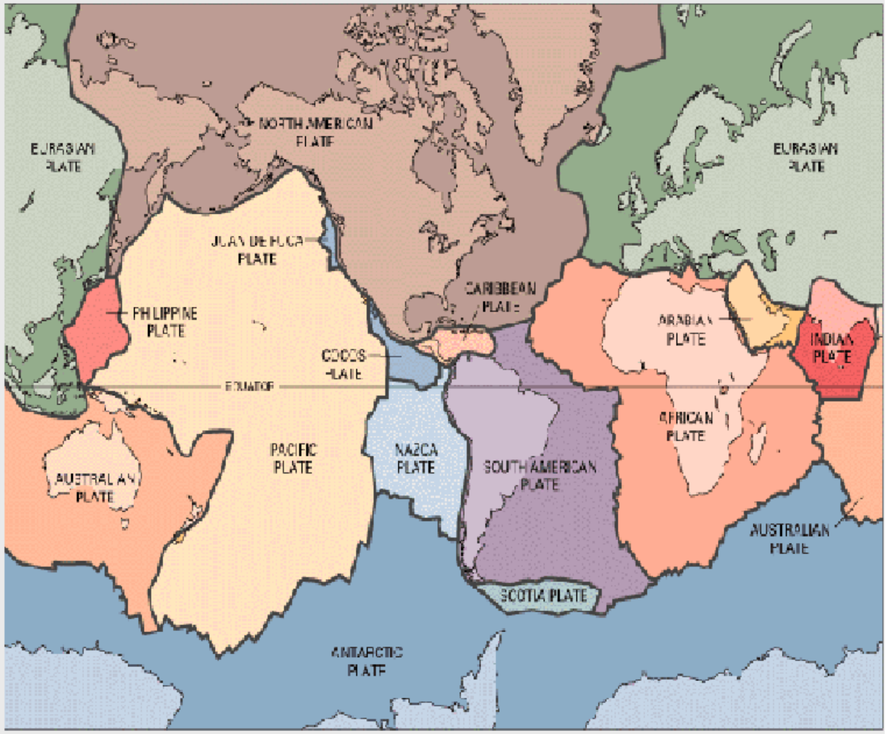
- Environmental Issues
  - Earthquake hazard
  - Location of landfill sites
  - Contamination cleanup
  - Distribution of groundwater
  - Mineral exploration

Scale in Structural Geology

- **Microscopic** – Need magnification
  - Foliation, Micro folds
- **Mesoscopic** – Hand specimens and outcrops
  - Foliation, Folds, Faults
- **Macroscopic** – Mountainside to map levels
  - Basins, domes, Metamorphic Core Complexes

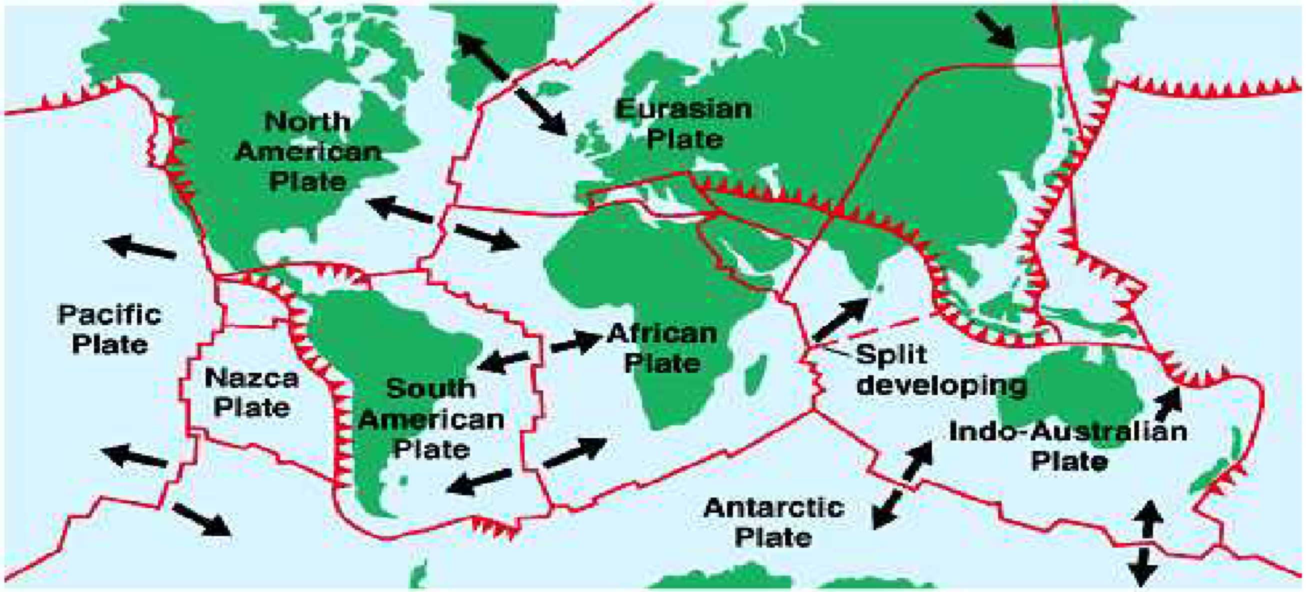
Plate Tectonics

- Theory of Plate Tectonics
  - The surface of the Earth is composed of about a dozen major rigid, moving crustal plates and several smaller plates
  - **Continental Drift** – states that the continents have drifted and still are drifting apart.

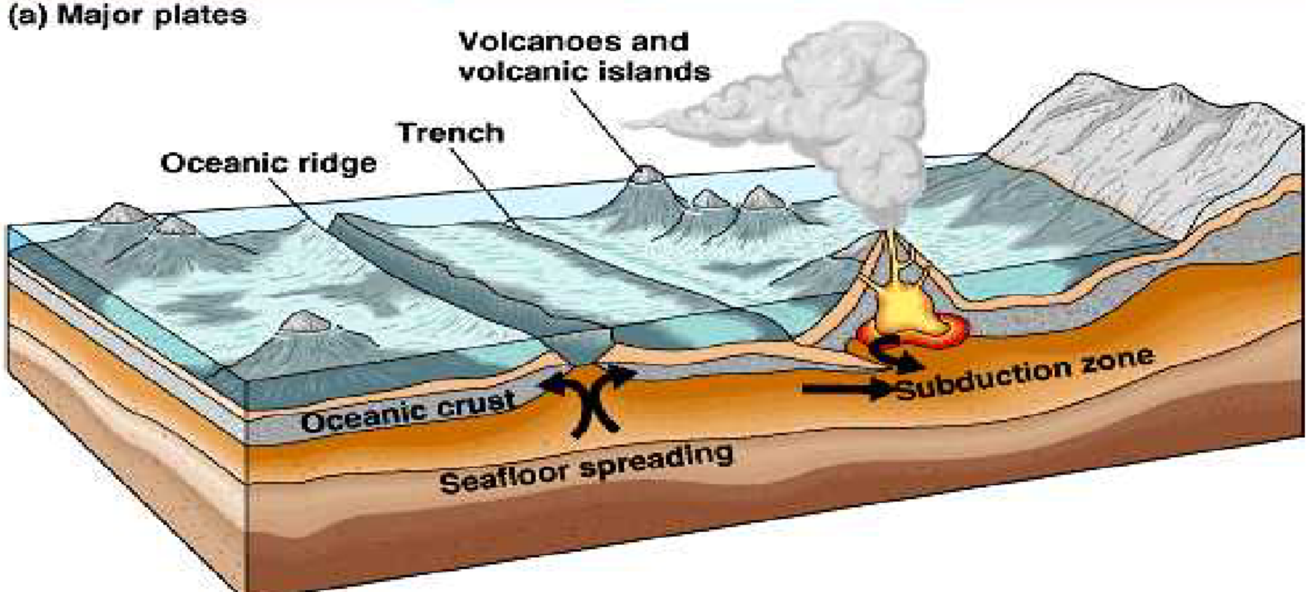


Why do the plates move?

1. Due to tremendous heat, rock in the asthenosphere is like hot taffy
2. This allows plates to ride on top of hot, flowing rock.
3. Plates move because heat is being released from deep inside the earth.
4. Convection currents causes hot material to rise and expand (plates diverge) and cooler material to sink and contract (plates converge).



(a) Major plates



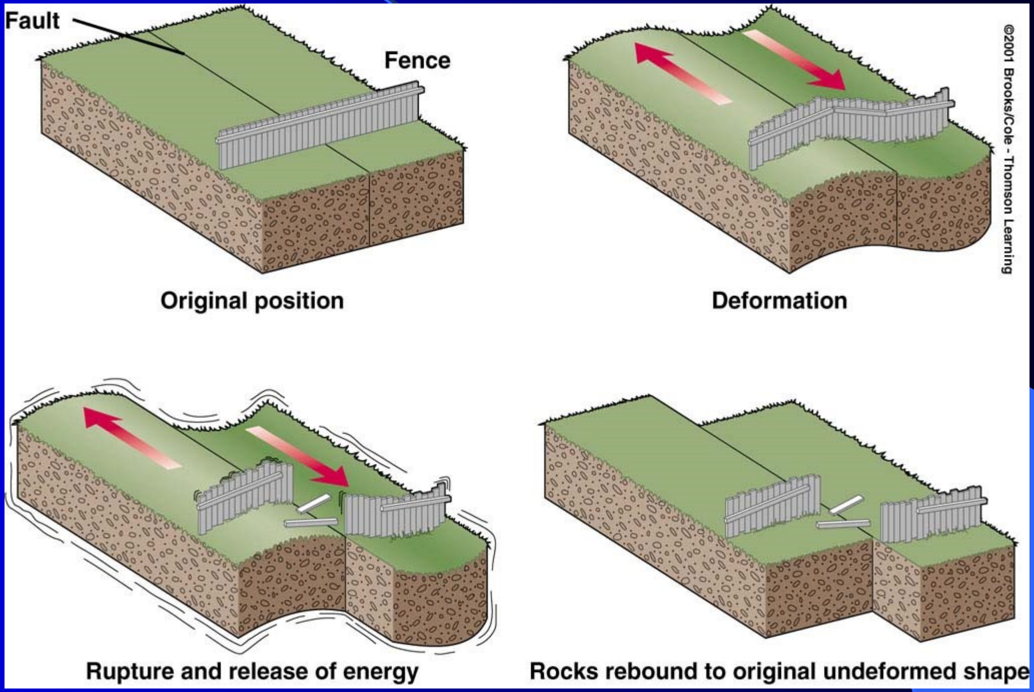
(b) Events at plate boundaries

What are Earthquakes?

- The shaking or trembling caused by the sudden release of energy
- Usually associated with faulting or breaking of rocks
- Continuing adjustment of position results in aftershocks

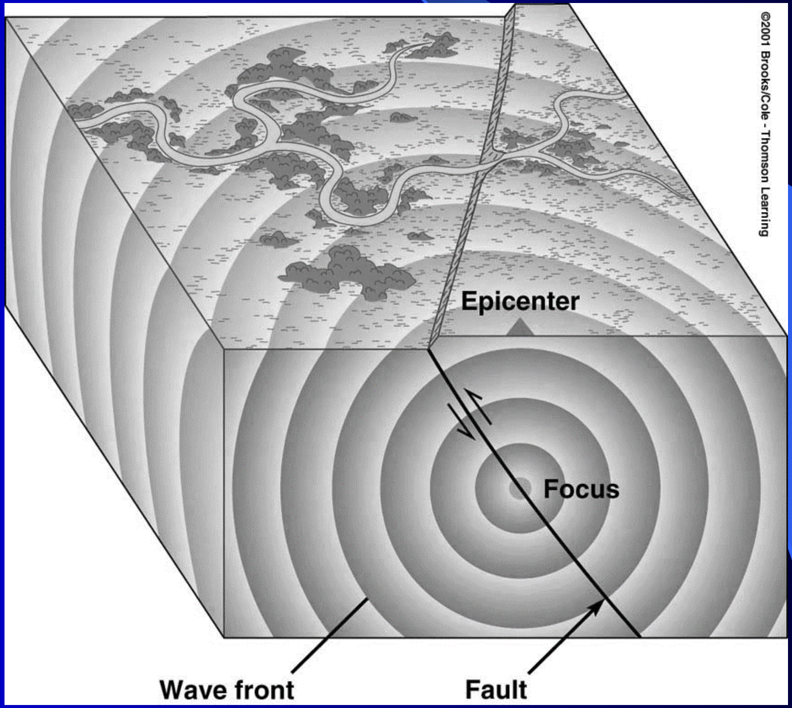
What is the Elastic Rebound Theory?

- Explains how energy is stored in rocks
  - Rocks bend until the strength of the rock is exceeded
  - Rupture occurs and the rocks quickly rebound to an undeformed shape
  - Energy is released in waves that radiate outward from the fault

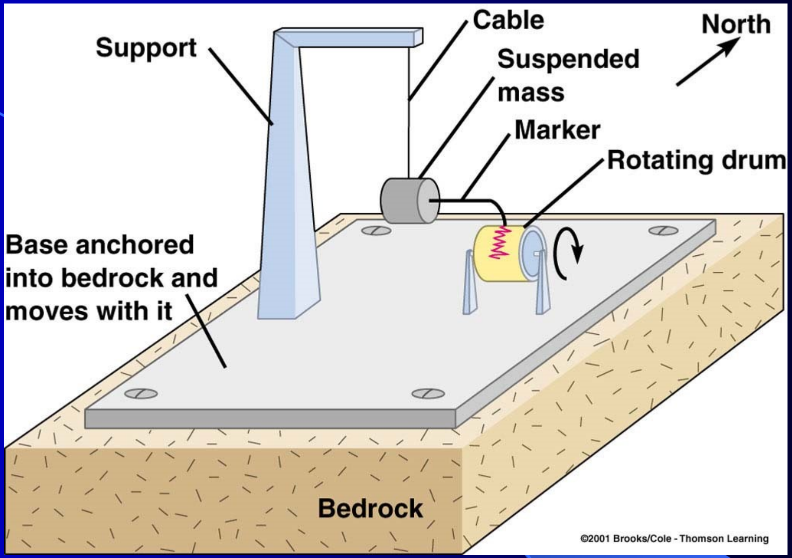


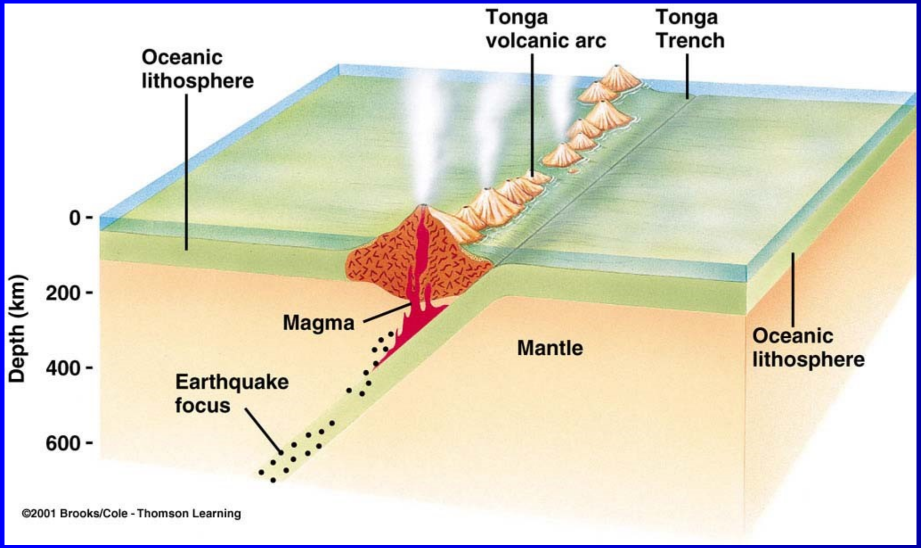
The Focus and Epicenter of an Earthquake

- The point within Earth where faulting begins is the focus, or hypocenter
- The point directly above the focus on the surface is the epicenter



Seismographs record earthquake events



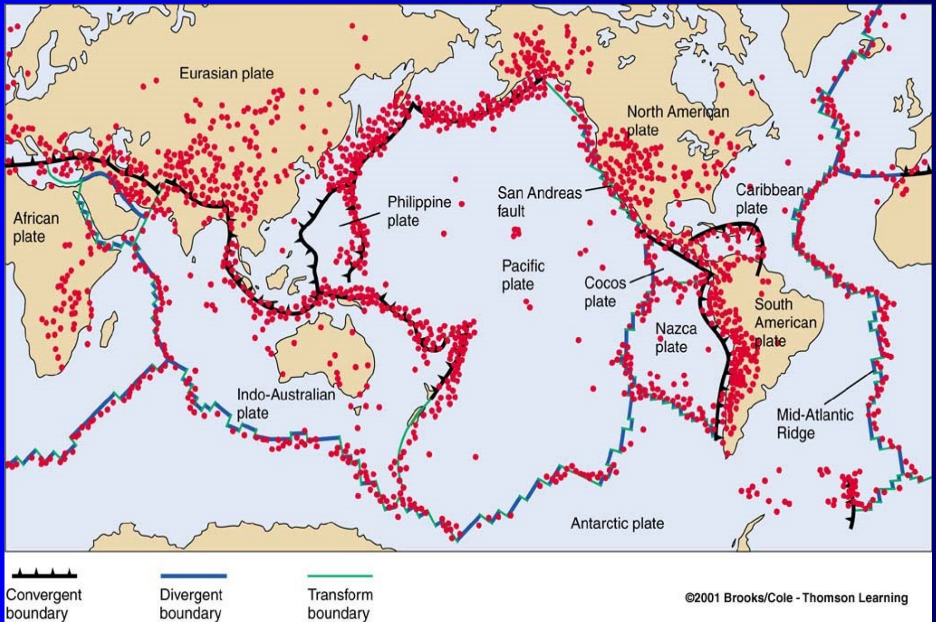


At convergent boundaries, **focal depth** increases along a dipping seismic zone called a **Benioff zone**

Where Do Earthquakes Occur and How Often?

~80% of all earthquakes occur in the circum-Pacific belt

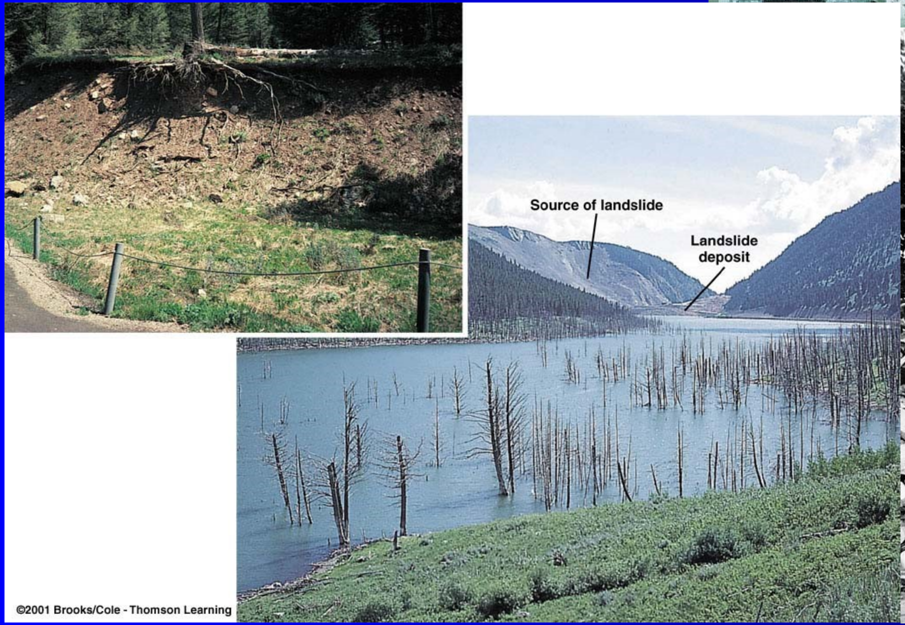
- most of these result from convergent margin activity
- ~15% occur in the Mediterranean-Asiatic belt
- remaining 5% occur in the interiors of plates and on spreading ridge centers
- more than 150,000 quakes strong enough to be felt are recorded each year



The Economics and Societal Impacts of EQs

- Building collapse
- Fire
- Tsunami
- Ground failure

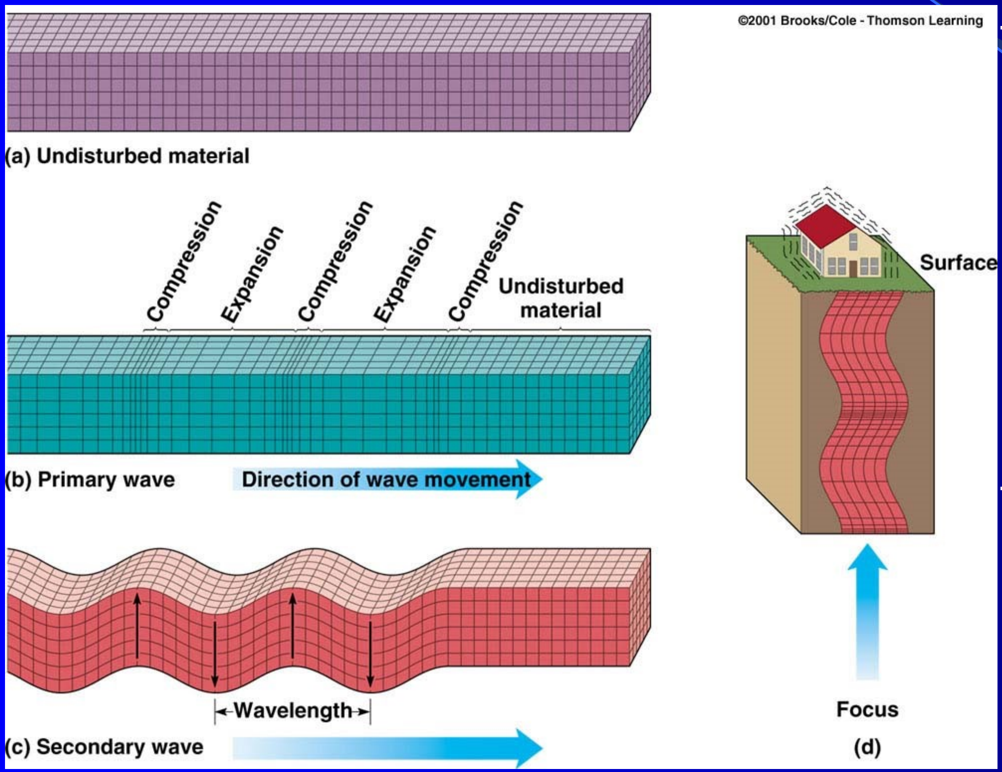

Damage in Oakland, CA, 1989



What are Seismic Waves?

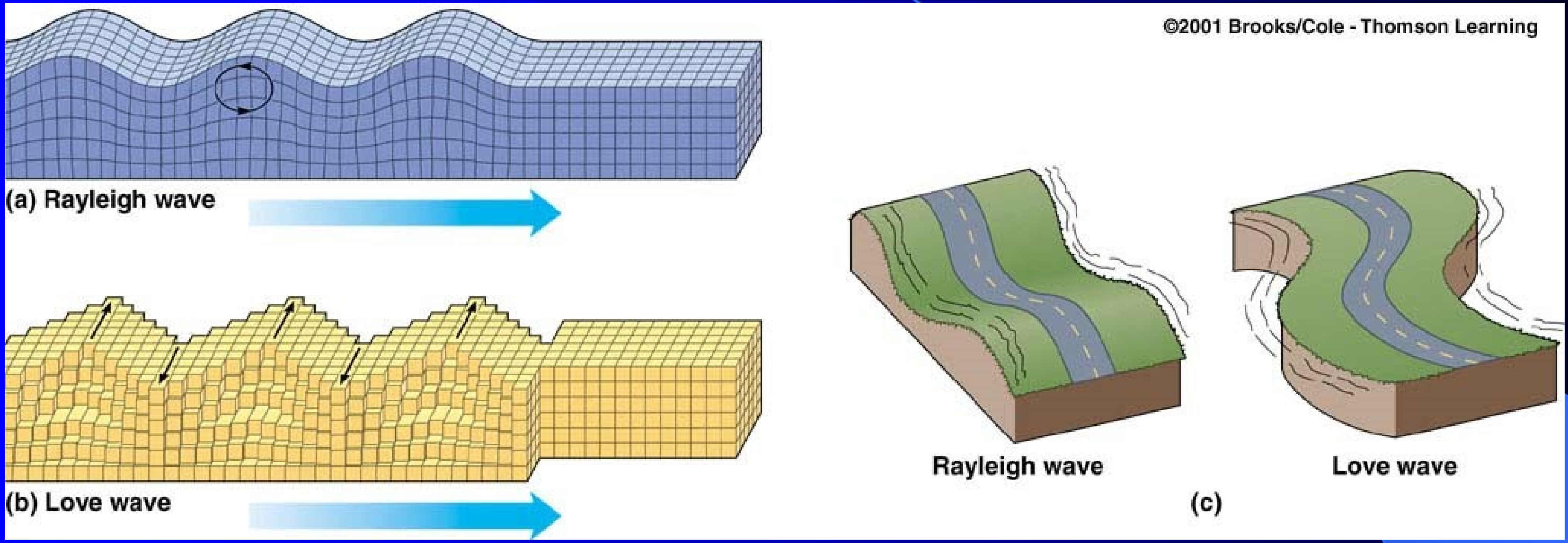
- Response of material to the arrival of energy fronts released by rupture
- Two types:
  - Body waves
    - P and S
  - Surface waves
    - R and L

Body Waves: P and S waves



- Body waves
  - P or primary waves
    - fastest waves
    - travel through solids, liquids, or gases
    - compressional wave, material movement is in the same direction as wave movement
  - S or secondary waves
    - slower than P waves
    - travel through solids only
    - shear waves - move material perpendicular to wave movement

Surface Waves: R and L waves

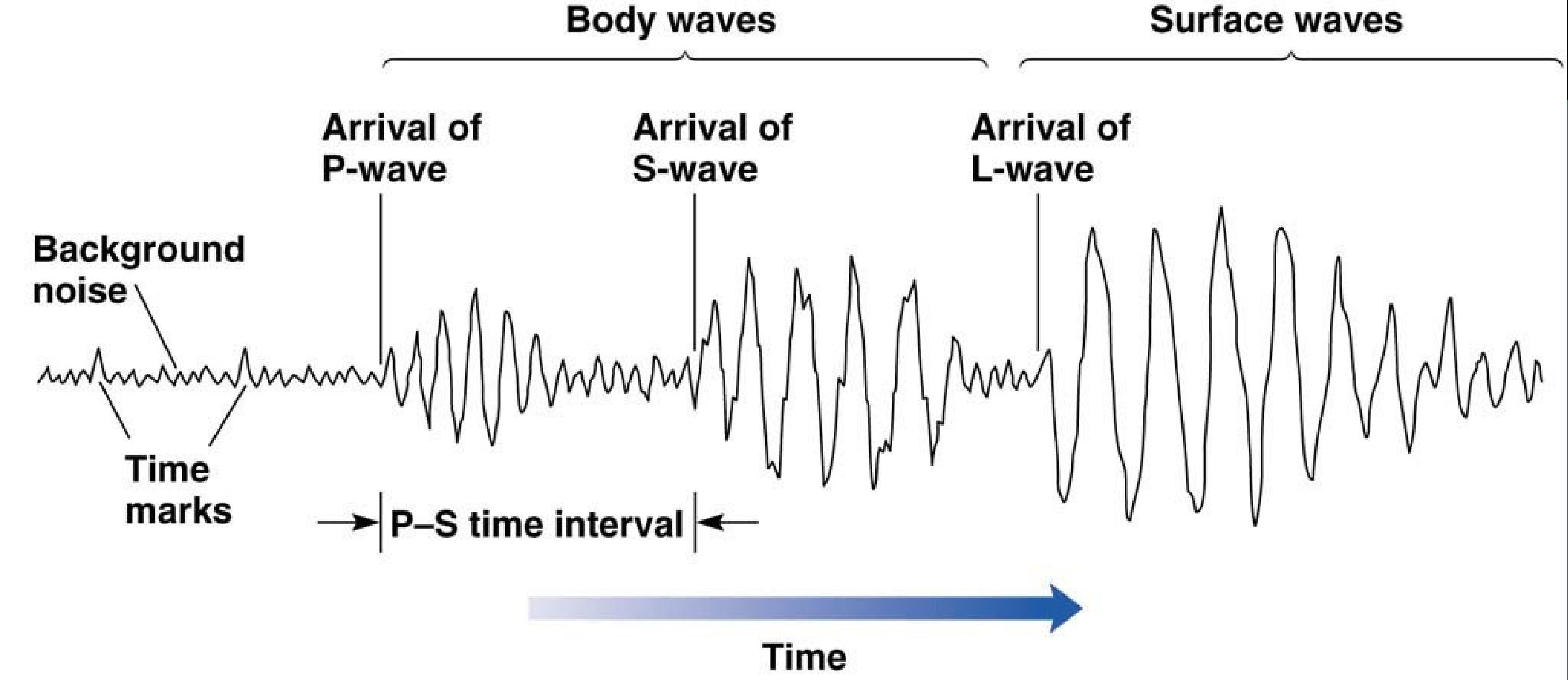


- Surface Waves
  - Travel just below or along the ground's surface
  - Slower than body waves; rolling and side-to-side movement
  - Especially damaging to buildings

How is an Earthquake's Epicenter Located?

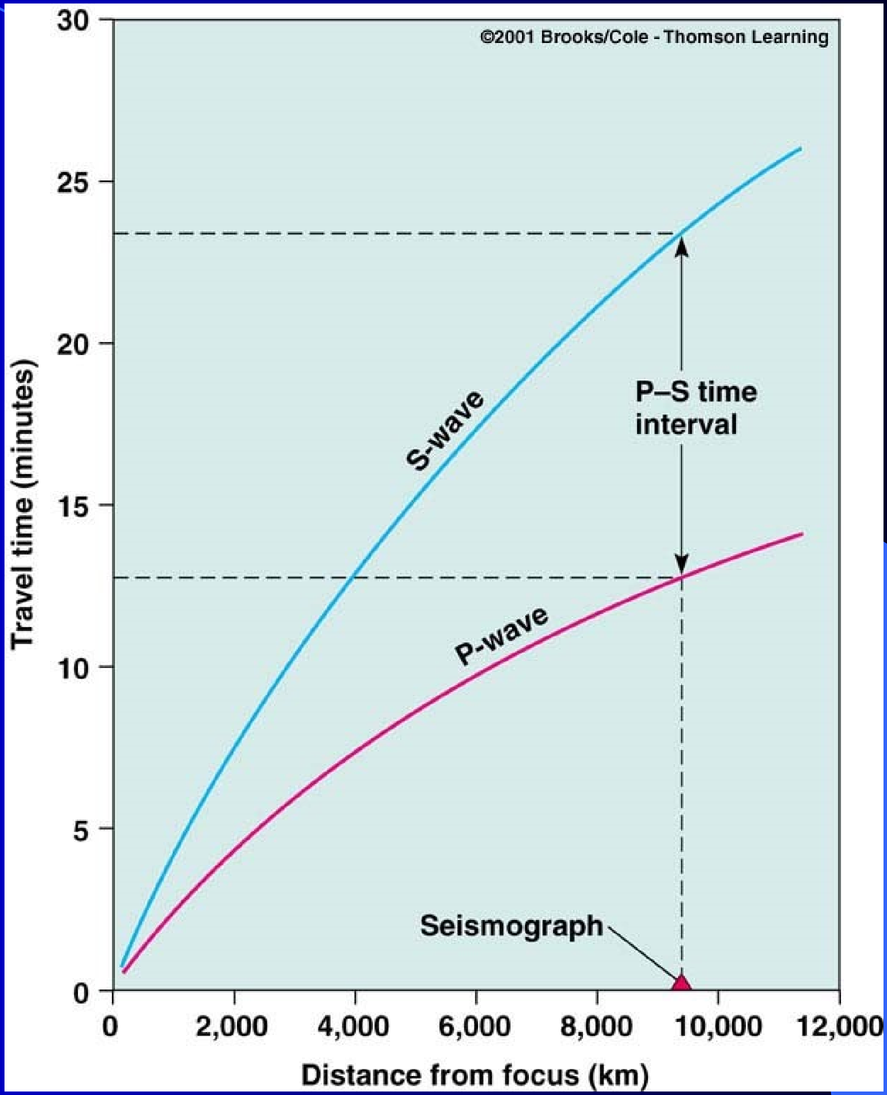
Seismic wave behavior

- P waves arrive first, then S waves, then L and R
- Average speeds for all these waves is known
- After an earthquake, the difference in arrival times at a seismograph station can be used to calculate the distance from the seismograph to the epicenter.



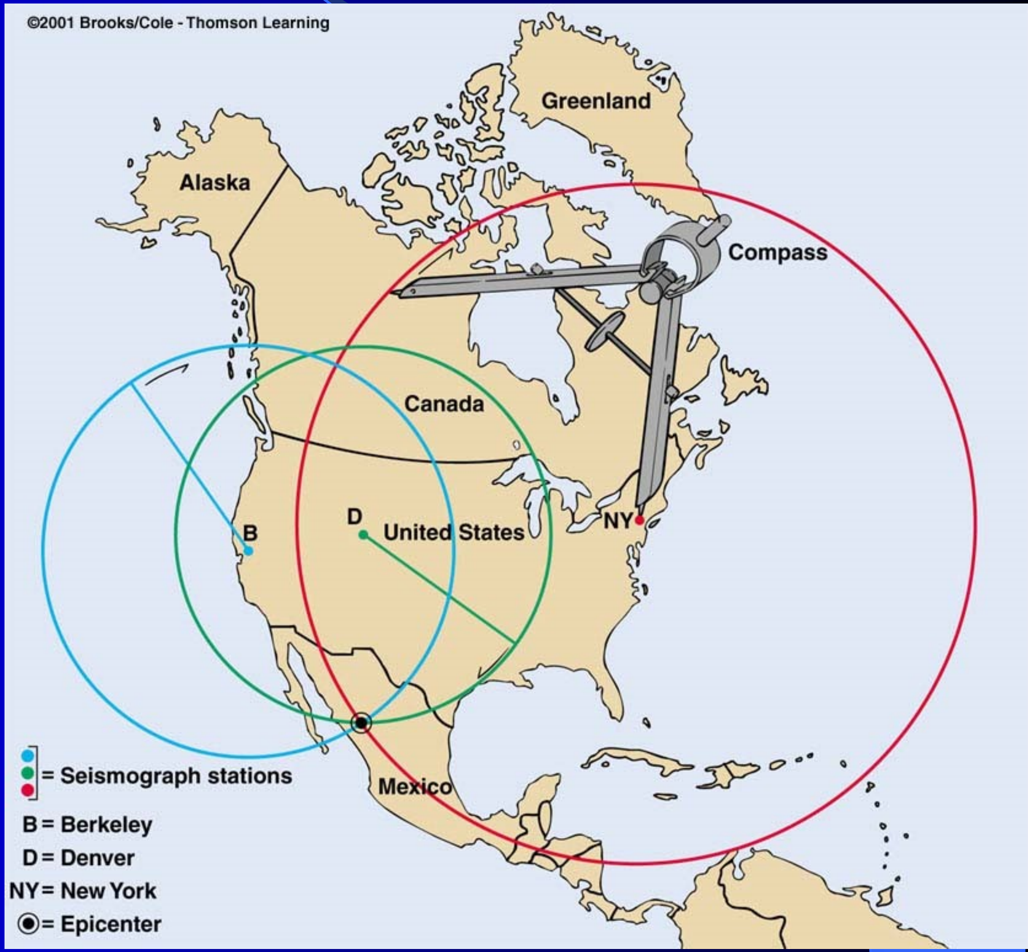
How is an Earthquake's Epicenter Located?

Time-distance graph showing the average travel times for P- and S-waves. The farther away a seismograph is from the focus of an earthquake, the longer the interval between the arrivals of the P- and S- waves

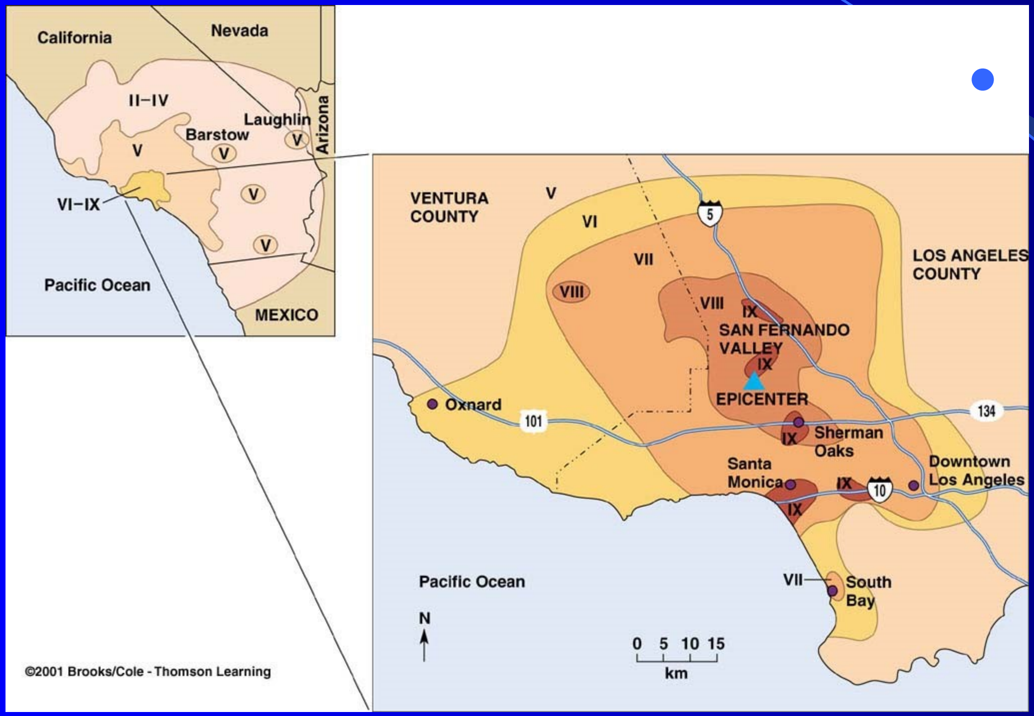


How is an Earthquake's Epicenter Located?

- Three seismograph stations are needed to locate the epicenter of an earthquake
- A circle where the radius equals the distance to the epicenter is drawn
- The intersection of the circles locates the epicenter



How are the Size and Strength of an Earthquake Measured?

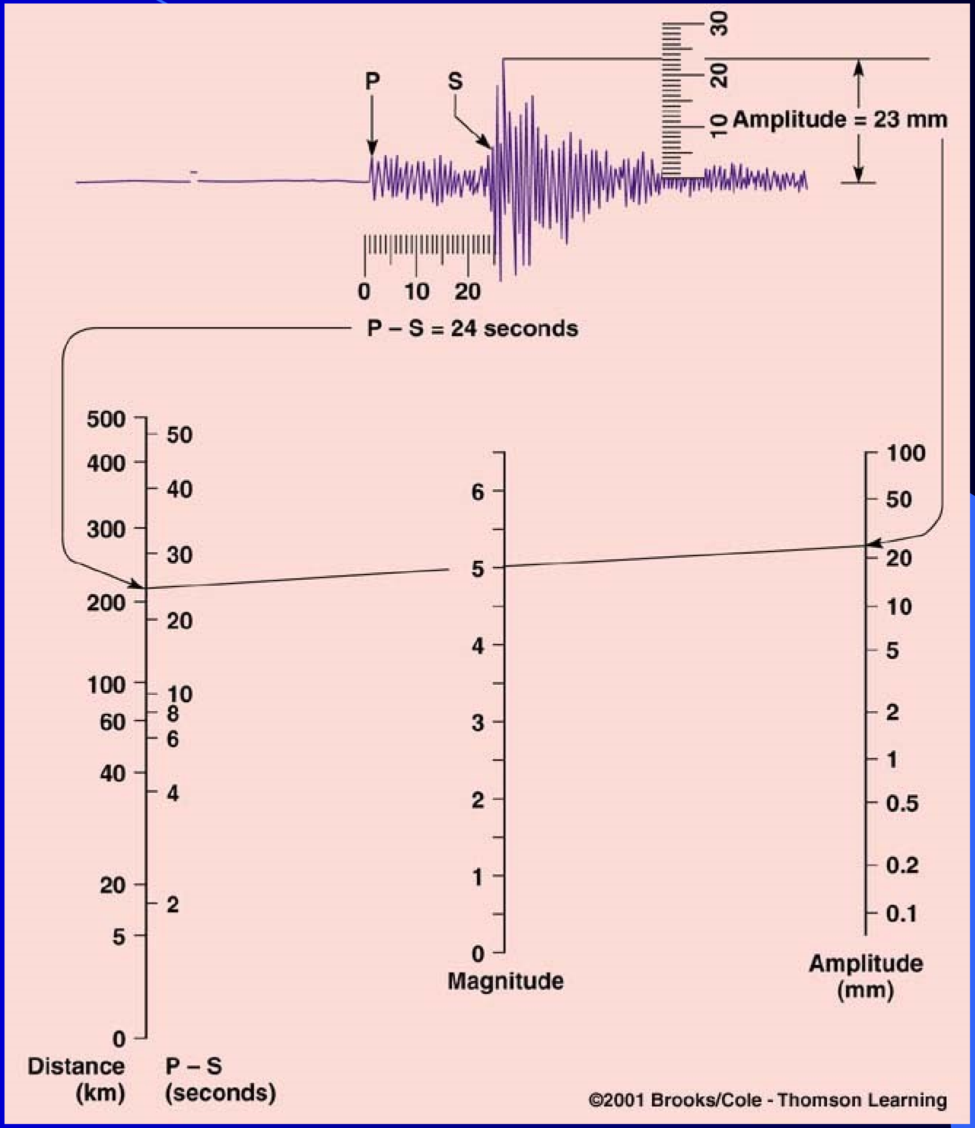


- Intensity
  - subjective measure of the kind of damage done and people's reactions to it
  - isoseismal lines identify areas of equal intensity

- Modified Mercalli Intensity Map
  - 1994 Northridge, CA earthquake, magnitude 6.7

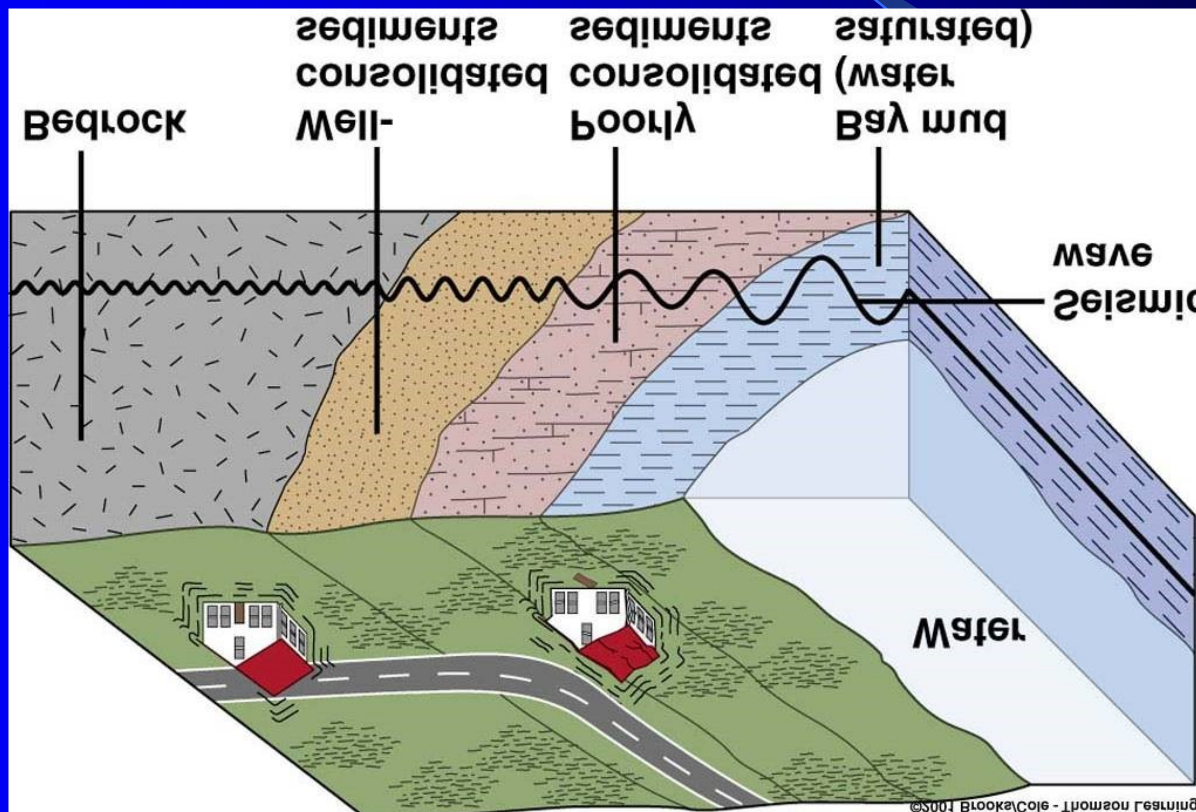
How are the Size and Strength of an Earthquake Measured?

- Magnitude
  - Richter scale measures **total amount of energy** released by an earthquake; independent of intensity
  - Amplitude of the largest wave produced by an event is corrected for distance and assigned a value on an open-ended logarithmic scale



What are the Destructive Effects of Earthquakes?

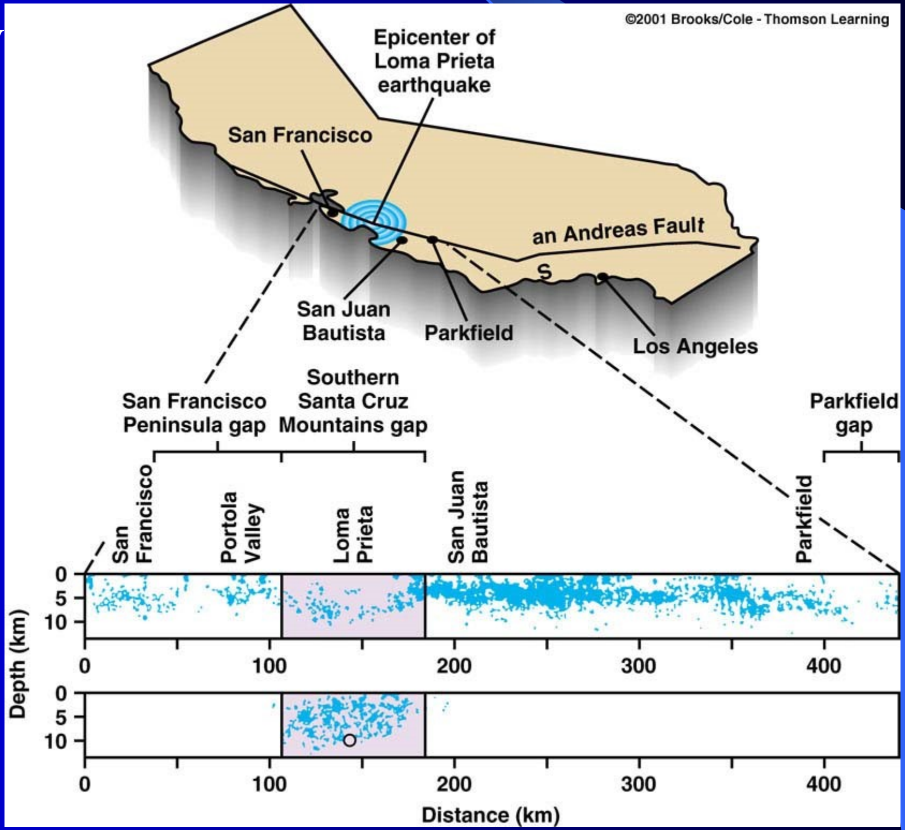
- Ground Shaking
  - amplitude, duration, and damage increases in poorly consolidated rocks



Can Earthquakes be Predicted?

Earthquake Precursors

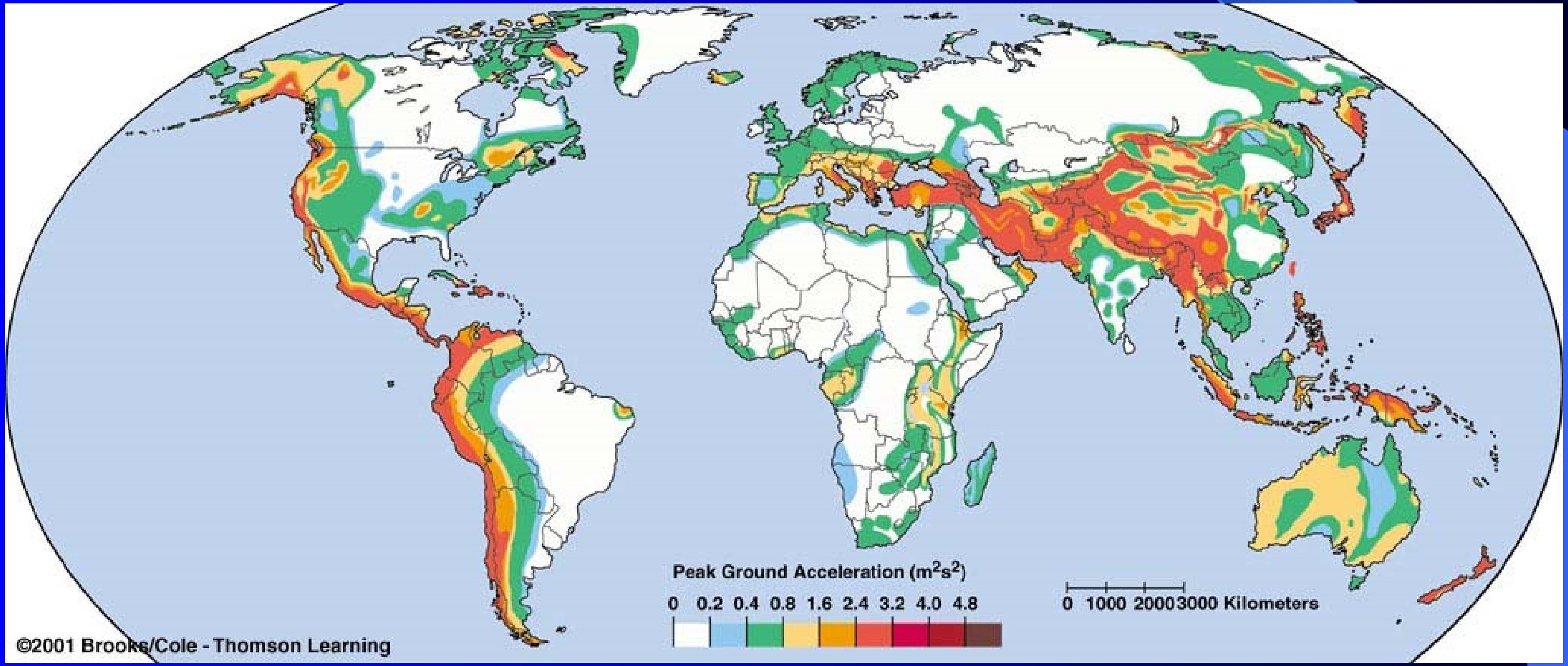
- changes in elevation or tilting of land surface, fluctuations in groundwater levels, magnetic field, electrical resistance of the ground
- seismic dilatancy
- seismic gaps



Can Earthquakes be Predicted?

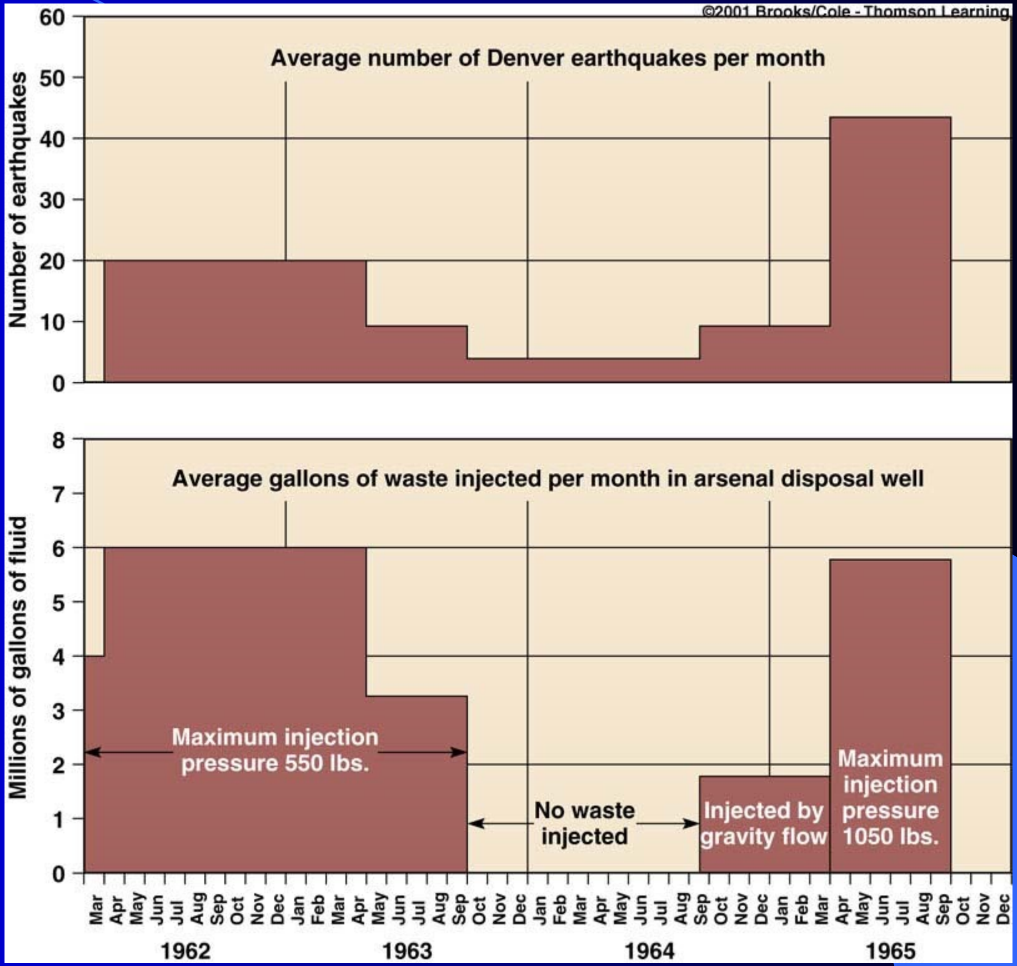
Earthquake Prediction Programs

- include laboratory and field studies of rocks before, during, and after earthquakes
- monitor activity along major faults
- produce risk assessments

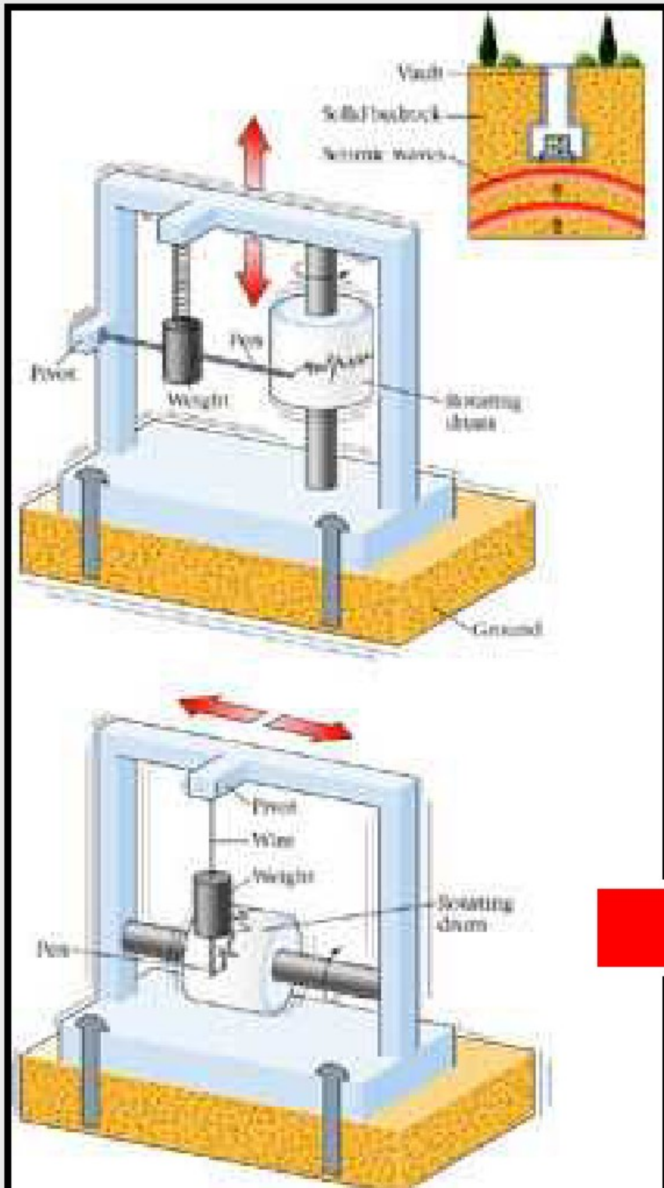


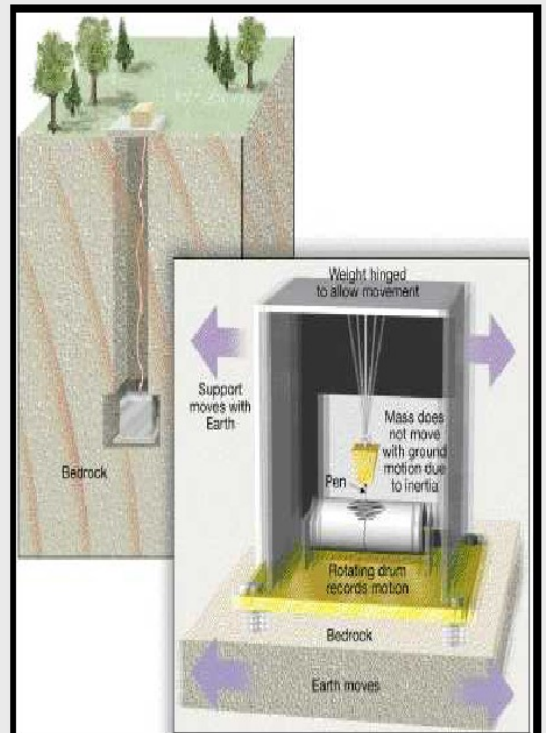
Can Earthquakes be Controlled?

- Graph showing the relationship between the amount of waste injected into wells per month and the average number of Denver earthquakes per month
- Some have suggested that pumping fluids into seismic gaps will cause small earthquakes while preventing large ones

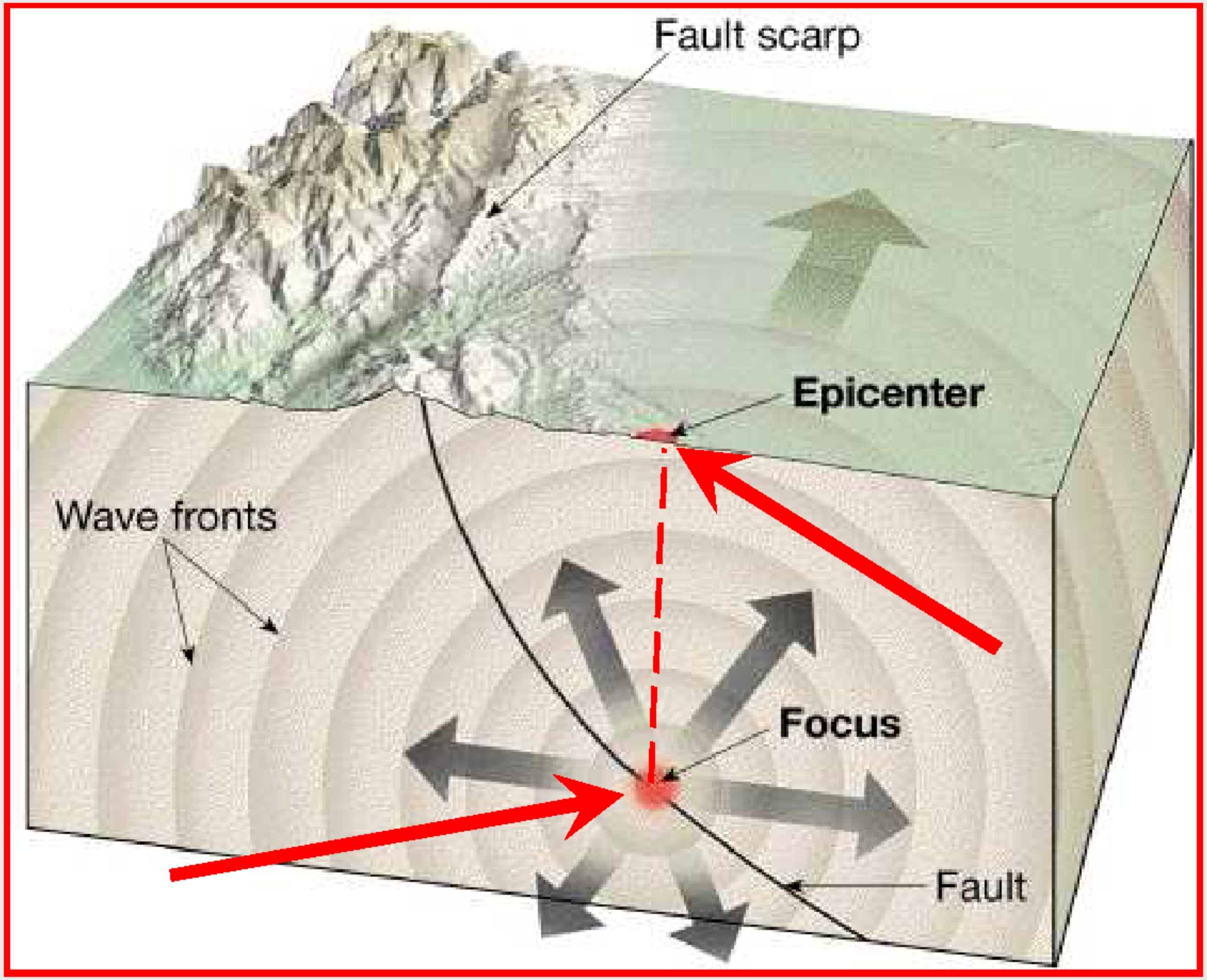


Types of Seismographs





Focus and Epicenter of Earthquake



Determining the magnitude of an earthquake

Magnitude -- measure of energy released during earthquake. There are several different ways to measure magnitude.

Most common magnitude measure is **Richter Magnitude**, named for the renowned seismologist, Charles Richter.

Richter Magnitude:

- Measure amplitude of largest S wave on seismograph record.
- Take into account distance between seismograph & epicenter.

Richter Scale

- Logarithmic numerical (NOT a physical) scale
- Increasing one whole unit on Richter Scale represents 10 times greater magnitude.
- Going up one whole unit on Richter Scale represents about a 30 times greater release of energy.

Intensity

- Intensity refers to the amount of damage done in an earthquake
- Mercalli Scale is used to express damage.

Hazards associated with Quakes

- Shaking:

  Frequency of shaking differs for different seismic waves.

  High frequency body waves shake low buildings more.

  Low frequency surface waves shake high buildings more.

  Intensity of shaking also depends on type of subsurface material.

  Unconsolidated materials amplify shaking more than rocks do.

  Fine-grained, sensitive materials can lose strength when shaken. They lose strength by ***liquefaction***.

Buildings respond differently to shaking depending on construction styles, materials

Wood -- more flexible, holds up well

Earthen materials -- very vulnerable to shaking.

- Ground displacement:

  Ground surface may shift during an earthquake (esp. if focus is shallow).

  Vertical displacements of surface produce ***fault scarps***.

- Tsunamis (NOT tidal waves)

  Tsunamis are huge waves generated by earthquakes undersea or below coastal areas.

  If earthquake displaces sea surface, wave is generated that can grow as it moves over sea surface.

- Fires

  Usually occurs from shifting of subsurface utilities (gas lines)

Earthquakes and volcanic activity

- Earthquakes often occur in volcanic regions and are caused there, both by tectonic faults and the movement of magma in volcanoes.

- Such earthquakes can serve as an early warning of volcanic eruptions, as during the Mount St. Helens eruption of 1980

- Earthquake swarms can serve as markers for the location of the flowing magma throughout the volcanoes.

- These swarms can be recorded by seismometers and tiltmeters (a device which measures the ground slope) and used as sensors to predict imminent or upcoming eruptions

Buildings and Earthquakes
Underlying Physics

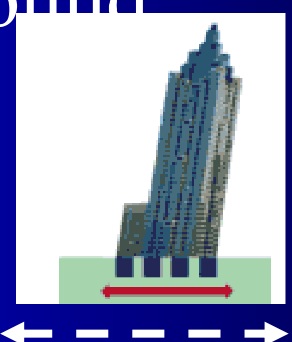
- Newton's Second Law

$$F = ma$$

where m = mass of building

a = acceleration of ground

Question:
What do the physics tell us about the magnitude of the forces that different types of buildings feel during an earthquake?

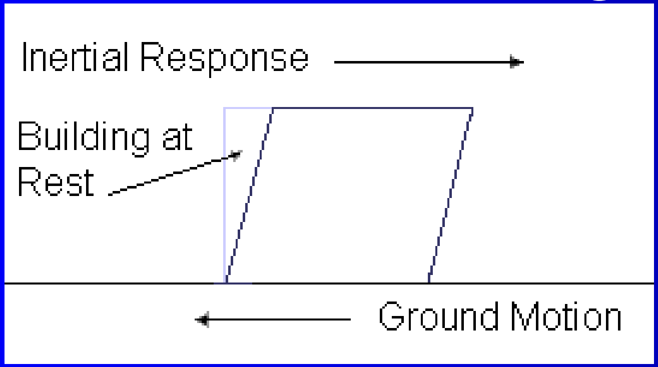


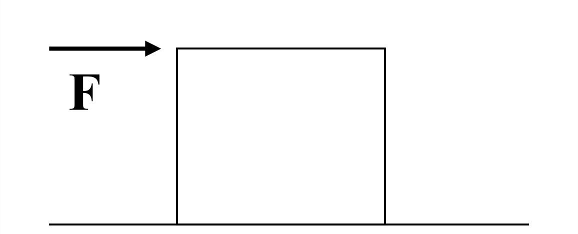
ground acceleration

Animation from www.exploratorium.edu/faultline/engineering/engineering5.html

What is really happening?

- **F** is known as an **inertial** force,
  - created by building's tendency to remain at rest, in its original position, although the ground beneath it is moving

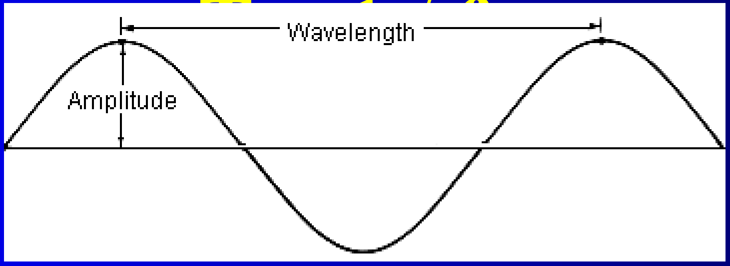




Engineering representation of earthquake force

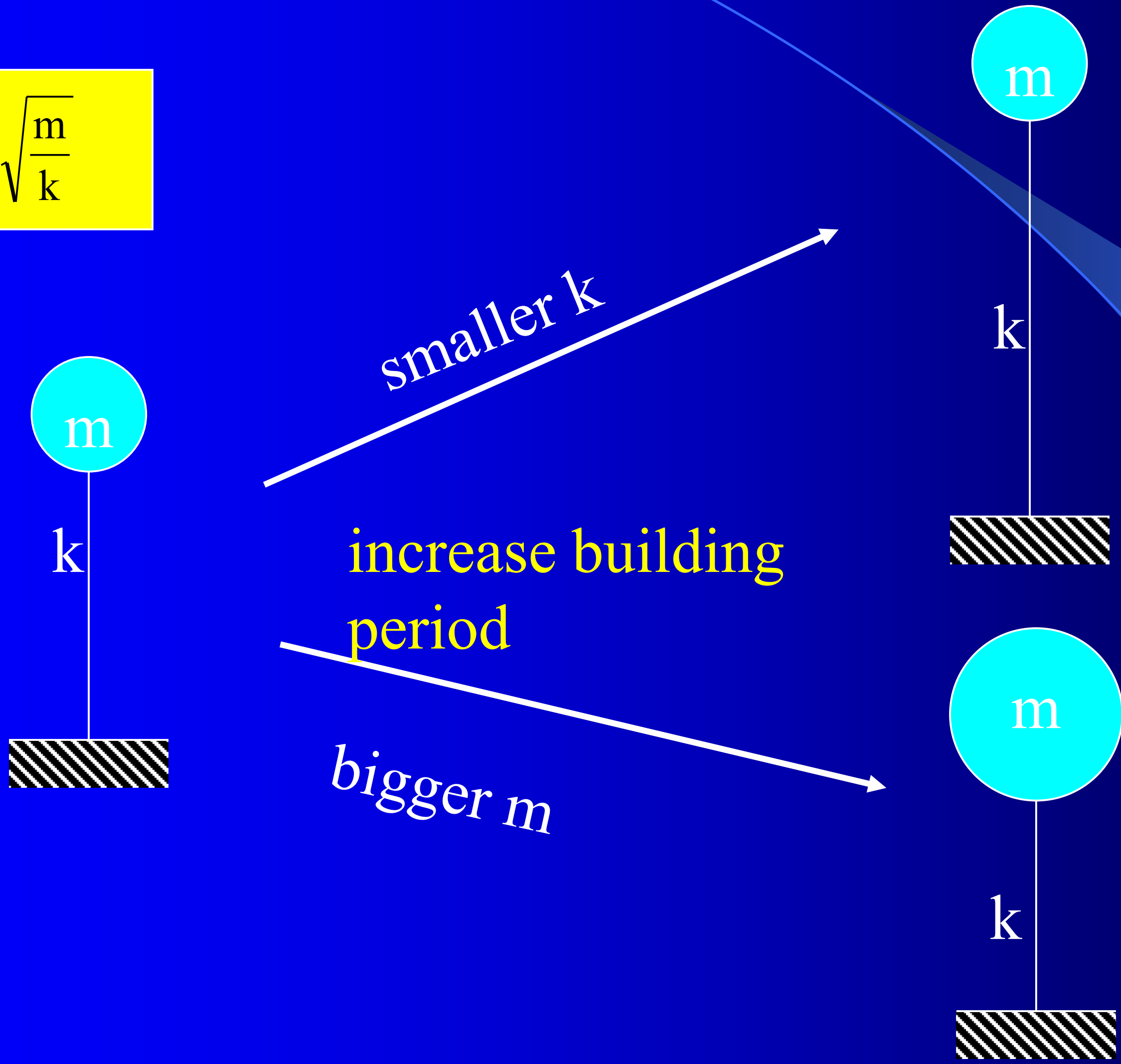
Period and Frequency

- **Frequency (f)** = **number of complete cycles of vibration per second**
- **Period (T)** = **time needed to complete one full cycle of vibration**



Idealized Model of Building

$$T = 2\pi \sqrt{\frac{m}{k}}$$



Natural Period of Buildings

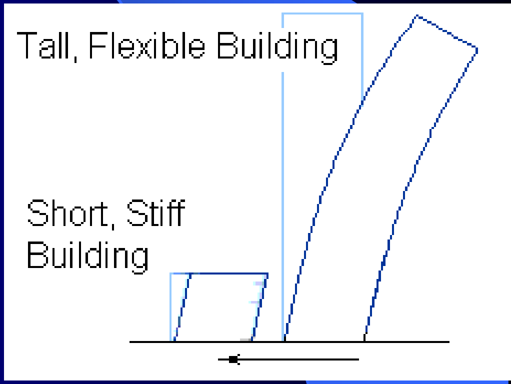
- Each building has its own natural period (frequency)

Building Height	Typical Natural Period	Natural Frequency
2 story	0.2 seconds	5 cycles/sec
5 story	0.5 seconds	2 cycles/sec
10 story	1.0 seconds	?
20 story	2.0 seconds	?
30 story	3.0 seconds	?

slower shaking

Resonance

- Resonance = frequency content of the ground motion is close to building's natural frequency
  - tends to increase or **amplify** building response
  - building suffers the greatest damage from ground motion at a frequency close or equal to its own natural frequency
- Example: Mexico City earthquake of September 19, 1985
  - majority of buildings that collapsed were around 20 stories tall
  - natural period of around 2.0 seconds
  - other buildings, of different heights and different natural frequencies, were undamaged even though located right next to damaged 20 story buildings



What affects building performance & damage?

- Shape (configuration) of building:
  - Square or rectangular usually perform better than L, T, U, H, +, O, or a combination of these.
- Construction material: steel, concrete, wood, brick.
  - Concrete is the most widely used construction material in the world.
  - Ductile materials perform better than brittle ones. Ductile materials include steel and aluminum. Brittle materials include brick, stone and unstrengthened concrete.
- Load resisting system
- Height of the building: (i.e. natural frequency)
- Previous earthquake damage
- Intended function of the building (e.g. hospital, fire station, office building)
- Proximity to other buildings
- Soil beneath the building
- Magnitude and duration of the earthquake
- Direction and frequency of shaking

Proximity to Other Buildings - Pounding

- Buildings are so close together that they repeatedly hit each other during an earthquake
- Can cause collapse of frame buildings

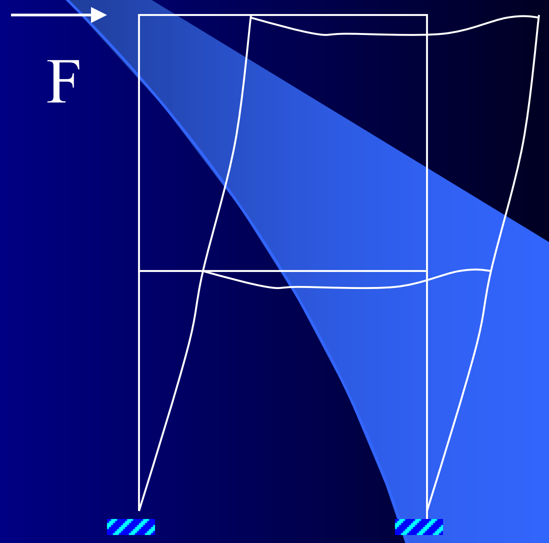
Key Factor in Building Performance

Good connections

- Need to transfer loads from structural elements into foundation and then to ground

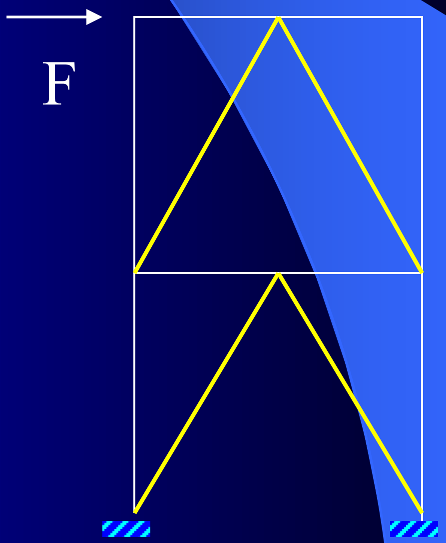
Building Systems: Frames

- Frame built up of beams and columns
  - Steel
  - Concrete
- Resists lateral load by bending of beams and columns
- Provides lots of open interior space
- Flexible buildings



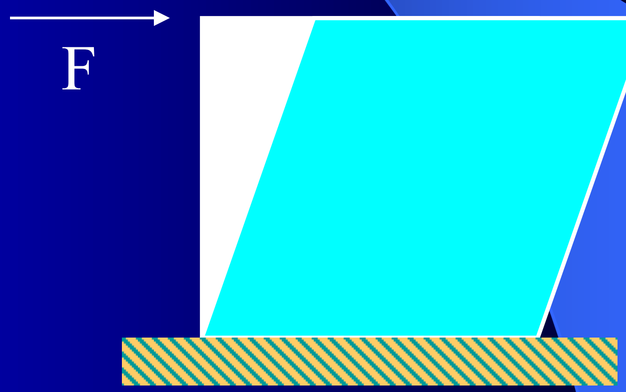
Building Systems: Braced Frame

- Braces used to resist lateral loads
  - steel or concrete
- Damage can occur when braces buckle
- Stiffer than pure frame



Building Systems: Shear Walls

- wall elements designed to take vertical as well as in-plane horizontal (lateral) forces
  - Concrete buildings
  - Wood buildings
  - Masonry buildings
- resist lateral forces by shear deformation
- stiffer buildings

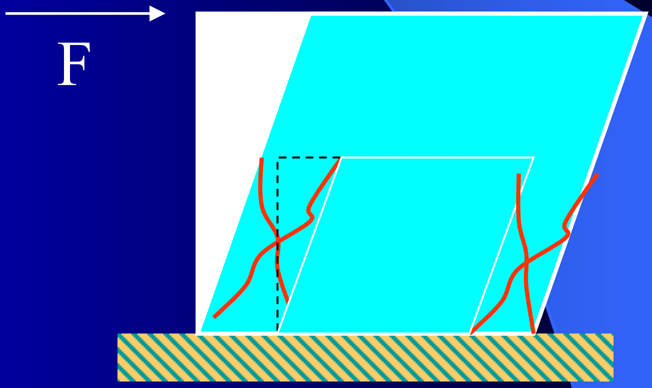


Shear Deformation

Building Systems: Shear Walls

- Large openings in shear walls
  - a much smaller area to transfer shear
  - resulting large stresses cause cracking/failure

West Anchorage High School, 1964



Cracking around openings

Wood Frame Construction

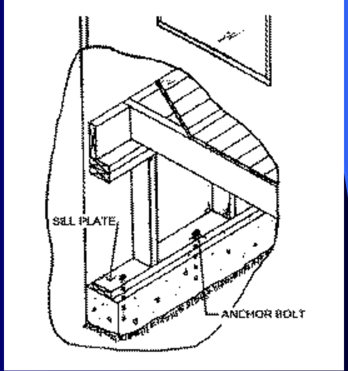
- Most houses and low rise apartments in California, some strip malls
- Shear wall type construction
- Light weight (except if has clay tile roof)
- Generally perform well in earthquakes
- Damage often consists of cracked plaster and stucco

Wood Frame Damage

Chimneys
collapse

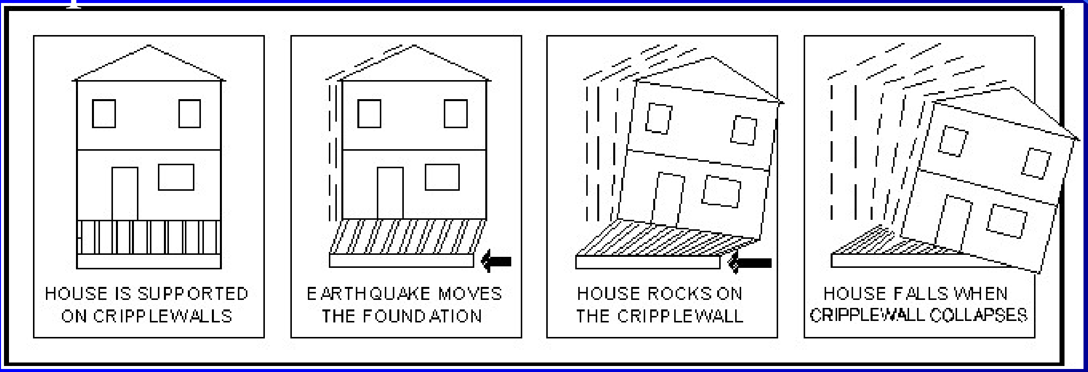
generally
don't collapse
because have
many interior
walls

Slide off foundation –
generally pre-1933 because
bolting inadequate



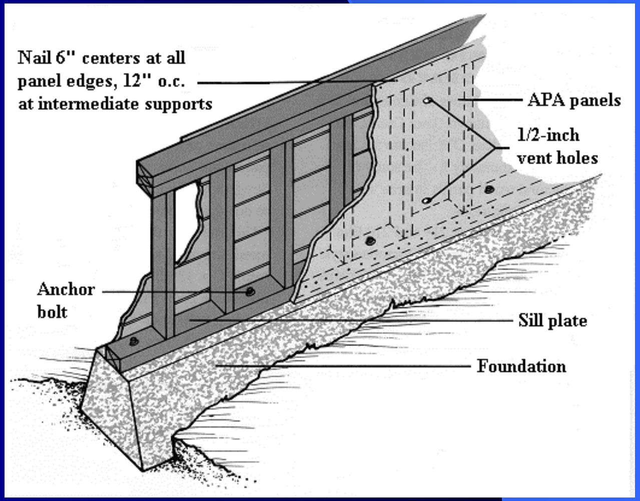
Wood Frame Damage – Cripple Wall Failure

the problem



short walls that connect foundation to floor base - common in houses built before 1960

the fix



the damage

MUSE 11B

Soft First Story

Occurs when first story much less stiff than stories above

Typical damage – collapse of first story

Tuck Under Parking

Typical apartment building with tuck under parking

Retrofit can include installation of a steel frame to limit the deformation of

Unreinforced Masonry (URM)

- Built of heavy masonry walls with no reinforcing
  - anchorage to floors and roof generally missing
  - floors, roofs and internal partitions are usually of wood
  - older construction – no longer built
- Typical damage
  - Walls collapse and then roof (floors) come down
  - Parapets fall from roof

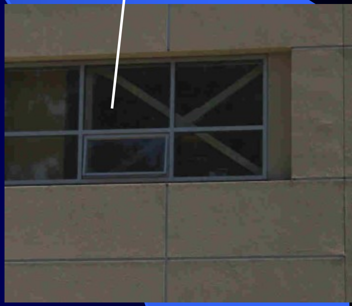
Tilt-up Construction

- Shear wall load resisting system
- Quick and inexpensive to build
- Warehouses (Costco), industrial parks
- Typical damage
  - Walls fall outward, then roof collapses

Mobile Home

- Factory-built dwelling (lightweight)
  - built of light-weight metal construction or a combination of a wood and steel frame structure
- Typical damage
  - jacks on which the coach is placed tip, and coach falls off some or all of its supports.
  - jacks to punch holes through the floors of the coach
  - usually stays in tact
  - mobile home becomes detached from utilities (possible fire)

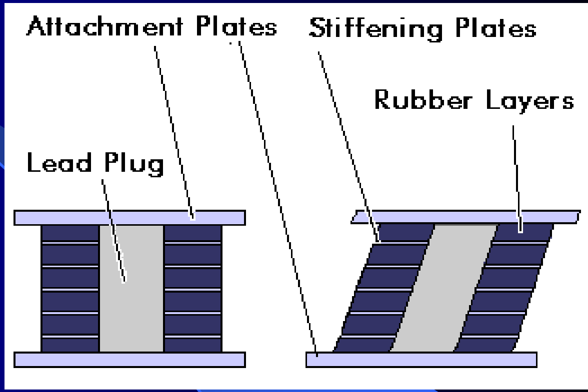
Seismic Retrofit

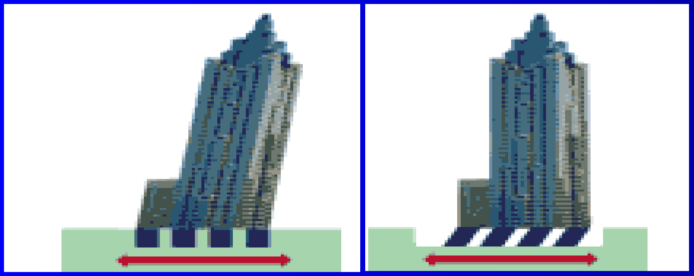


Frames can be used to strength en older concrete building

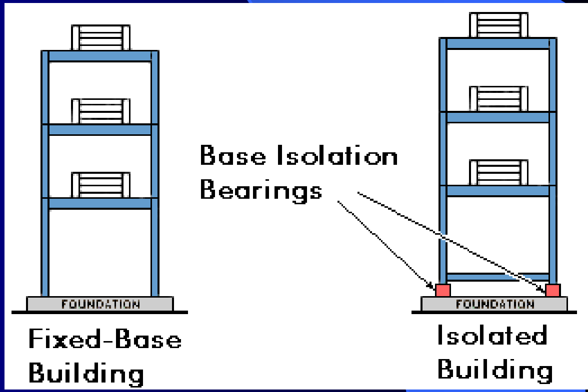
Base Isolated Buildings

- Supported by a series of bearing pads placed between the building and its foundation
- Most of deformation in isolators and acceleration of the building is reduced = less damage





not isolated　　isolated



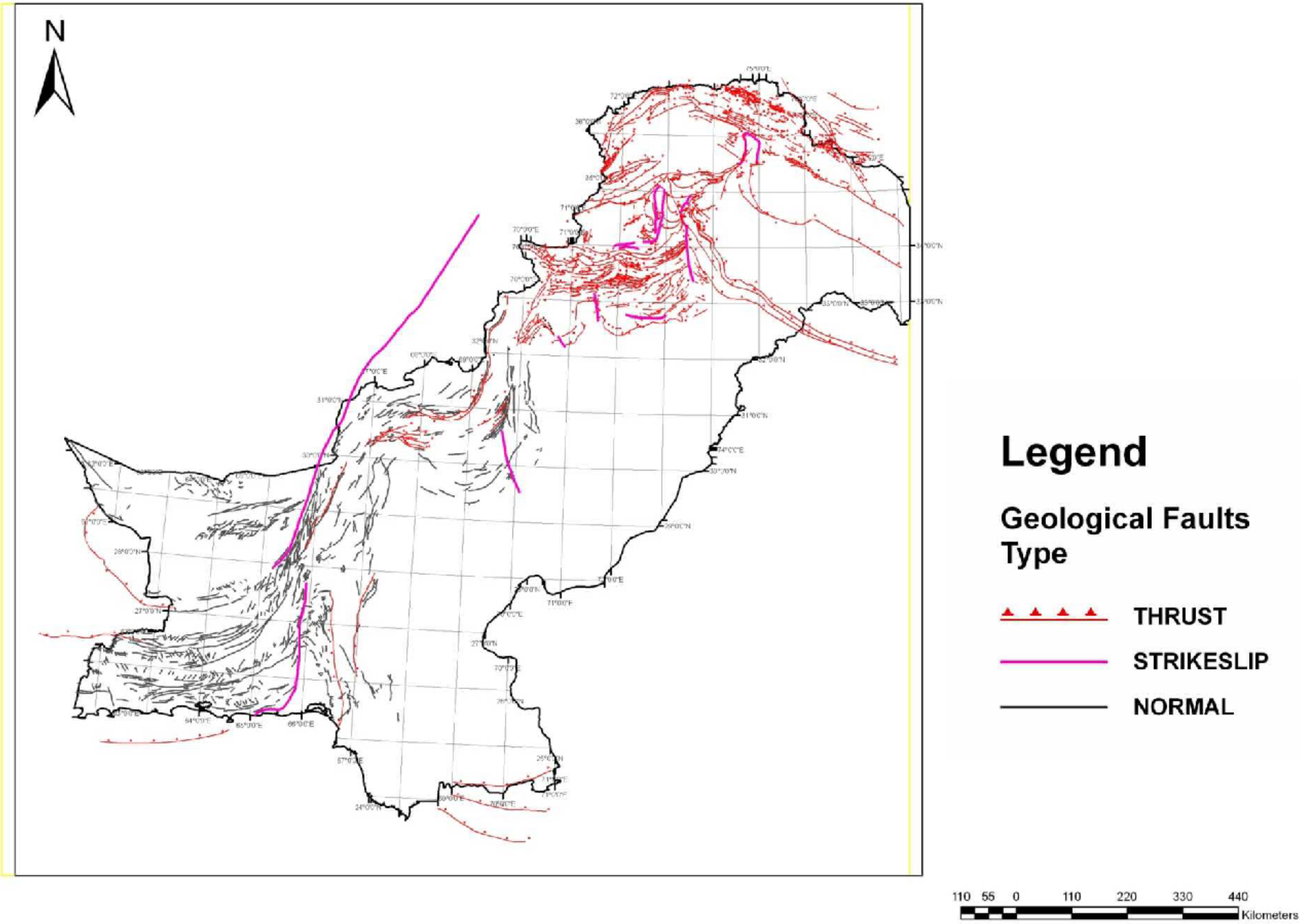
Non Structural Issues

Good connections of non-structural building contents with building

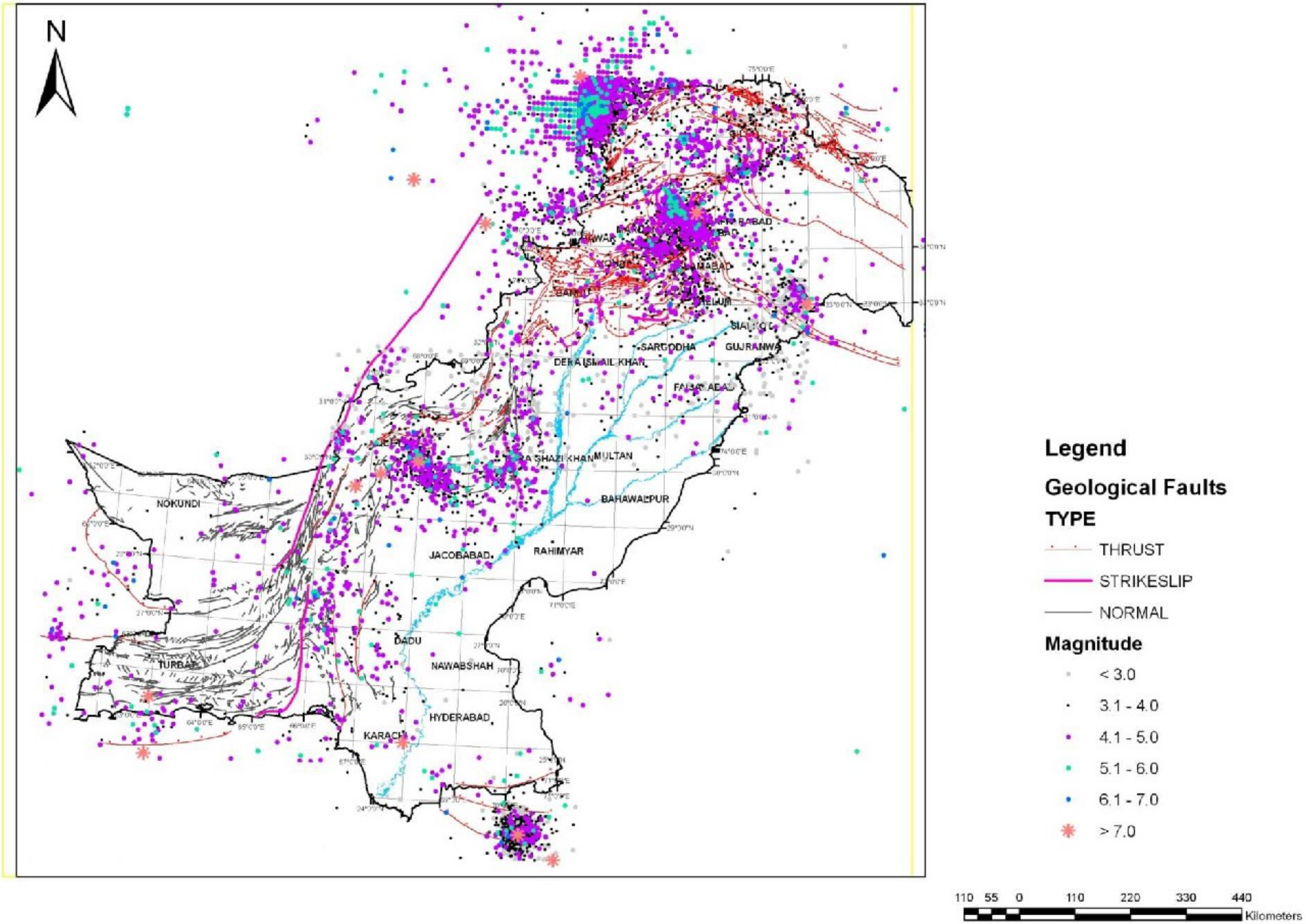
Engineering Geology and Earthquakes

- **The following information about the area is essential:**
- Estimate of the likely strength, frequency and location of future earthquakes
- Geology of the region around the construction site and a survey of past earthquake events
- An assessment of the likely response of the proposed structure and any other structures in the vicinity of the proposed structure, to the anticipated tremors.
- Knowledge of the vulnerability of coastal sites (if that is where the structure is to be built) to sudden flooding by tidal waves (*tsunamis) generated by off-shore earthquakes* that can cause an abrupt vertical displacement of the ocean floor.
- Attention must be given to the effects of earthquakes on infrastructure (roads, water, supply, electricity supply, etc.) as well as on the principal constructions so that, in the event that a major earthquake occurs, sufficient infrastructure remains for relief

FAULT MAP OF PAKISTAN



SEISMOTECTONIC MAP OF PAKISTAN



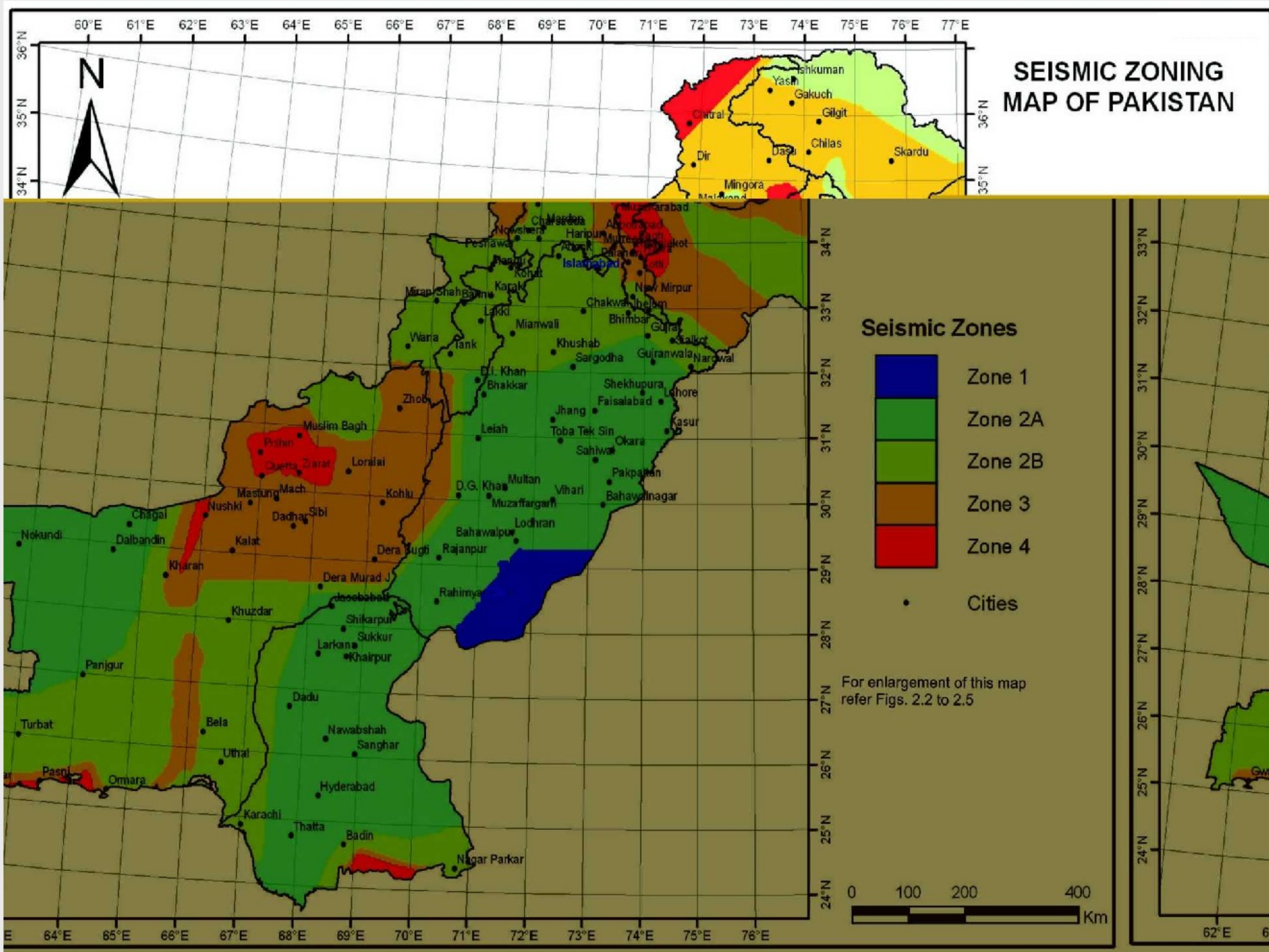
SEISMIC ZONING MAPS

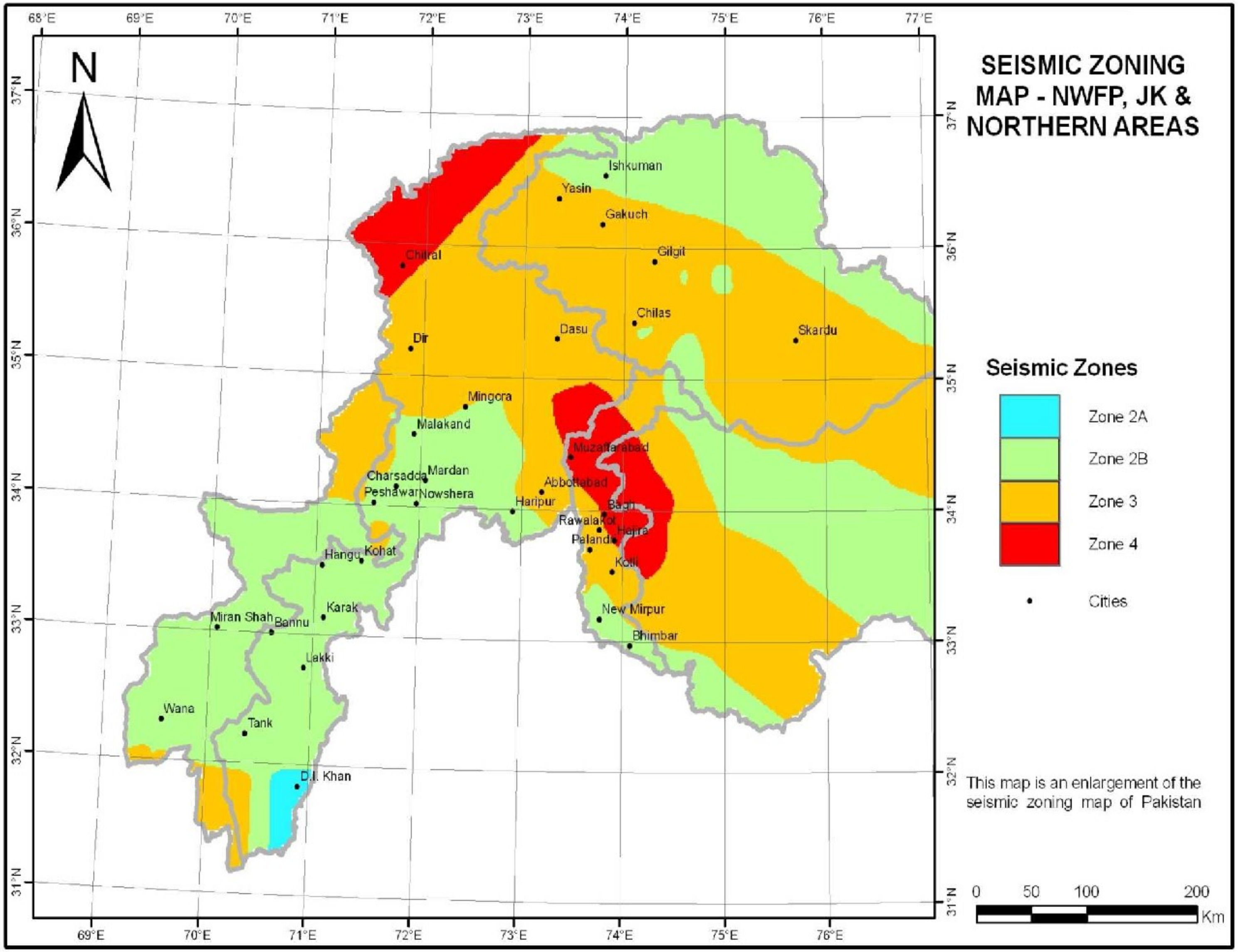
- **ALL POSSIBLE SEISMIC SOURCES WERE CONSIDERED**
- **PROBABILISTIC HAZARD ANALYSIS WAS MADE USING LATEST SOFTWARE**
- **GROUND MOTION WITH 10% PROBABILITY OF EXCEEDANCE IN 50 YEARS (RETURN PERIOD 500 YEARS) WERE CALCULATED AT A GRID OF 0.1 DEGREE**
- **SEISMIC ZONING MAP FOR PAKISTAN WAS PREPARED USING ABOVE EXHAUSTIVE WORK WHICH DIVIDED THE COUNTRY INTO FIVE ZONES, FOLLOWING UBC-1997.**

BASIS OF SEISMIC ZONING

SEISMIC ZONE	PEAK HORIZONTAL GROUND ACCELERATION
1	0.05 to 0.08g
2A	0.08 to 0.16g
2B	0.16 to 0.24g
3	0.24 to 0.32g
4	> 0.32g

Where “g” is the acceleration due to gravity.


SEISMIC ZONING
MAP OF PAKISTAN
N
Seismic Zones
Zone 1
Zone 2A
Zone 2B
Zone 3
Zone 4
Cities
For enlargement of this map
refer Figs. 2.2 to 2.5
0 100 200 400
Km
Chitral
Gilgit
Skardu
Chilas
Dir
Mingora
Peshawar
Islamabad
Mianwali
Sargodha
Gujranwala
Lahore
Faisalabad
Jhang
Multan
Bahawalpur
Quetta
Zhob
Loralai
Sibi
Kalat
Khuzdar
Panjgur
Turbat
Bela
Pasni
Ormara
Karachi
Hyderabad
Thatta
Badin
Nawabshah
Sanghar
Dadu
Larkana
Sukkur
Khairpur
Shikarpur
Nagar Parkar
Nokundi
Dalbandin
Chagai
Nushki
Kharan


SEISMIC ZONING MAP - NWFP, JK & NORTHERN AREAS
Seismic Zones
Zone 2A
Zone 2B
Zone 3
Zone 4
Cities
This map is an enlargement of the seismic zoning map of Pakistan
0 50 100 200 Km
N
Ishkuman
Yasin
Gakuch
Chitral
Gilgit
Chilas
Dasu
Dir
Skardu
Mingora
Malakand
Muzaffarabad
Mardan
Charsadda
Peshawar
Nowshera
Abbottabad
Haripur
Bagh
Rawalakot
Hajira
Palandri
Hangu
Kohat
Kotli
Karak
New Mirpur
Miran Shah
Bannu
Bhimbar
Lakki
Wana
Tank
D.I. Khan