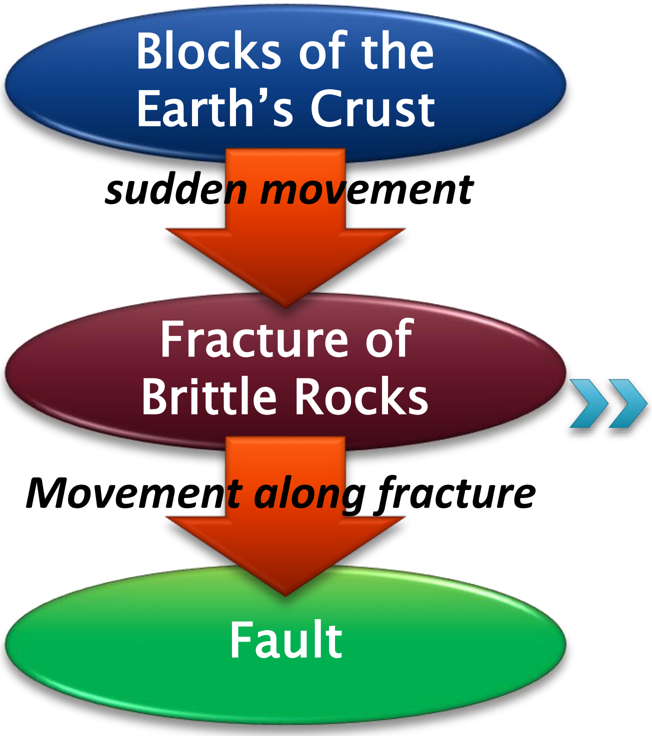
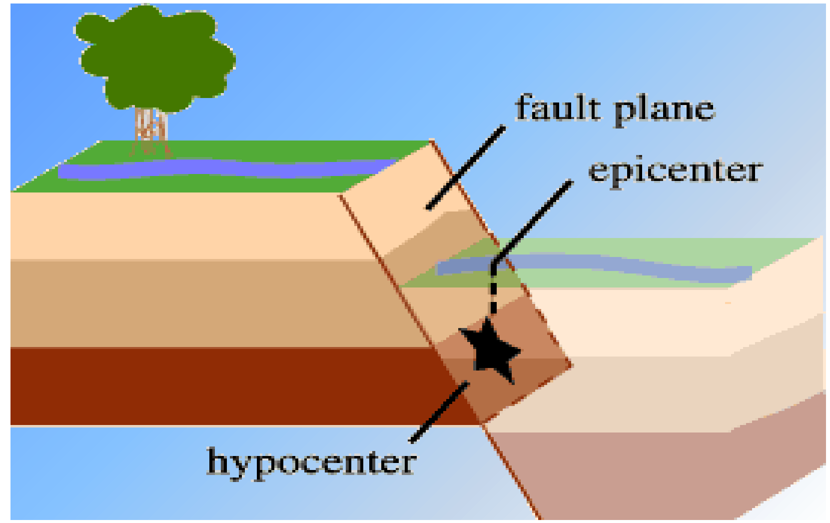
Earthquakes

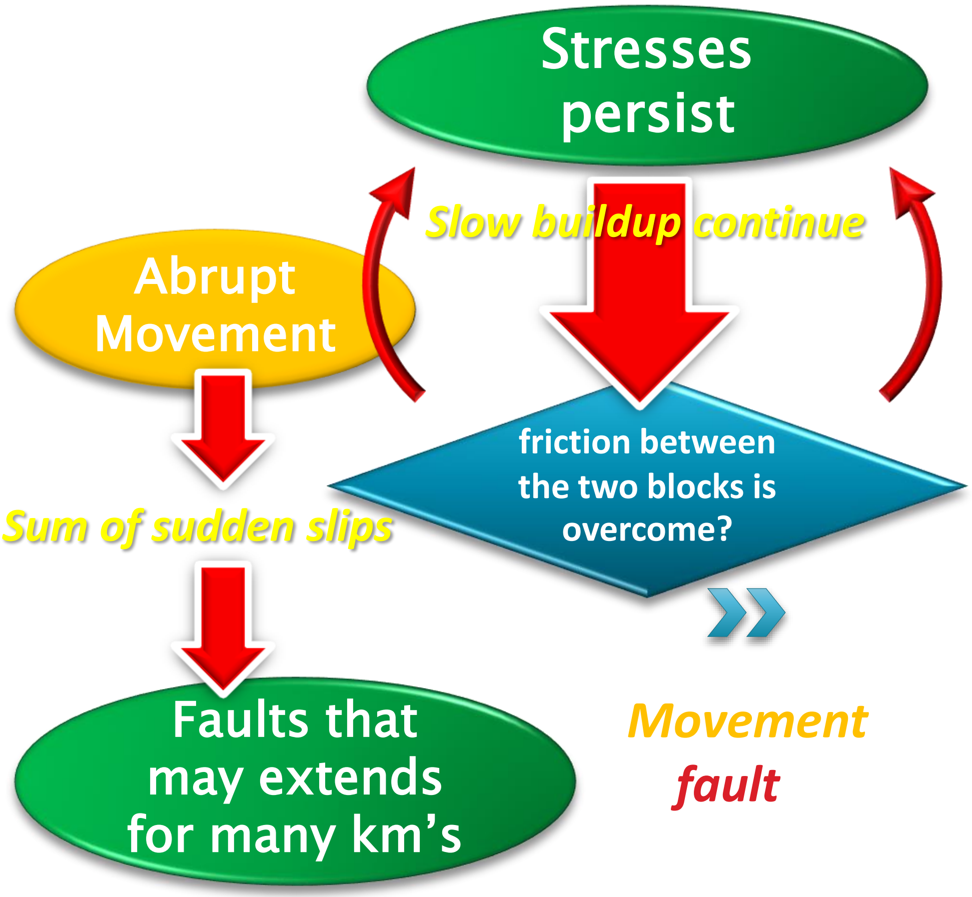
What Causes Earthquakes?





Tectonic forces produce ***stress***, or ***direction pressure***, which causes large blocks of rock on either side of a ***fault*** to move past one another.

Stress builds up slowly until the friction between the two blocks is overcome; then ***the blocks slip abruptly again***.



Detailed measurements along the **San Andreas Fault** in California reveal places where <u>gradual</u> slipping occurs, sometimes by as much as 5 cm a year.

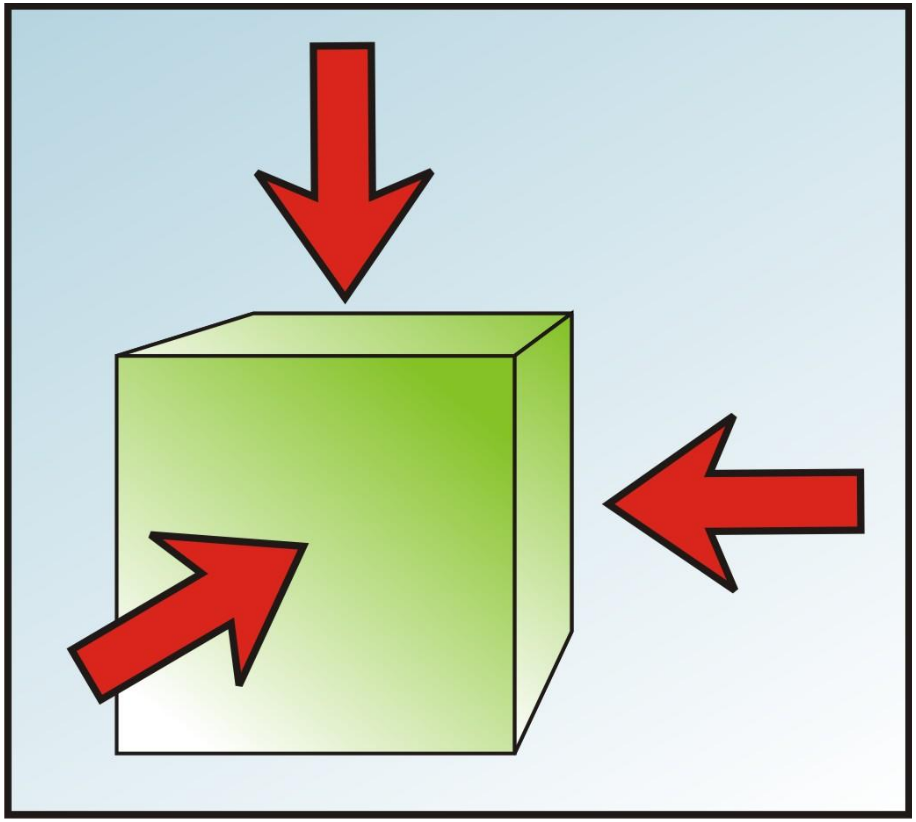
STRESS

Stress is a ***force applied over an area***.

One common type of stress is the **uniform stress**, called **pressure**.

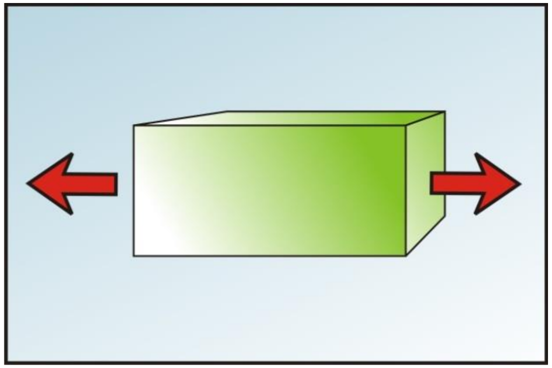
A **uniform stress** is where ***the forces act equally from all directions***.

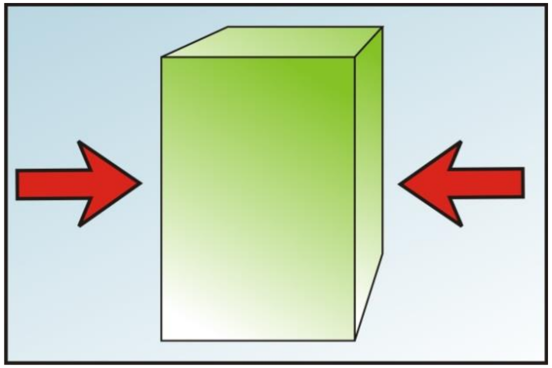
In the Earth *the pressure due to the weight of overlying rocks is a* **uniform stress** and is referred to as confining stress.

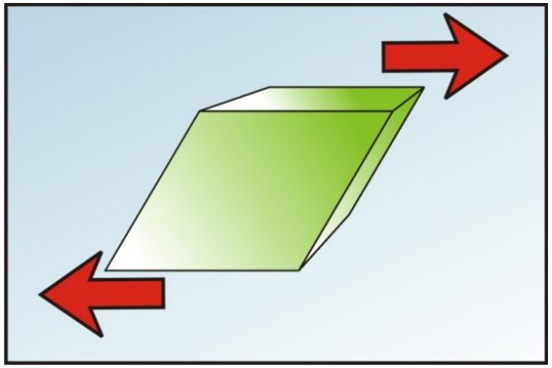


If **stress** is ***not equal from all directions then the stress is a*** **differential stress**. Three kinds of differential stress occur.

Tension	Compression	Shear
Stretches rock	Squeezes rock	Slippage and translation of rock







Stages of Deformation

When a rock is subjected to increasing **stress**, its **shape** or **volume** changes.

***Such change in shape or volume is referred to as* strain**.

When **stress** is applied to rock, the rock passes through **three successive stages of deformation**:

Elastic

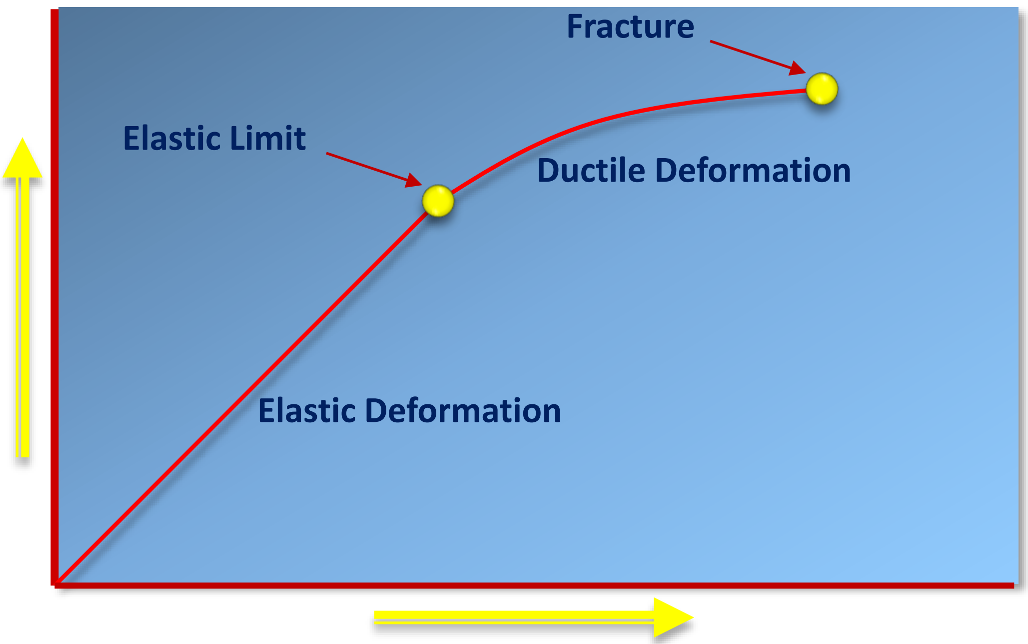
Strain is reversible

Ductile

Strain is irreversible

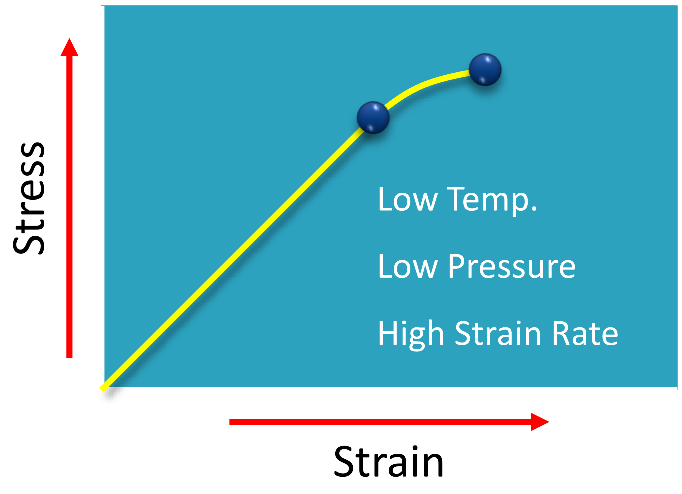
Fracture

Irreversible strain where the material breaks

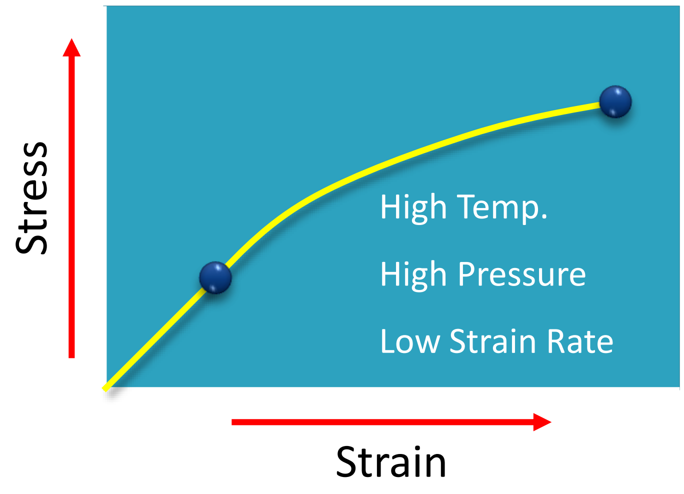


Materials

Brittle material has a small to large region of elastic behavior, but only a small region of ductile behavior before they fracture.



Ductile material has a small region of elastic behavior and a large region of ductile behavior.



The behavior of a material under stress depends on

- Temperature
- Pressure
- Strain rate
- Composition

Brittleness

Deforming Stresses →

- *Solid material will fracture*
- *Deformation becomes permanent*
- *Material will not be able to rebound to its original shape and volume*

Ductile Deformation

At greater depths High T and P → Rocks will bend and fold → Fracture will not take place neither store elastic energy → Shape will change even after forces removal

Fracture of Brittle Rocks

FAULTS

Faults occur when **brittle rocks fracture** and there is an **offset along the fracture**.

Types of Faults

Faults are classified according to

(1) ***the inclination, or slope, of the fault (called its dip)*** and

(2) ***the direction of relative movement along the fault***.

The common classes of faults are:

Dip-Slip Faults

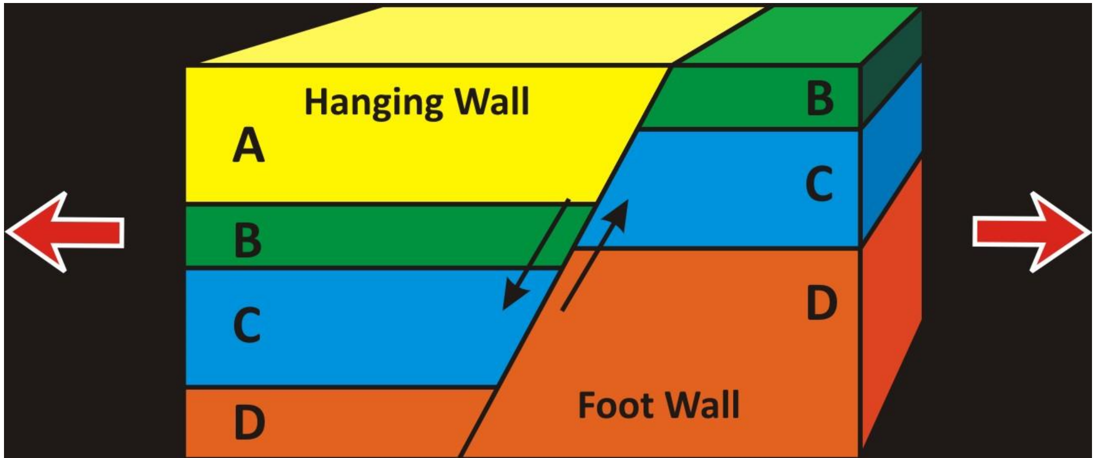
- Normal Faults
- Reverse Faults
- Thrust Faults

Strike-Slip Faults

- Right-Lateral Faults
- Left-Lateral Faults
- Transform Faults

Dip-Slip Faults

Normal Faults



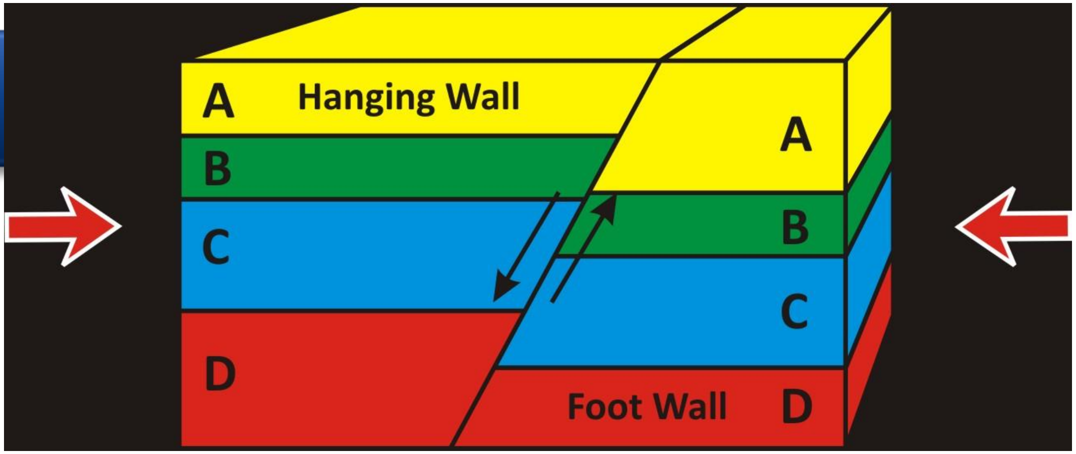
They are caused by tensional stress, that is, by movement that tends to pull crustal blocks apart.

The relative movement is such that one block of crustal material (hanging wall) moves downward relative to the other (foot wall).

They tend to stretch and thin the crust.

Dip-Slip Faults

Reverse Faults



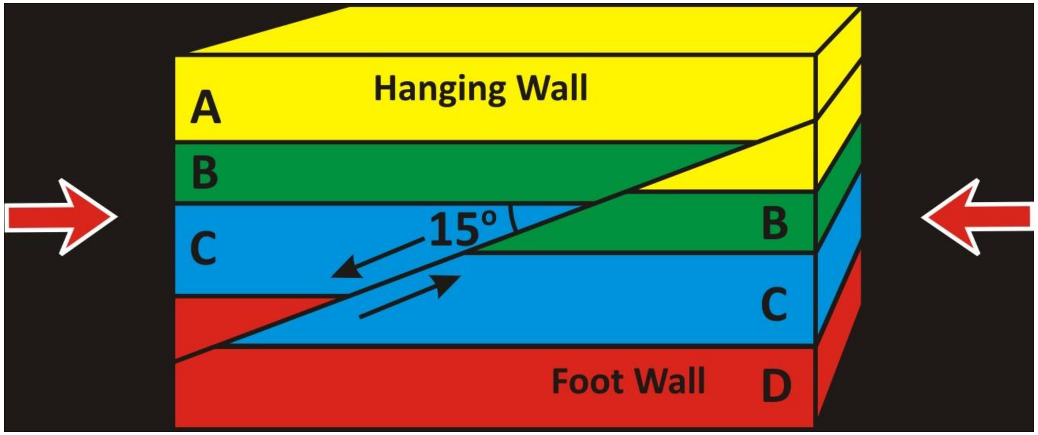
They arise from compressional stress, that is, movement that tends to push crustal blocks together.

The relative movement is such that one block of crustal material (hanging wall) moves upward relative to the other (foot wall).

Reverse fault movement shortens and thickens the crust.

Dip-Slip Faults

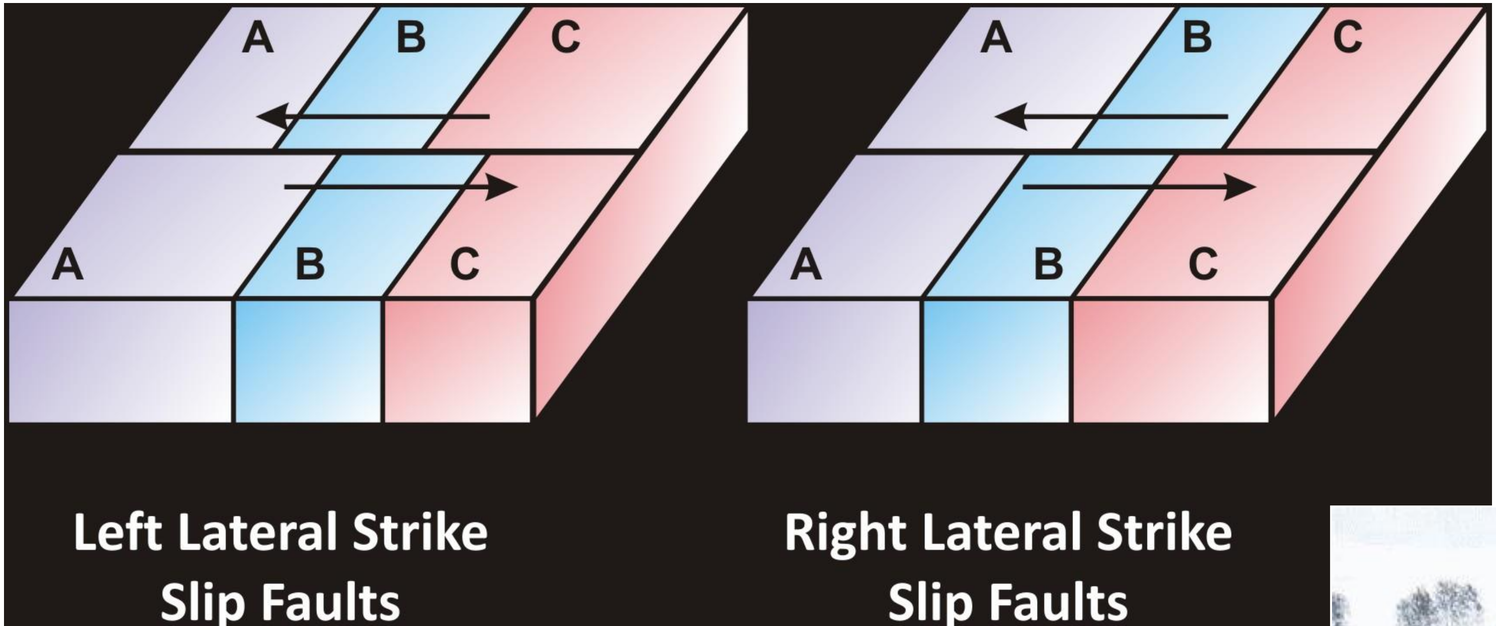
Thrust Faults



They are a special case of reverse faults where the dip of the fault is less than 15°.

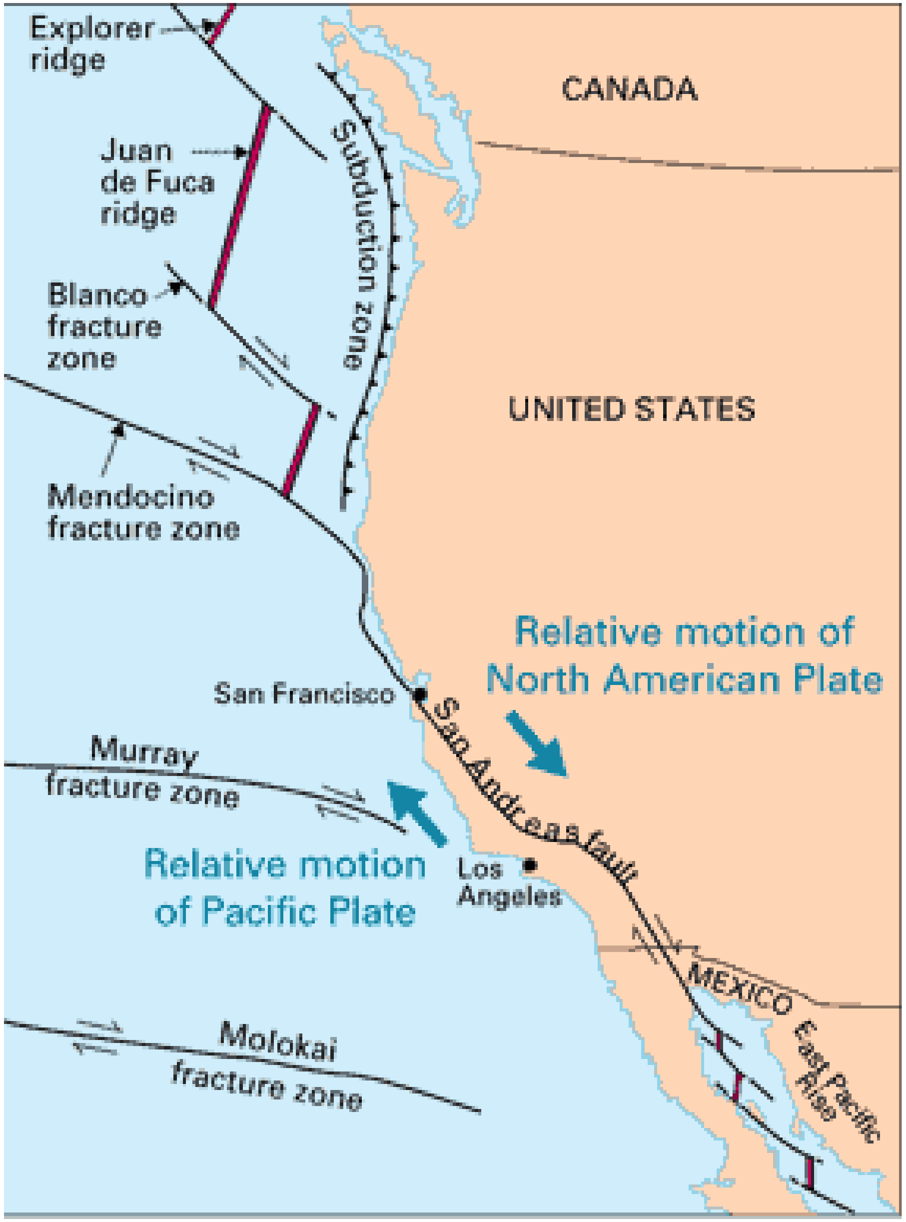
Such faults, which are common in great mountain chains, are noteworthy because along some of them
(1)the relative movement of crustal blocks may amount to hundreds of kilometers and
(2)can result in older strata overlaying younger strata.

Strike-Slip Faults



They arise from shear stresses that lead to horizontal, or translational, motions of the fault blocks; in other words, the two crustal blocks are sliding past one another.

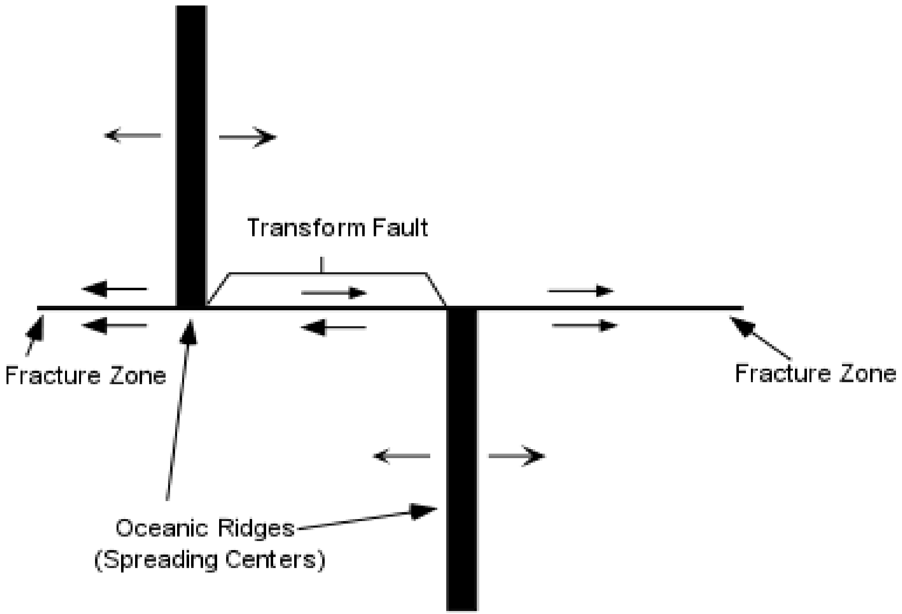
Strike-Slip Faults



The San Andreas Fault, for example, is a right-lateral strike-slip fault.

Strike-Slip Faults

Transform Faults



Transform faults are a special class of strike-slip faults.
They are plate boundaries along which two plates slide past one another in a horizontal manner.

The most common type of transform faults occur where oceanic ridges are offset.
Note that the transform fault only occurs between the two segments of the ridge.
Outside this area there is no relative movement because blocks are moving in the same direction. These areas are called fracture zones.
The San Andreas Fault in California is also a transform fault.

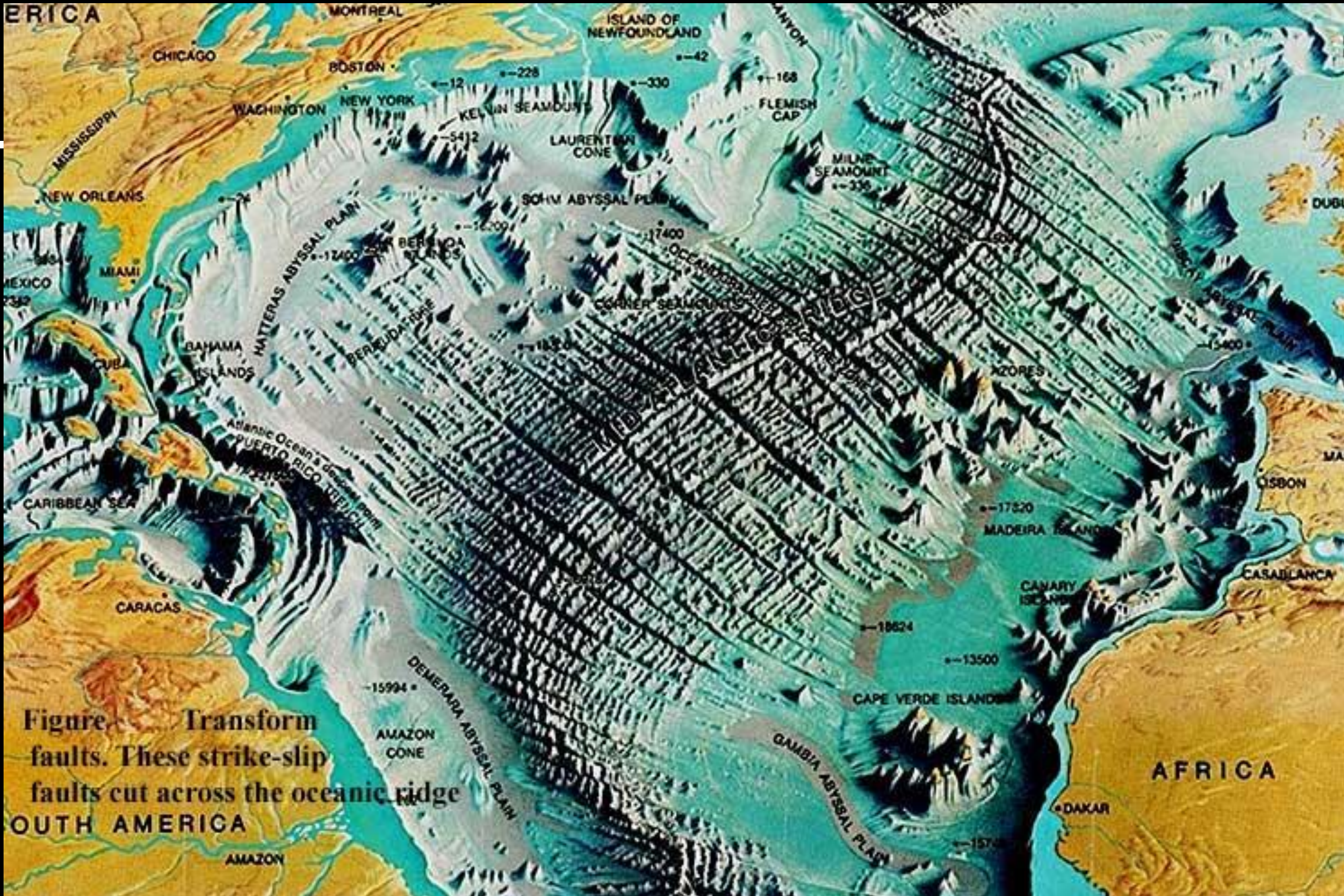


Figure Transform faults. These strike-slip faults cut across the oceanic ridge

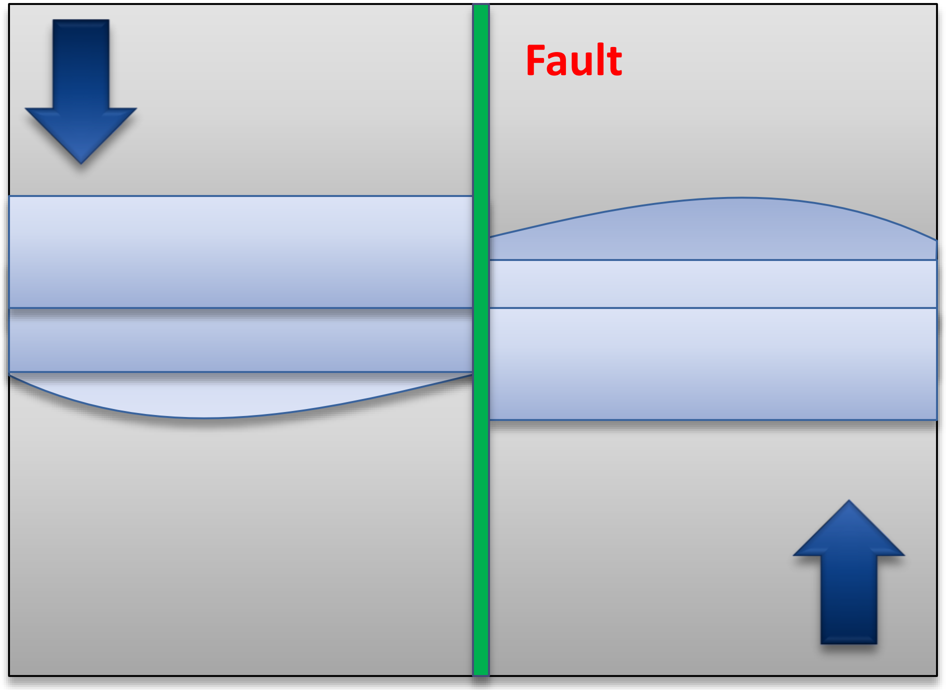
Elastic Rebound Theory

The most widely accepted explanation of the origins of earthquakes is the elastic rebound theory.

It is based on the mechanics of elastic deformation of rocks;
The elastic rebound theory suggests that energy can be stored in elastically deformed bodies of rock when they are subjected to stress along a fault. Eventually the stored energy is sufficient to overcome the friction between the blocks. The energy is suddenly released in the form of an earthquake, and the elastically strained bodies of rock rebound to their original shapes.

If slippage along the fault is hindered such that the elastic strain energy builds up in the deforming rocks on either side of the fault

When slippage occur, energy released causing earthquake



Earthquakes, therefore, are phenomena of the brittle, outer, cooler portion of the Earth.

How Earthquakes Are Studied?

The study of earthquakes is known as **seismology**, from the ancient Greek word for earthquakes, ***seismos***.

Scientists who study earthquakes are called **seismologists**.

Seismographs

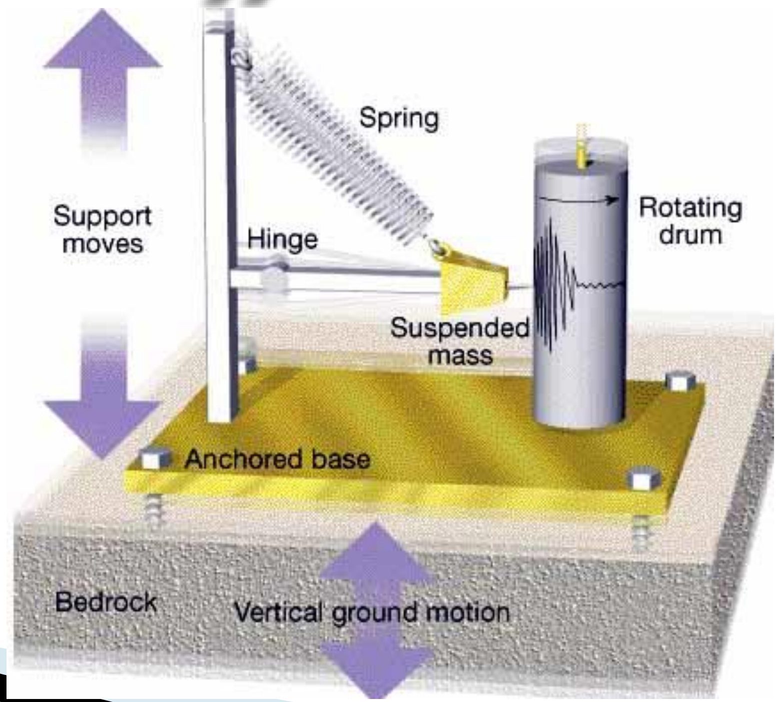
The device used to record the shocks and vibrations caused by earthquakes is a **seismograph or seismometer**.

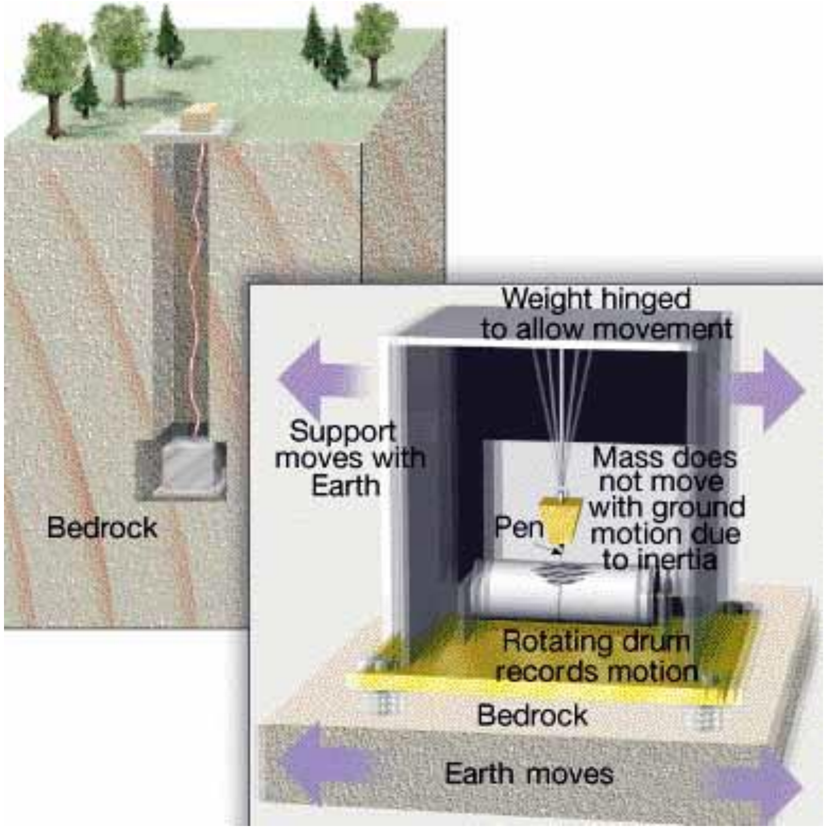
If you suspend a heavy mass, such as a block of iron, from a light spring and suddenly lift the spring, the mass remains almost stationary while the spring stretches.

Seismic waves travel through the earth as vibrations

The resulting graph that shows the vibrations is called a **seismogram**.

seismogram a heavy mass is supported by a spring and the spring is connected to support that in turn is connected to the ground. When the ground vibrates, the spring expands and contracts but the mass remains almost stationary.

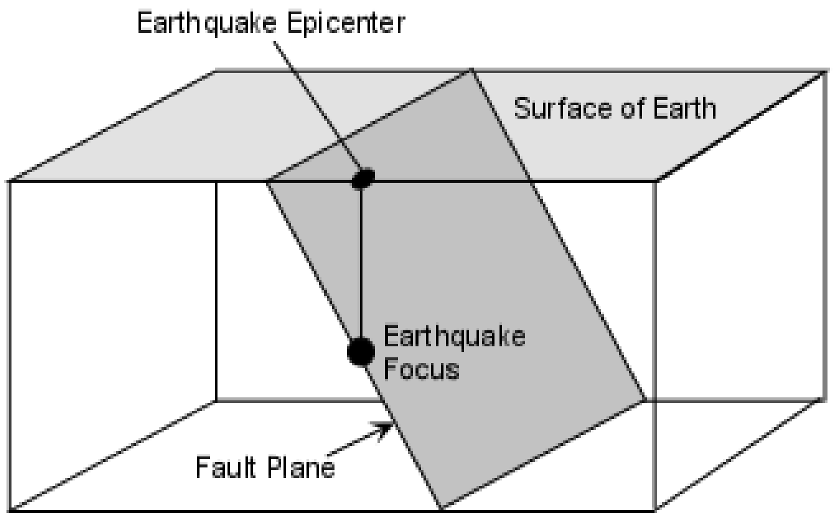



Bedrock
Weight hinged
to allow movement
Support
moves with
Earth
Mass does
not move
with ground
motion due
to inertia
Pen
Rotating drum
records motion
Bedrock
Earth moves

Focus of an Earthquake

The place where energy is first released to cause an earthquake

Earthquake foci lie below the surface, ranging from shallow (just bellow the surface) to deep (up to 700 km below the surface)



Epicenter of an Earthquake

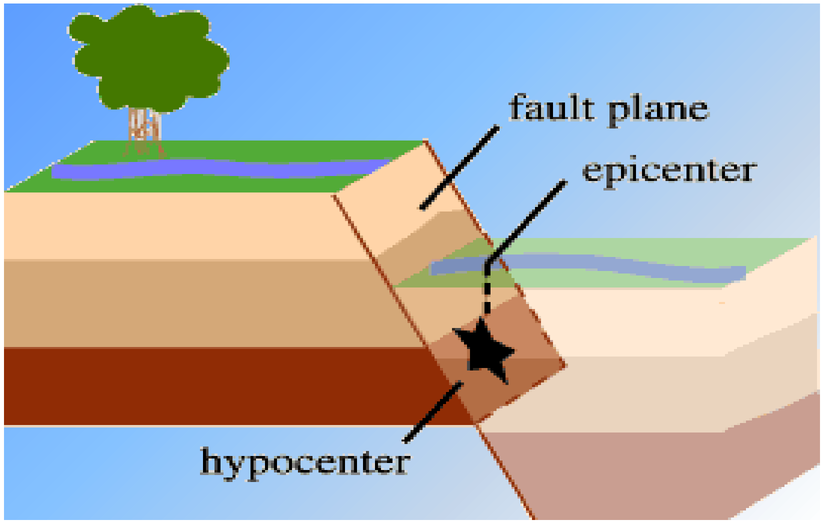
The point on the Earth's surface lying vertically above the focus

A good way to describe the **location of an earthquake's focus** is to state the **location of its epicenter** and its **focal depth**, that is, how far below the surface it lies

Focus :The source of an earthquake

Exact location of the seismic waves

Epicenter; ***the point at the surface directly above the focus***

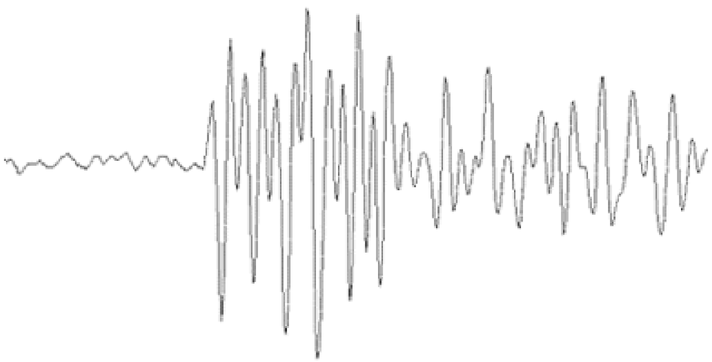


Seismic Waves

The elastically stored energy released by an earthquake is transmitted to other parts of the Earth.

Waves, called **seismic waves**, spread outward in all directions from the earthquake's point of origin.

Whenever an earthquake occurs, the characteristic signatures and arrival times of each seismic wave are recorded by many seismographs; the records obtained in this way are called seismograms.



The record of earthquake, a seismograms.

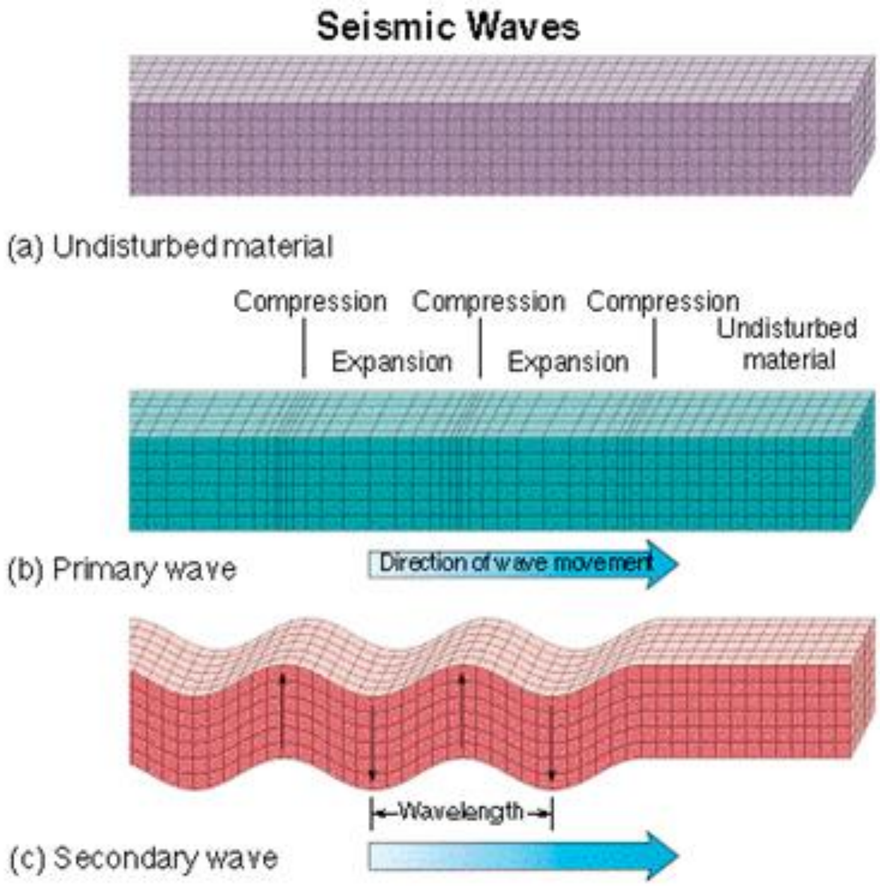
Will be a plot of vibrations versus time

*The recording the seismograph makes is called a **seismogram**.*

Seismic waves are of two main types.

Body Waves

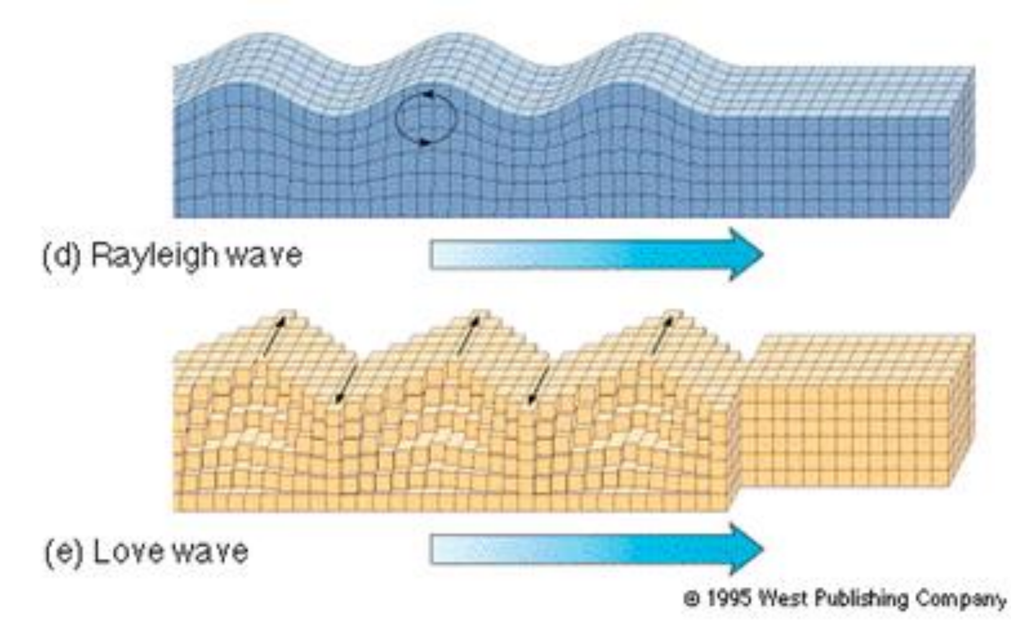
- Primary Waves
- Secondary Waves



Seismic waves are of two main types.

Surface Waves

- Rayleigh Waves
- Love Waves



Compressional (P or Primary) Waves

Deform rocks through a **change in volume**

Pass through **solids**, **liquids**, and **gases**

Consist of alternating pulses of compression and expansion acting in the direction in which the wave is traveling

When a compressional wave passes through a medium, the compression pushes atoms closer together

Expansion is an elastic response to compression that increases the distance between atoms

Have the greatest velocity of all seismic waves

The first to be recorded by a seismograph after an earthquake

Shear (S or Secondary) Waves

Deform material through a **change in shape**

Because gases and liquids do not have the elasticity to rebound to their original shape, they can be transmitted **only by solids**

Consist of alternating series of sidewise movements, ***each particle in the deformed solid being displaced in a direction perpendicular to the direction of wave travel***

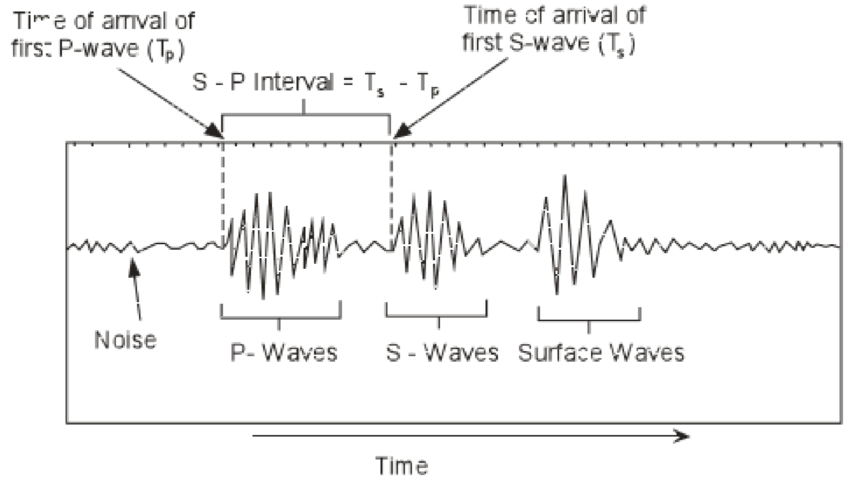
Slower than P waves

Reach a seismograph some time later after P waves

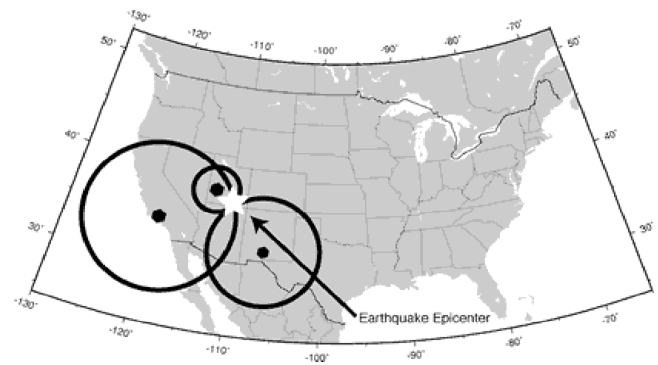
Locating the Epicenter

At least **three seismographs** should record the seismic waves generated by an earthquake

Then, the exact location of the epicenter can be determined by **triangulation**



By looking at the **difference in arrival time** of the **P** and **S** waves on a seismogram recorded by a seismograph, scientists can tell **how far away the earthquake was from the seismograph**



If sientists draw a circle on a map around the station where the *radius* of the circle is the determined *distance* to the earthquake, they know the earthquake lies somewhere on the circle

By drawing **three circles** around three different seismographs, the **intersection** of those three circles is the ***epicenter***!

Earthquake Magnitude and Intensity

The severity of an earthquake can be measured in terms of

»

and

Earthquake Magnitude

The **energy** of an earthquake is measured on a **magnitude scale**.

In 1935, *Charles Richter* invented the **Richter Magnitude Scale**. That is a scale of earthquake size

The scale is **logarithmic**.

The **magnitude** calculated for a given earthquake is **the same** whether you are standing at the epicenter or 1000 km away.

The scale is **open ended**, which means that theoretically there is no upper limit on the possible size of an earthquake.

The largest earthquakes recorded to date have **Richter magnitudes** of about **8.6**.

Earthquake Magnitude

Richter Magnitude Scale involves measuring the amplitude (height) of the largest recorded wave at a specific distance from the earthquake.

$$M = \text{LOG}\ (X/T) + \Delta\ (\text{attenuation factor})$$

Abetter measure of the size of the earthquake is the amount of energy released by the earthquake. While this is much more difficult to determine, Richter gave a means by which the amount of energy released can be estimated

$$\text{Log } E = 11.8 + 1.5\ M$$

Where E is the energy released in ergs, and M is the Richter Magnitude

Thus a ***magnitude 8*** earthquake is NOT twice as large as a ***magnitude 4*** quake but almost **1 million times** as large (31×31×31×31 = 810,500)!

The **Hiroshima atomic bomb** released energy equivalent to magnitude **5.5 earthquake**.

Earthquake Intensity

The **intensity of shaking** occurring at any given point on the Earth's surface is measured on an **intensity scale**.

The **modified Mercalli intensity scale**, developed in the late 1800s and later modified by *Father Giuseppi Mercalli* and others, is based on the ***amount of vibration people feel during low-magnitude quakes*** and the ***extent of damage to buildings during high-magnitude quakes***.

The scale ranges from **I** (*not felt except under favorable circumstances*) to **XII** (*waves seen on ground surface, practically all works of construction destroyed or greatly damaged*).

A single earthquake could have a **Mercalli intensity** of IX or X near the epicenter, where the intensity is greatest, whereas 400 or 500 km away its intensity would be only I or II.

This scale has been particularly useful in the study of earthquakes that occurred before the development of modern measurement equipment.

Intensity	Characteristic Effects	Richter Scale Equivalent
I	People do not feel any Earth movement	<3.4
II	A few people notice movement if at rest and/or on upper floors of tall buildings	
III	People indoors feel movement. Hanging objects swing back and forth. People outdoors might not realize that an earthquake is occurring	4.2
IV	People indoors feel movement. Hanging objects swing. Dishes, windows, and doors rattle. Feels like a heavy truck hitting walls. Some people outdoors may feel movement. Parked cars rock.	4.3 - 4.8
V	Almost everyone feels movement. Sleeping people are awakened. Doors swing open/close. Dishes break. Small objects move or are turned over. Trees shake. Liquids spill from open containers	4.9-5.4
VI	Everyone feels movement. People have trouble walking. Objects fall from shelves. Pictures fall off walls. Furniture moves. Plaster in walls may crack. Trees and bushes shake. Damage slight in poorly built buildings.	5.5 - 6.1
VII	People have difficulty standing. Drivers feel cars shaking. Furniture breaks. Loose bricks fall from buildings. Damage slight to moderate in well-built buildings; considerable in poorly built buildings.	5.5 - 6.1
VIII	Drivers have trouble steering. Houses not bolted down shift on foundations. Towers & chimneys twist and fall. Well-built buildings suffer slight damage. Poorly built structures severely damaged. Tree branches break. Hillsides crack if ground is wet. Water levels in wells change.	6.2 - 6.9
IX	Well-built buildings suffer considerable damage. Houses not bolted down move off foundations. Some underground pipes broken. Ground cracks. Serious damage to Reservoirs.	6.2 - 6.9
X	Most buildings & their foundations destroyed. Some bridges destroyed. Dams damaged. Large landslides occur. Water thrown on the banks of canals, rivers, lakes. Ground cracks in large areas. Railroad tracks bent slightly.	7.0 - 7.3
XI	Most buildings collapse. Some bridges destroyed. Large cracks appear in the ground. Underground pipelines destroyed. Railroad tracks badly bent.	7.4 - 7.9
XII	Almost everything is destroyed. Objects thrown into the air. Ground moves in waves or ripples. Large amounts of rock may move.	>8.0

Earthquake Hazards and Risks!

Hazard is a source of potential harm.

Risk is a concept that denotes a potential negative impact that may arise from some event.

Quantifying and Addressing the Risks

The **most disastrous earthquake** on record occurred in **1556** in **Shaanxi Province**, **China**.

Many of the estimated **830,000** people who died in that quake lived in cave dwellings excavated from cliffs made of loess (fine, wind-deposited silt), which collapsed as a result of the quake.

The **worst earthquake disaster of the twentieth century** also occurred in **China**. On **July 28, 1976**, while the 1 million inhabitants of **T'ang Shan** were asleep, about **3:42 am**, a **7.8 magnitude quake** leveled the city. The few that witnessed the first quake were destroyed by a second one (**7.1 magnitude**) that struck at **6:45 pm** the same day. About **240,000** people were dead.

Certain areas, some of them heavily populated, are known to be **earthquake prone**, and **building codes** in those areas require structures to be as resistant as possible to earthquake damage.

Even where special **building codes** are in effect, however, ***unanticipated problems*** may arise.

Structural engineers are continually refining their understanding of the factors that make tall buildings and other structures more resistant to collapse.

However, much of this understanding is **based on theory and laboratory work;** there are few real-life situations in which the response of a building to exceptionally intense ground motion can be tested and standards verified.

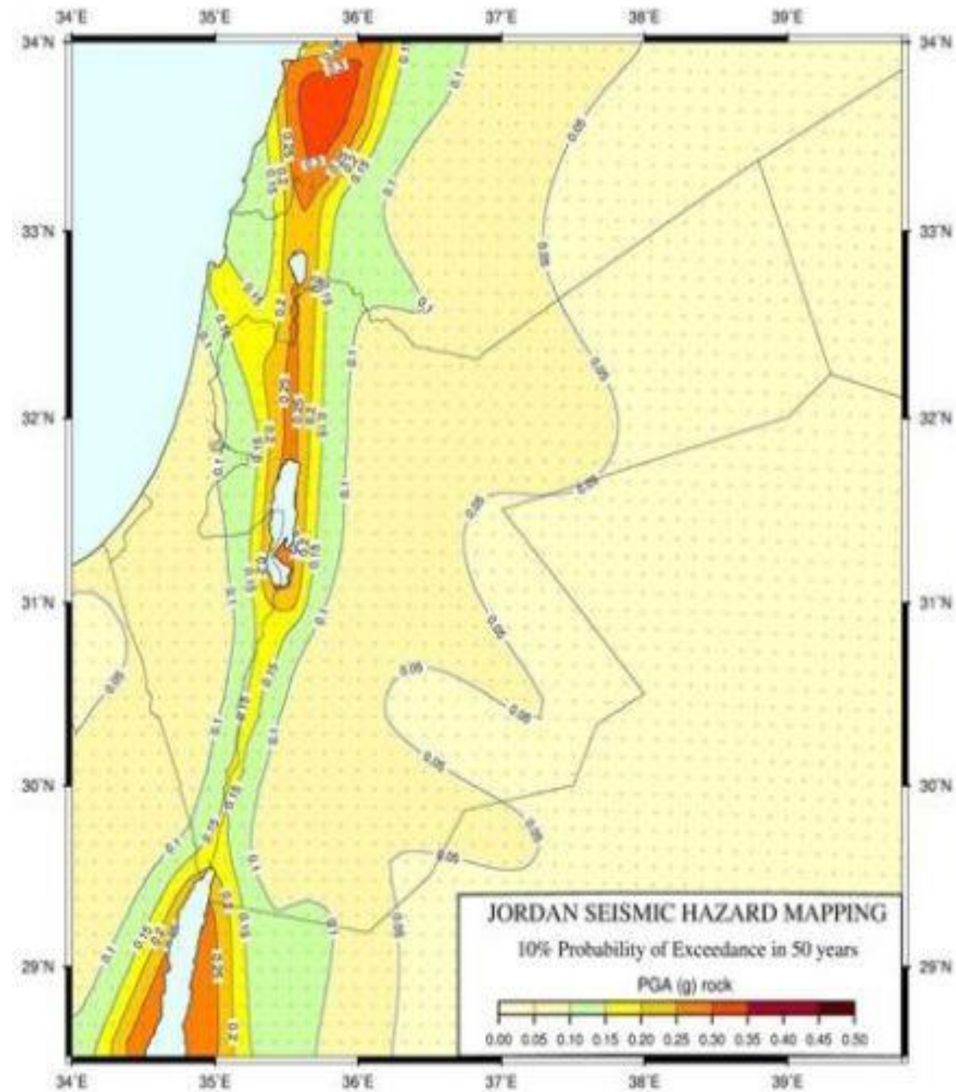
<u>Describing the nature and intensity of an expected event</u> is only one part of **risk and hazard assessment**.

Another important step is:

1.Determining exactly where such an event is most likely to occur and

2.Comparing the expected event with human factors such as *population distribution, building codes and zoning laws*, and *emergency preparedness* in the area.

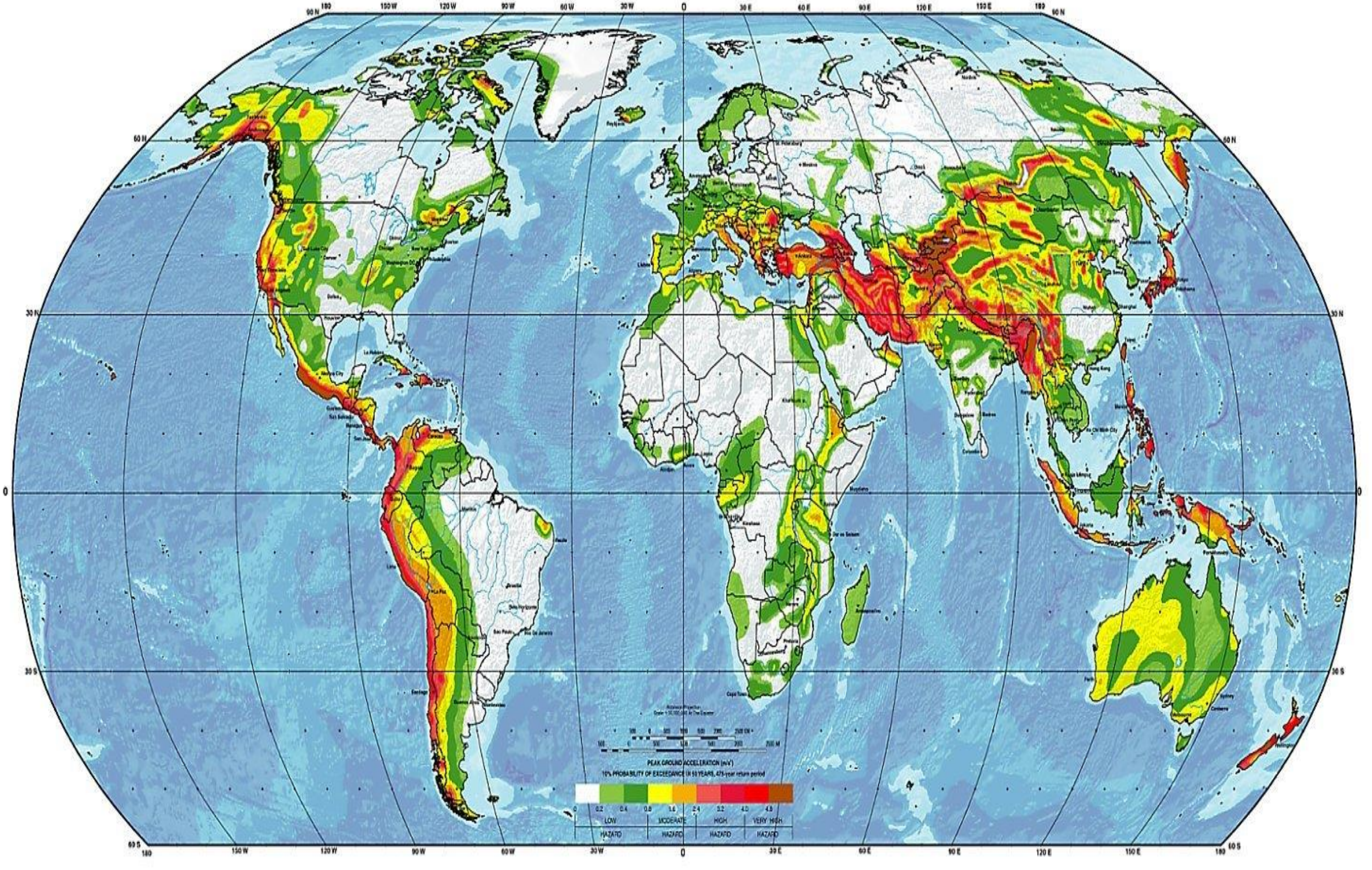
This is often done with **seismic hazard maps**.



GLOBAL SEISMIC HAZARD MAP

Produced by the Global Seismic Hazard Assessment Program (GSHAP),
a demonstration project of the UN/International Decade of Natural Disaster Reduction, conducted by the International Lithosphere Program.

Global map assembled by D. Giardini, G. GrŸnthal, K. Shedlock, and P. Zhang
1999



Hazards Associated with Earthquakes

- Ground Motion
- Faulting and Ground Rupture
- Aftershocks
- Fires
- Landslides
- Liquefaction
- Changes in Ground Level
- Tsunamis
- Flooding

Ground Motion

Ground motion results from the movement of ***seismic waves***, especially surface waves, through surface rock layers.

It is the most significant primary cause of damage from earthquakes.

Proper design of buildings and other structures can do much to prevent these effects, but in a very strong earthquake even the best designed buildings may suffer some damage.

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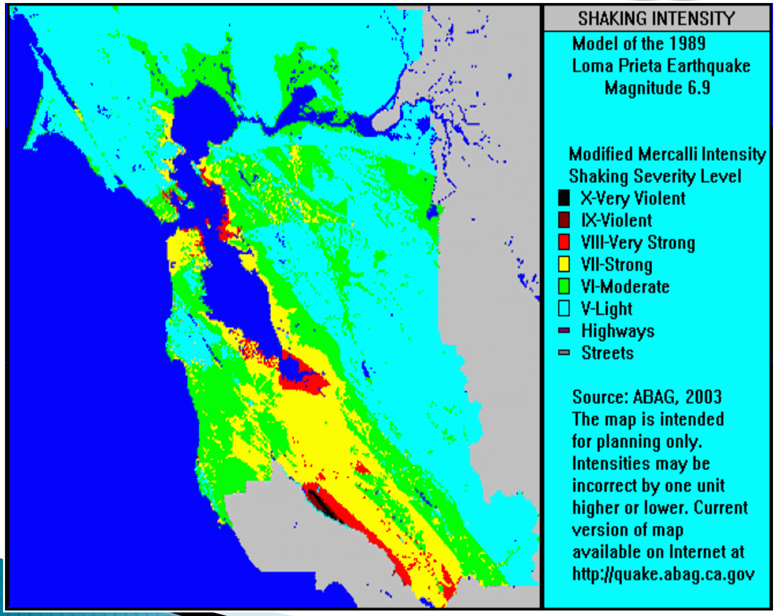
Enhanced ground motion is often attributable to the presence of **soft sediments**, like the landfill in the San Francisco bay area.



SHAKING INTENSITY
Model of the 1989
Loma Prieta Earthquake
Magnitude 6.9
Modified Mercalli Intensity
Shaking Severity Level
X-Very Violent
IX-Violent
VIII-Very Strong
VII-Strong
VI-Moderate
V-Light
Highways
Streets
Source: ABAG, 2003
The map is intended
for planning only.
Intensities may be
incorrect by one unit
higher or lower. Current
version of map
available on Internet at
http://quake.abag.ca.gov

Faulting and Ground Rupture

Where a fault breaks the ground surface, buildings can be split, roads disrupted, and any feature that lies on or that crosses the fault broken apart.

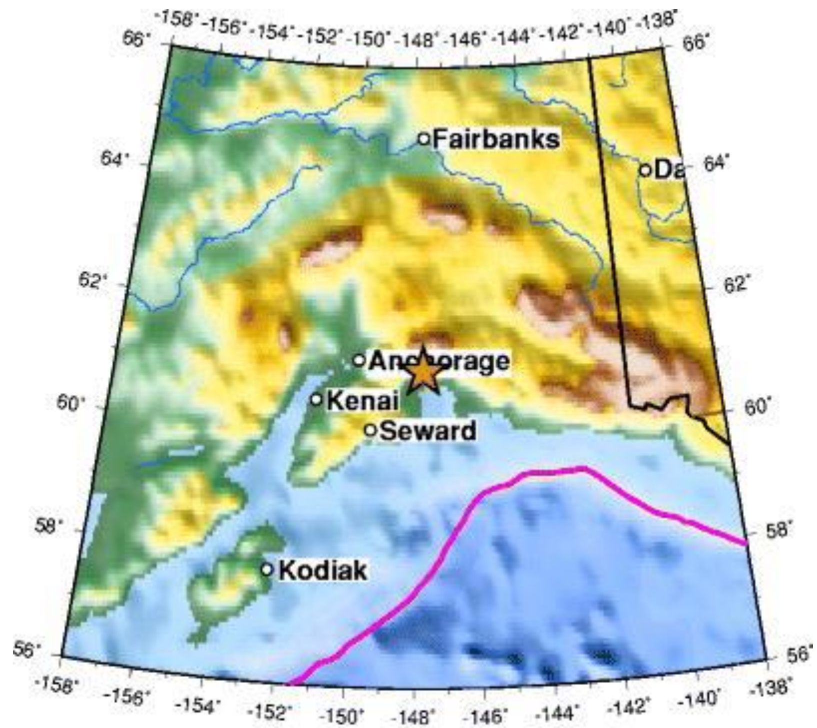
Large **cracks** and **fissures** can open in the ground.

For example, **surface ruptures** associated with the **1992 Landers Earthquake**, in **San Bernardino County**, extended for **50 miles** with displacements of an **inch** to **20 feet**.

Aftershocks

Earthquake crises are often exacerbated by **aftershocks**, ***the (usually) smaller earthquakes that occur shortly after a major quake***.

, in the four months following the 1964 Alaska earthquake (the Good Friday Earthquake or Great Alaska Earthquake), 1260 aftershocks were recorded.



PRINCE WILLIAM SOUND, ALASKA

Fires

A **secondary effect**, but one that can pose a greater hazard than ground motion, is fire.

Ground movement displaces stoves, breaks gas lines, and loosens wires, thereby starting fires.

For example, in the earthquake that struck **San Francisco in 1906** as much as **90%** of the damage to buildings was caused by fire.

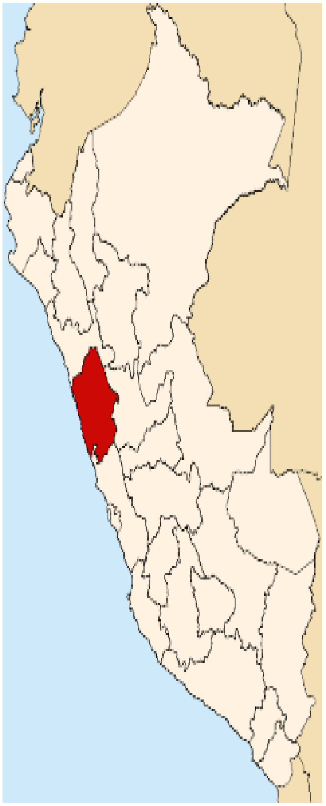
The fire destroyed **12 km^2**, or **521 city blocks**, in **3 days**.

For many years thereafter the quake was referred to as the "**Great Fire**."

Landslides

In regions with **steep slopes**, earthquake vibrations may cause ***slipping of regolith*** (Greek: ”Blanket Rock”) (a layer of loose, heterogeneous material covering solid rock), *collapse of cliffs*, and other *rapid downslope movements* of Earth material.

For example, in **1970**, a devastating **landslide** in **Yungay**, **Peru**, in which at least **18,000** people were killed, was triggered by an earthquake of **magnitude 7.75**. The earthquake was an undersea earthquake that occurred 30 km off the coast of Casma and Chimbote on the Pacific Ocean.



Aerial view of the town of Yungay before the earthquake

Aerial view of Yungay after the earthquake and landslide

Liquefaction

Earthquake waves can cause **water-saturated soil** to rearrange itself in such a way that it essentially becomes a **suspension of solids in the liquid**. Heavy structures on such areas can suddenly sink or shift. Buried objects can shift and relatively low density objects can float to the surface.

In **1964 liquefaction** and **uneven ground settling** from an earthquake caused apartment houses to sink and collapse in **Niigata, Japan**. Many of the buildings were not structurally damaged; they simply keeled over onto their sides.

Apartment dwellers who were later permitted to enter the buildings retrieved their belongings by rolling wheelbarrows up the walls and lowering themselves through the windows.

Broken asphalt road by Chuetsu earthquake, 2004, Ojiya, Niigata, Japan

Changes in Ground Level

Sometimes the **level of the ground** changes over vast areas as a result of a very large earthquake.

In the **1964 Alaska earthquake vertical displacements** occurred along almost 1000 km of the coastline from Kodiak Island to Prince William Sound.

The **ground-level changes** resulting from that earthquake included both **uplift** and **subsidence**.

Vertical uplift reached **11 m** in some places, whereas subsidence, a lowering of ground level, was as much as **2 m**.

Tsunamis

Another secondary effect of earthquakes is **seismic sea waves**, also called **tsunamis**.

Submarine earthquakes are the main cause of these waves, which are particularly destructive around the Pacific Ocean rim.

For example, the **December 26, 2004**, Indian Ocean earthquake, known by the scientific community as the **Sumatra-Andaman earthquake,** was an undersea earthquake. The earthquake triggered a series of **tsunamis** that spread throughout the Indian Ocean (the Asian Tsunami).

Initial estimates have put the worldwide death toll at over **275,000** with thousands of others missing.

The magnitude of the earthquake was originally recorded as **9.0** on the Richter scale, but has been upgraded to between **9.1** and **9.3**. At this magnitude, it is the second largest earthquake ever recorded on a seismograph.

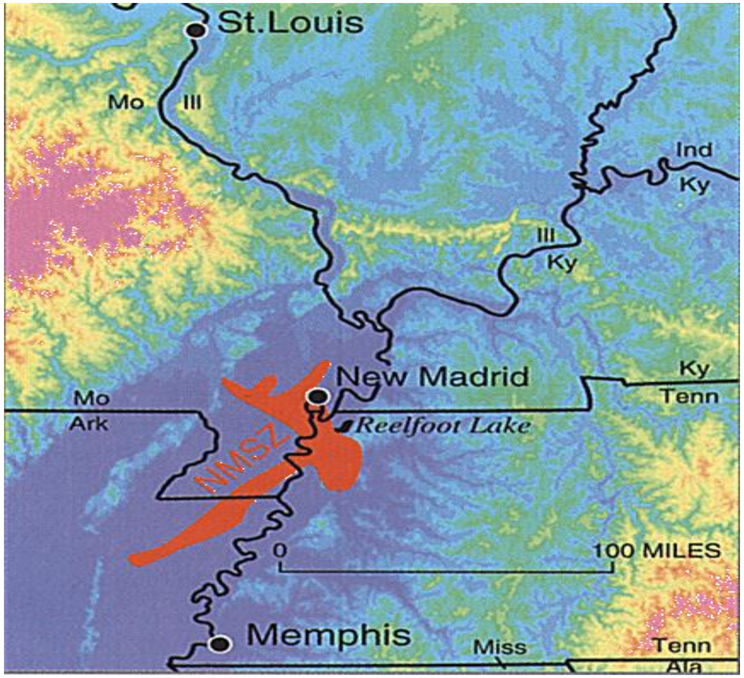
This earthquake was also reported to be the longest duration of faulting ever observed, lasting between **500** and **600 seconds**, and it was large enough that it caused the entire planet to vibrate at least half an inch, or over a centimeter. It also triggered earthquakes in other locations as far away as Alaska.

Flooding

Flooding usually results from *ground subsidence*, the *rupture of dams*, or *tsunamis*.

For example, **Reelfoot Lake**, across from New Madrid on the Tennessee side of the Mississippi River, was created by **flooding** following **ground subsidence** during the series of **1811-1812 earthquakes**.

The **New Madrid Seismic Zone**, also known as the **Reelfoot Rift**, is a major seismic zone located in the Midwestern United States. The New Madrid fault system was responsible for the **1812** New Madrid Earthquake and has the potential to produce damaging earthquakes on an average of **every 300 to 500 years**.



Prediction and Control of Earthquakes!

Charles Richter once said, "***Only fools, charlatans, and liars predict earthquakes***."

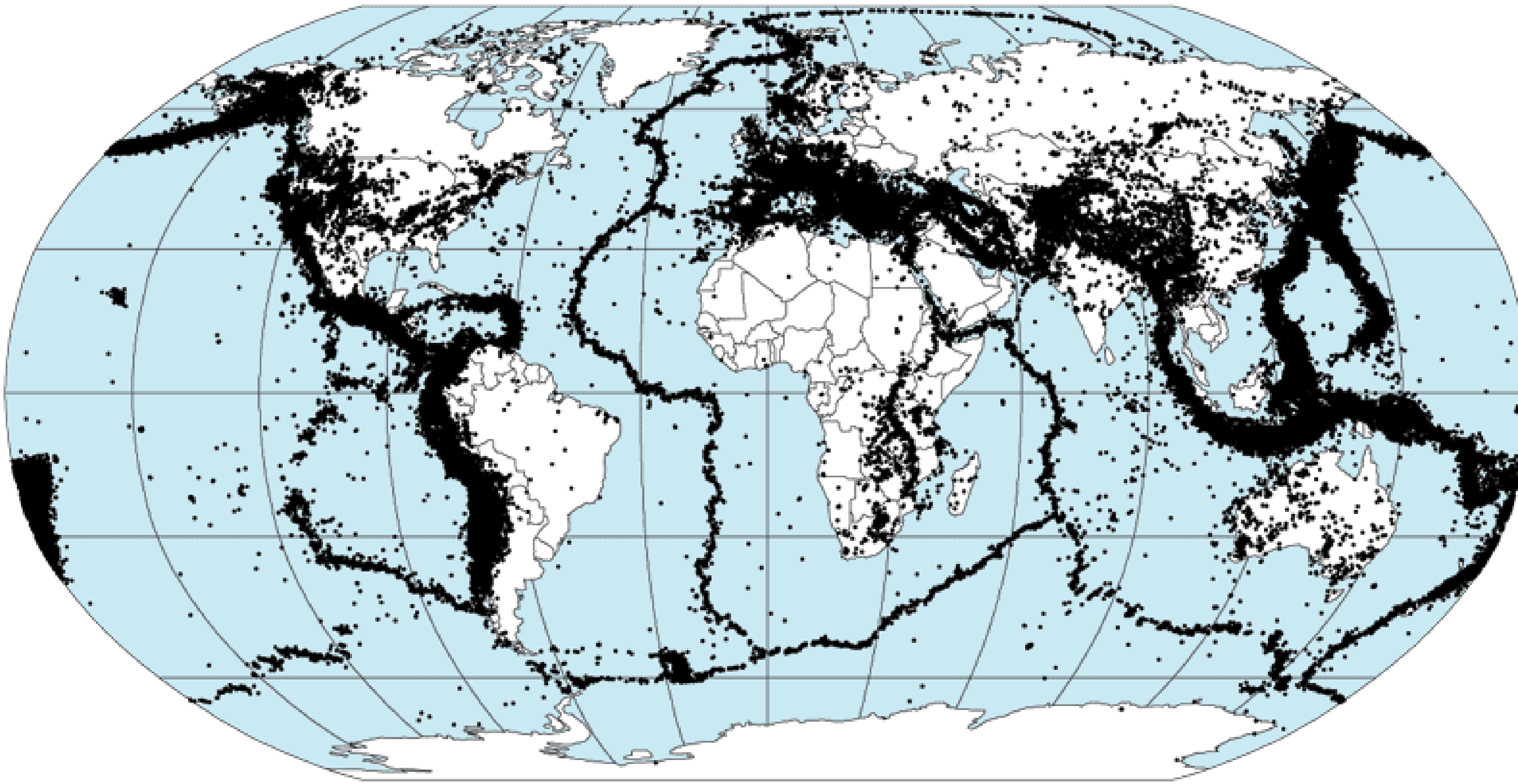
Today, however, seismologists use sensitive instruments and sophisticated techniques to monitor seismically active zones.

We **still <u>CANNOT</u> predict the exact magnitude and time of occurrence of an earthquake**, but our knowledge about **seismic hazards** and **mechanisms and our awareness of the tectonic environments** in which earthquakes occur have improved greatly since Richter's time.

The World Distribution of Earthquakes

The first step in **earthquake prediction** is to **examine the *world distribution of earthquakes*** and **establish connections between the *plate tectonic cycle*** and **the *mechanisms by which earthquakes are generated***.

Preliminary Determination of Epicenters
358,214 Events, 1963 - 1998



Approaches to Earthquake Prediction

earthquake prediction.

forecasting

early warnings

Long-Term Prediction

Paleoseismology and Seismic Gaps

Short-Term Prediction

Physical Precursors

Long-Term Forecasting (Paleoseismology and Seismic Gaps)

The **long-term prediction** of earthquakes is based on knowledge of the **tectonic cycle**.

In places where earthquakes are known to occur repeatedly, such as along plate boundaries, it is sometimes possible to detect a regular pattern in the **recurrence interval** (*the average interval between occurrences of two events of equal magnitude*) of large quakes. To do so seismologists require information about **seismic activity** going back much farther than historical records. This information is provided by experts in **paleoseismology**, *the study of prehistoric earthquakes*.

*The primary goal of **paleoseismology** is to search for evidence of major earthquakes and, if possible, to discern the intervals between them.*

Studies of recurrence patterns have identified a number of **seismic gaps** around the Pacific rim. *These are places along a fault where earthquakes have not occurred for a long time even though tectonic stresses are still active and elastic energy is steadily building up.*

Seismic gaps receive a lot of attention from seismologists because they are considered to be the places most likely to experience large earthquakes.

Short-Term Prediction (Physical Precursors)

Short-term prediction of earthquakes is based on observations of **precursor** phenomena: *anomalous physical occurrences that may serve as **early warning** signs of earthquake activity*.

Most research on **short-term earthquake prediction** involves **monitoring**

1.Changes in the properties of elastically strained rocks – properties such as rock magnetism and electrical conductivity

2.Changes in the level of water or the amount of radon (an inert gas) in water wells

3.Tilting or bulging of the ground and slow rises and falls in elevation that indicate strain build up

4.Small cracks and fractures that develop in severely strained rock and can cause swarms of tiny earthquakes – foreshocks – that may be a clue that a big quake is coming

5.Unusual animal behavior

The **long-term prediction** of earthquakes (i.e., ***predictions of quakes in particular areas within the next few years or decades***) has met with **reasonable success**.

The **short-term prediction** of earthquakes (i.e., ***pinpointing the actual day or time of the event and issuing an early warning***) has been rather **less successful**.