

UNIT - 7

# EARTHQUAKES



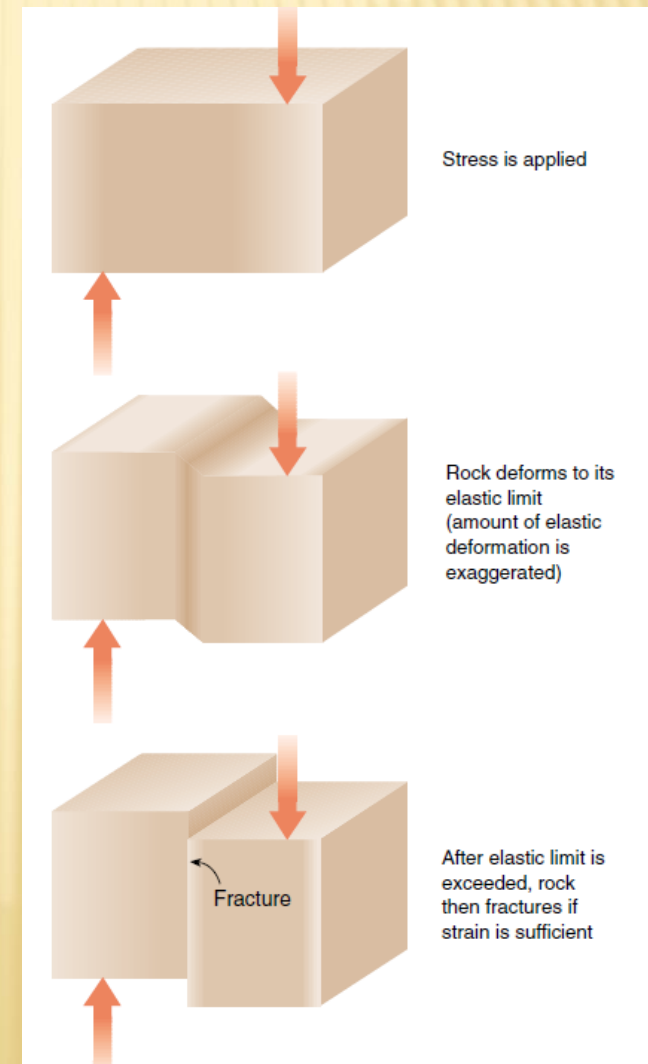
# WHAT IS AN EARTHQUAKE

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- AN **EARTHQUAKE** IS A SUDDEN MOTION OR TREMBLING OF THE EARTH CAUSED BY THE ABRUPT RELEASE OF ENERGY THAT IS STORED IN ROCKS.
- MODERN GEOLOGISTS KNOW THAT MOST EARTHQUAKES OCCUR ALONG PLATE BOUNDARIES, WHERE HUGE TECTONIC PLATES SEPARATE, CONVERGE, OR SLIP PAST ONE ANOTHER.
- EARTHQUAKES ALSO OCCUR WHEN ROCK SLIPS ALONG PREVIOUSLY ESTABLISHED FAULTS.
- TECTONIC PLATE BOUNDARIES ARE HUGE FAULTS THAT HAVE MOVED MANY TIMES IN THE PAST AND WILL MOVE AGAIN IN THE FUTURE.

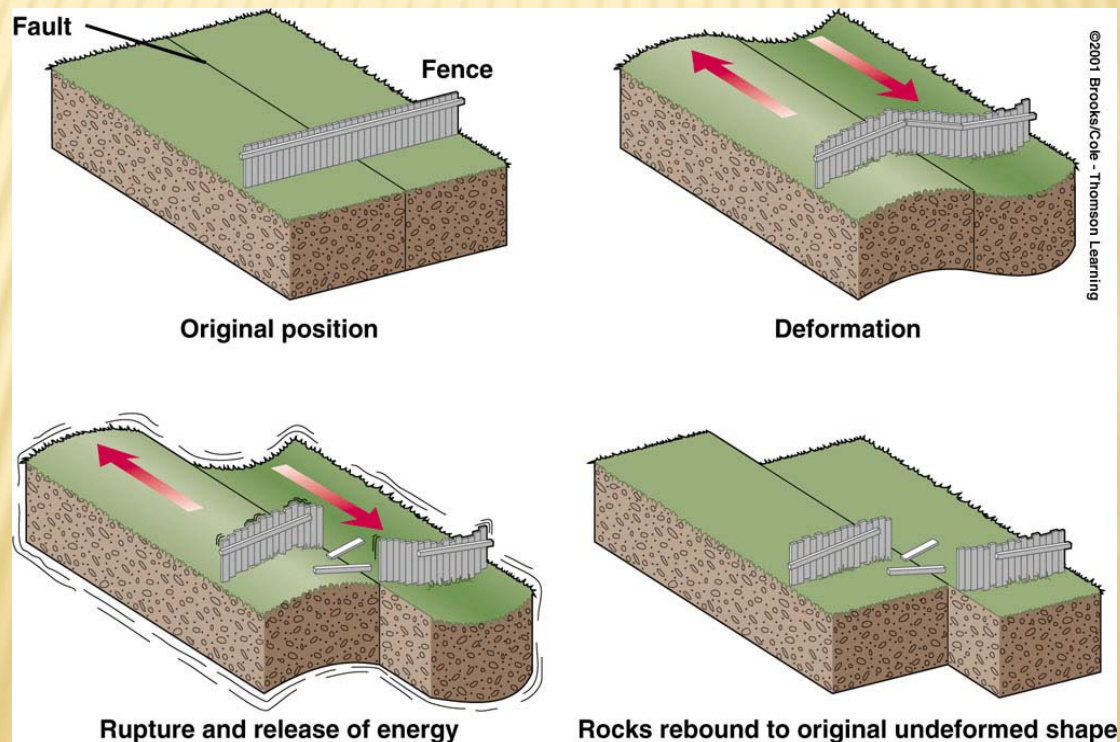
# HOW EARTHQUAKE OCCURS

- EVERY ROCK HAS A LIMIT BEYOND WHICH IT CANNOT DEFORM ELASTICALLY.
- UNDER CERTAIN CONDITIONS, WHEN ITS ELASTIC LIMIT IS EXCEEDED, A ROCK CONTINUES TO DEFORM.
- THIS BEHAVIOR IS CALLED **PLASTIC DEFORMATION**.
- EARTHQUAKES DO NOT OCCUR WHEN ROCKS DEFORM PLASTICALLY.
- UNDER OTHER CONDITIONS, AN ELASTICALLY STRESSED ROCK MAY RUPTURE BY **BRITTLE FRACTURE**.
- THE FRACTURE RELEASES THE ELASTIC ENERGY, AND THE SURROUNDING ROCK **SPRINGS** BACK TO ITS ORIGINAL SHAPE.
- THIS RAPID MOTION CREATES VIBRATIONS THAT TRAVEL THROUGH THE EARTH AND ARE FELT AS AN **EARTHQUAKE**.



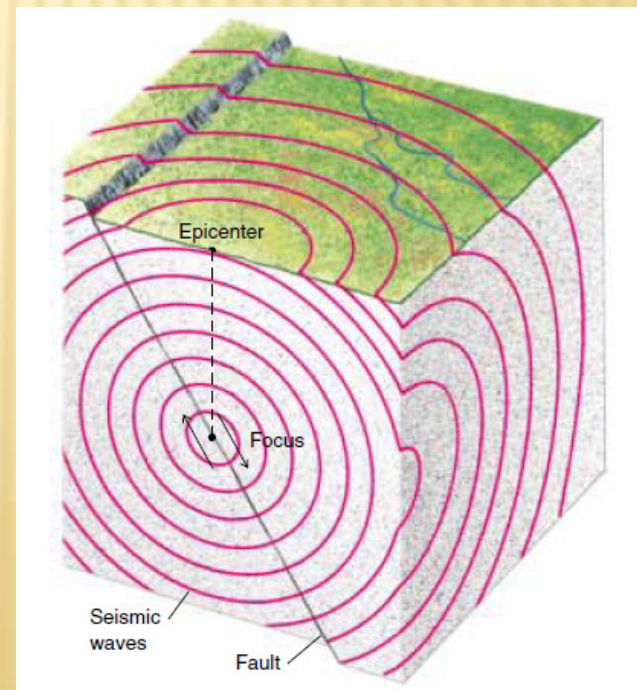
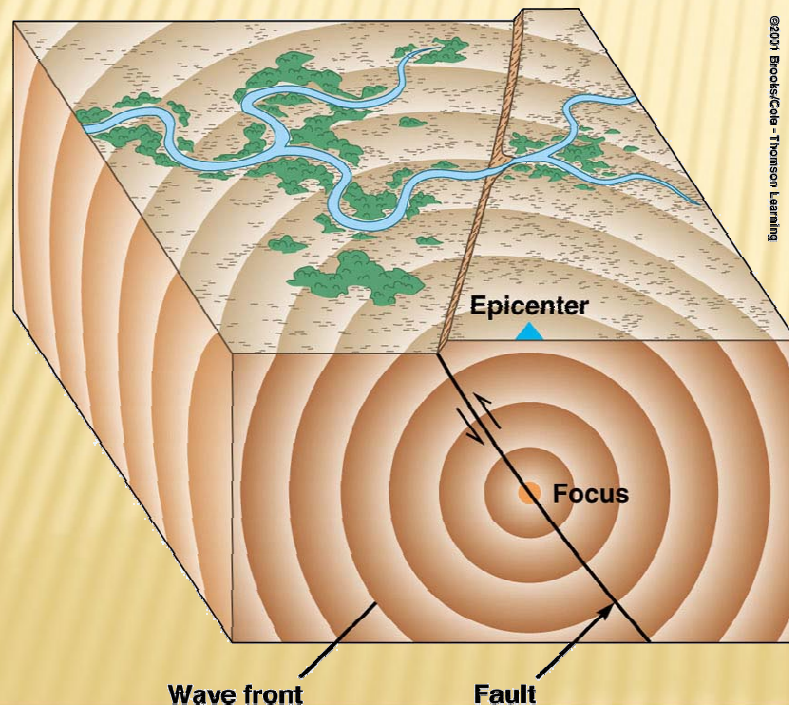
# THE ELASTIC REBOUND THEORY

- 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**



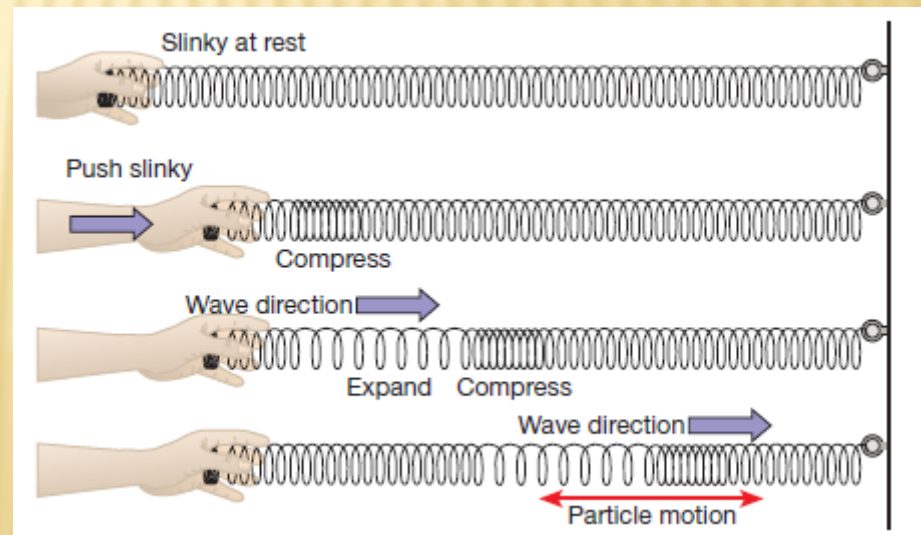
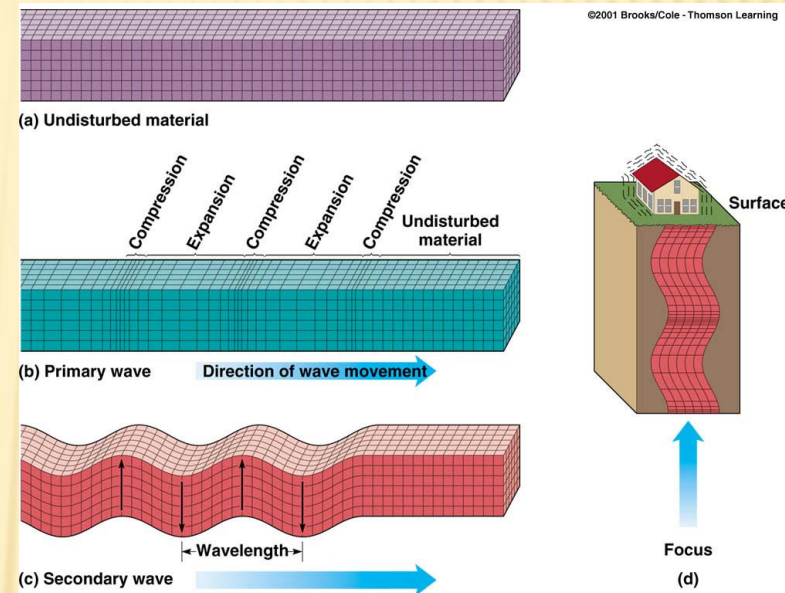
# WHAT ARE SEISMIC WAVES

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- × WAVES THAT TRAVEL THROUGH ROCK ARE CALLED **SEISMIC WAVES**.
- × EARTHQUAKES AND EXPLOSIONS PRODUCE SEISMIC WAVES.
- × **SEISMOLOGY** IS THE STUDY OF EARTHQUAKES AND THE NATURE OF THE EARTH'S INTERIOR BASED ON EVIDENCE FROM SEISMIC WAVES.
- × AN EARTHQUAKE PRODUCES SEVERAL DIFFERENT TYPES OF SEISMIC WAVES.
- × TWO TYPES OF WAVES ARE PRODUCED DURING AN EARTHQUAKE
  - + **BODY WAVES**
    - × **P AND S**
  - + **SURFACE WAVES**
    - × **R AND L**

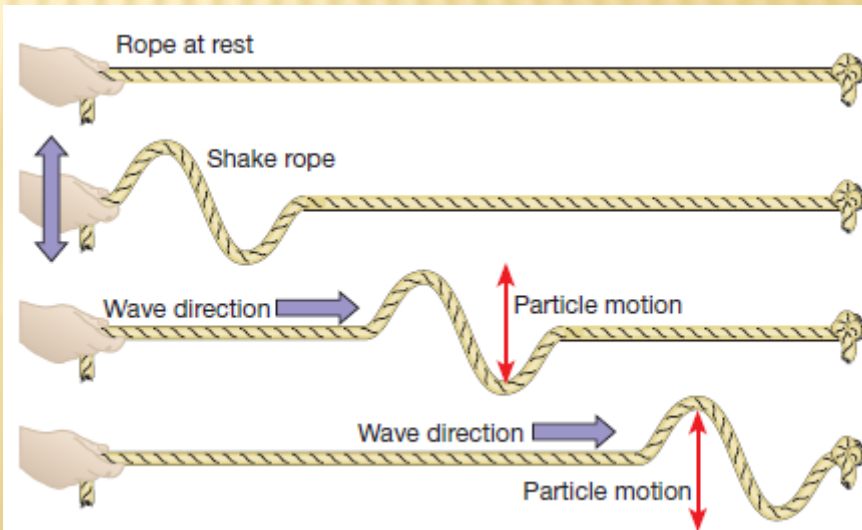
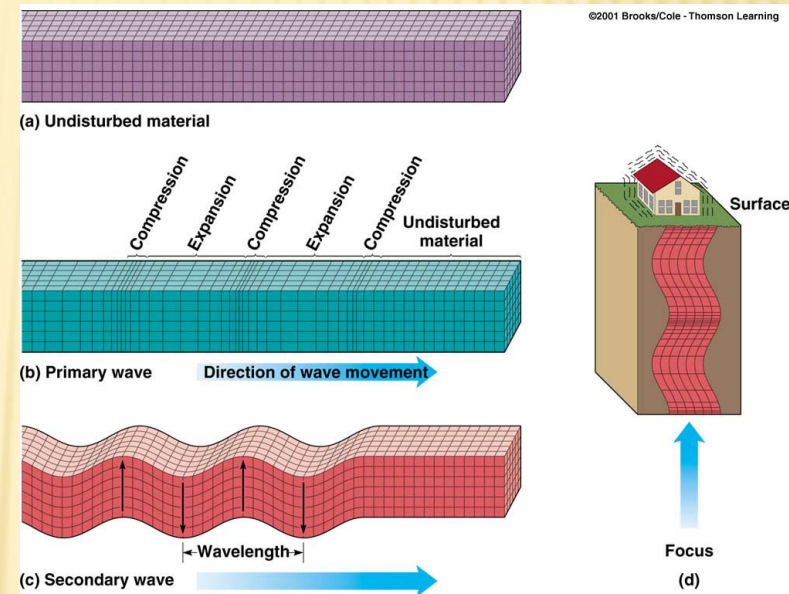
# BODY WAVES: P WAVES

- TWO MAIN TYPES OF BODY WAVES TRAVEL THROUGH THE EARTH'S INTERIOR.
- **P WAVE** (ALSO CALLED A **COMPRESSIONAL WAVE**) IS AN ELASTIC WAVE THAT CAUSES ALTERNATE COMPRESSION AND EXPANSION (RAREFACTION) OF THE ROCK.
- **P WAVES TRAVEL THROUGH AIR, LIQUID, AND SOLID MATERIAL.**
- P WAVES TRAVEL AT SPEEDS BETWEEN 4 AND 7 KILOMETERS PER SECOND IN THE EARTH'S CRUST AND AT ABOUT 8 KILOMETERS PER SECOND IN THE UPPERMOST MANTLE.
- P WAVES ARE ALSO KNOWN AS **PRIMARY WAVES**.



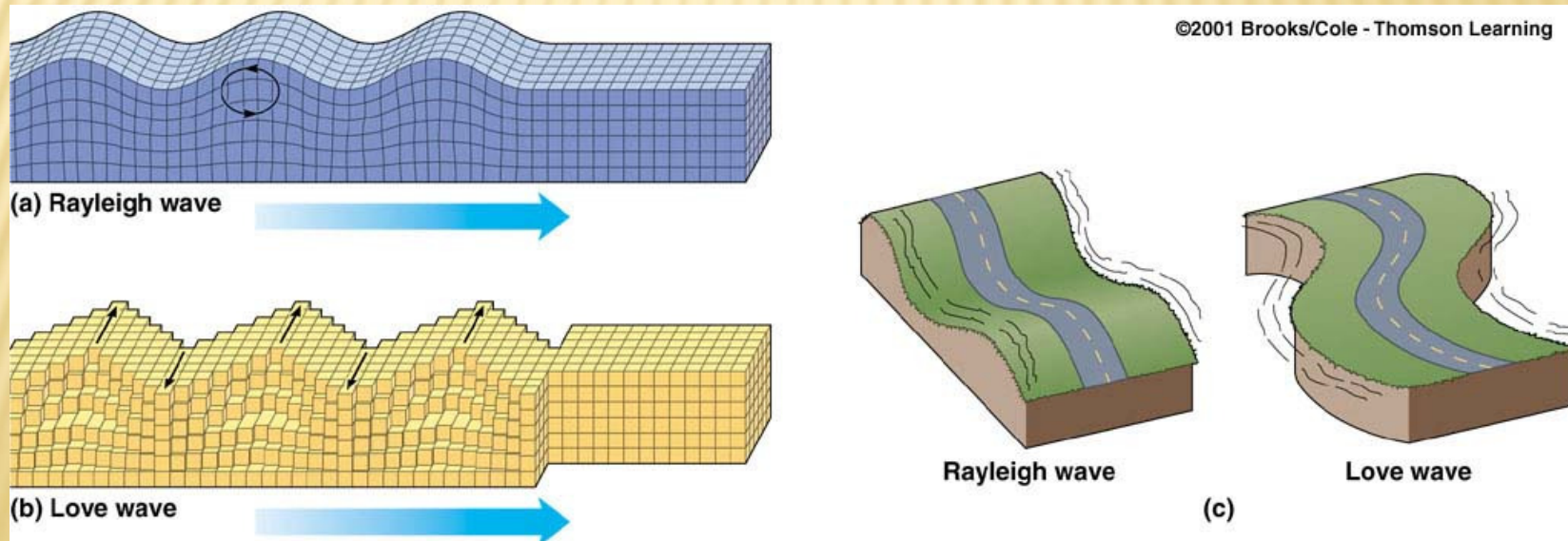
# BODY WAVES: S WAVES

- A SECOND TYPE OF BODY WAVE, CALLED AN **S WAVE**, IS A **SHEAR WAVE**.
- THEY ARE TRANSVERSE WAVES MEANING THAT WAVE PARTICLES TRAVEL PERPENDICULAR TO THE DIRECTION OF THE PROPAGATION OF THE WAVE.
- S WAVES ARE SLOWER THAN P WAVES AND TRAVEL AT SPEEDS BETWEEN 3 AND 4 KILOMETERS PER SECOND IN THE CRUST.
- AS A RESULT, S WAVES ARRIVE AFTER P WAVES.
- THE S WAVES ARE ALSO KNOWN AS **SECONDARY WAVES**.
- UNLIKE P WAVES, **S WAVES MOVE ONLY THROUGH SOLIDS**.



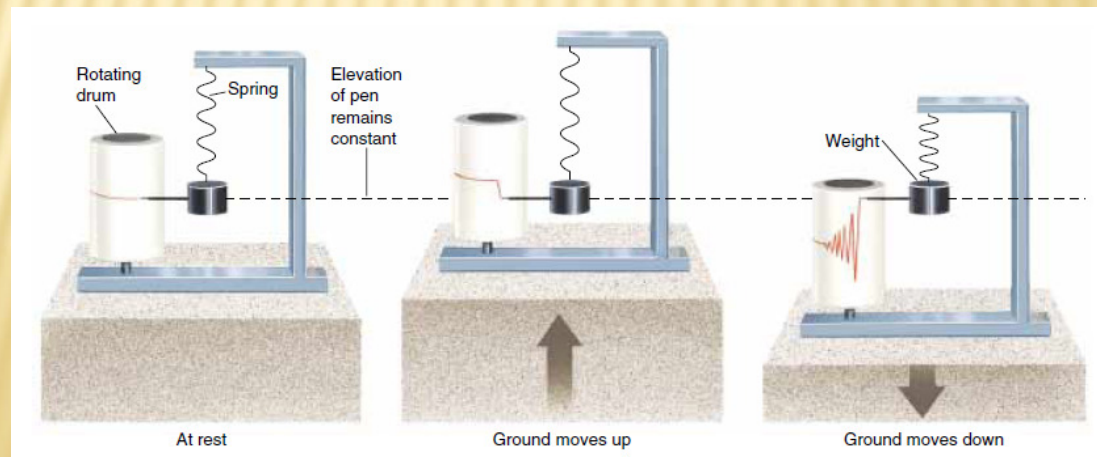
# SURFACE WAVES

- SURFACE WAVES TRAVEL MORE SLOWLY THAN BODY WAVES. TWO TYPES OF SURFACE WAVES OCCUR SIMULTANEOUSLY IN THE EARTH.
- 1. **RAYLEIGH WAVE** MOVES WITH AN UP-AND DOWN ROLLING MOTION LIKE AN OCEAN WAVE.
- 2. **LOVE WAVES** PRODUCE A SIDE-TO-SIDE VIBRATION.



# MEASUREMENT OF SEISMIC WAVES

- A **SEISMOGRAPH** is THE DEVICE THAT SCIENTISTS USE TO MEASURE EARTHQUAKES.
- THE GOAL OF A SEISMOGRAPH IS TO ACCURATELY RECORD THE MOTION OF THE GROUND DURING A QUAKE.
- A SEISMOGRAPH HAS A PEN THAT IS HANGING IN THE AIR, THE PEN TOUCHES A ROLL OF PAPER CALLED A DRUM. WHEN AN EARTHQUAKE HAPPENS, THE ROLL OF PAPER SHAKES. THE PEN DOES NOT. A WEIGHT HOLDS THE PEN STILL.
- THE MARKS ON THE PAPER SHOW THE SIZE OF THE EARTHQUAKE. A SMALL MOTOR ROLLS THE DRUM OF PAPER, THIS LETS THE SEISMOGRAPH RECORD WHAT HAPPENS AS TIME PASSES.
- A **SEISMOGRAM** is A GRAPH OUTPUT BY A SEISMOGRAPH. IT IS A RECORD OF THE GROUND MOTION AT A MEASURING STATION AS A FUNCTION OF TIME

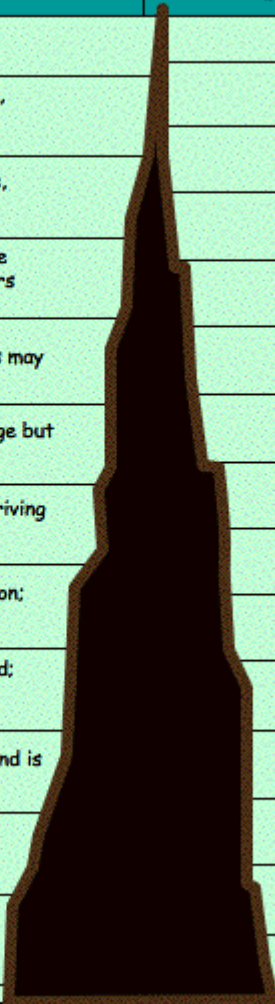


# MEASUREMENT OF EARTHQUAKE STRENGTH

- **EARTHQUAKE INTENSITY** IS A MEASURE OF THE EFFECTS OF AN EARTHQUAKE IN A PARTICULAR PLACE.
- **MODIFIED MERCALLI SCALE** IS USED FOR MEASURING THE INTENSITY OF EARTHQUAKES, ADAPTED FROM THE ORIGINAL MERCALLI SCALE.
- THE MERCALLI SCALE WAS DEvised IN 1902 BY ITALIAN SEISMOLOGIST GIUSEPPE MERCALLI.
- AMERICAN SEISMOLOGISTS HARRY O. WOOD AND FRANK NEUMANN CREATED THE MODIFIED MERCALLI SCALE IN 1931 TO MEASURE THE INTENSITY OF EARTHQUAKES THAT OCCUR IN CALIFORNIA.
- THE MODIFIED MERCALLI SCALE HAS **12 LEVELS OF INTENSITY**.
- EACH LEVEL IS DEFINED BY A GROUP OF OBSERVABLE EARTHQUAKE EFFECTS, SUCH AS SHAKING OF THE GROUND AND DAMAGE TO STRUCTURES SUCH AS BUILDINGS, ROADS, AND BRIDGES.
- THE LEVELS ARE DESIGNATED BY THE **ROMAN NUMERALS I TO XII**.
- LEVELS I THROUGH VI ARE USED TO DESCRIBE WHAT PEOPLE SEE AND FEEL DURING A SMALL TO MODERATE EARTHQUAKE.
- LEVELS VII THROUGH XII ARE USED TO DESCRIBE DAMAGE TO STRUCTURES DURING A MODERATE TO CATASTROPHIC EARTHQUAKE.

# MEASUREMENT OF EARTHQUAKE STRENGTH

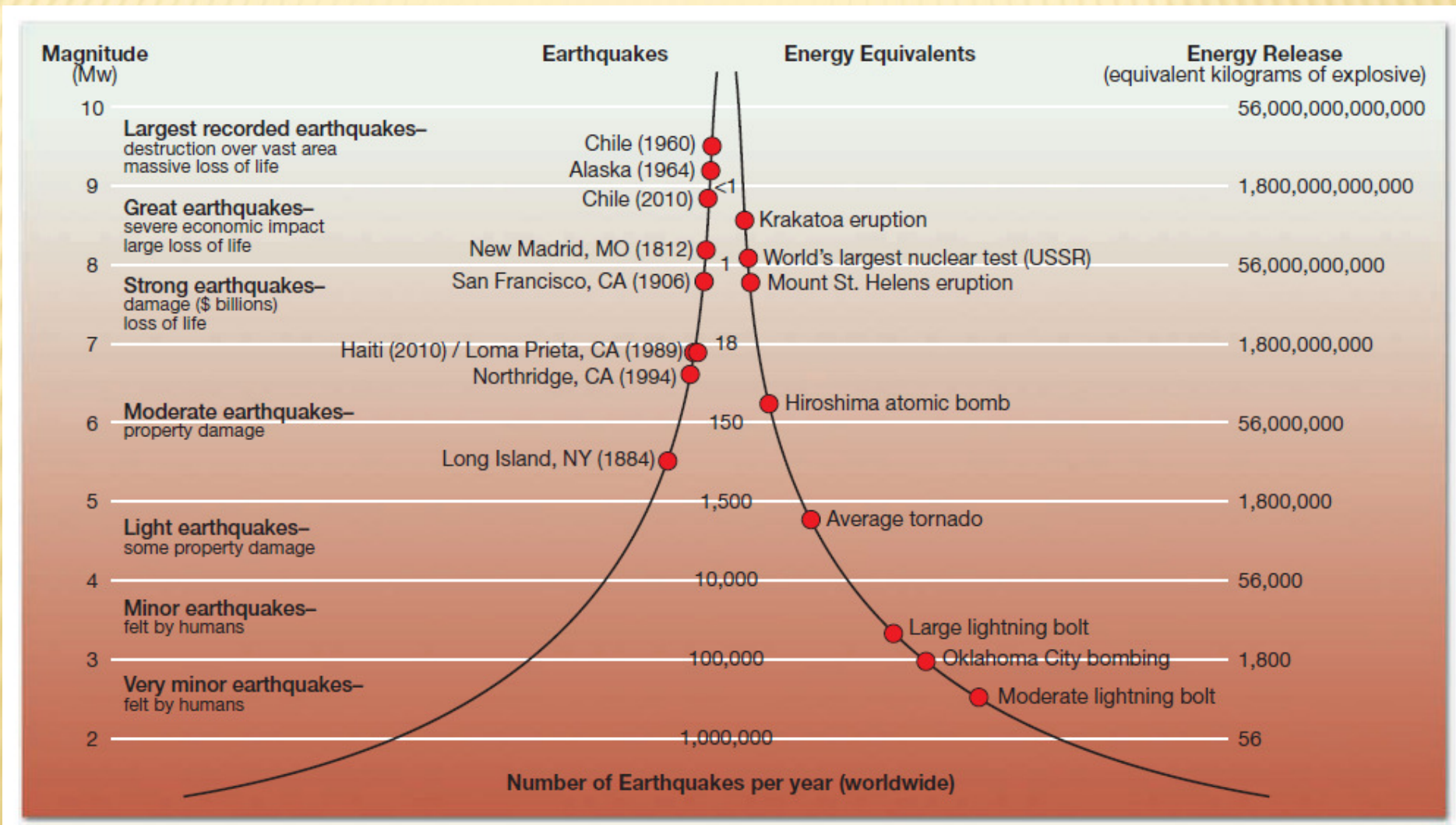
Modified Mercalli Scale		Richter Magnitude Scale	
I	Only felt by sensitive instruments		1.5
II	Felt by few persons at rest, especially on upper floors, delicate suspended objects may swing		2.0
III	Felt indoors, but may not be recognized as earthquake, vibrations like large passing truck		2.5
IV	Felt indoors by many, some outdoors, may awaken some sleeping persons; dishes, windows, doors may move, cars rock.		3.0
V	Felt by most; some windows, dishes break; tall objects may fall.		3.5
VI	Felt by by all, falling plaster and chimneys, light damage but some fear.		4.0
VII	Very noticeable, damage to weaker buildings on fill; driving automobiles notice.		4.5
VIII	Walls, monuments, chimneys, bookcases fall; liquifaction; driving is difficult		5.0
IX	Buildings shifted off foundations, cracked and twisted; ground is cracked and underground pipes are broken.		5.5
X	Most structures severely damaged to destroyed; ground is cracked, rails are bent, landslides on steep slopes		6.0
XI	Few structures standing; bridges and roads severely damaged or destroyed, large fissures in ground		6.5
XII	Total damage; can see the earthquake wave move through the ground; gravity overcome and objects thrown into the air		7.0
			7.5
			8.0



# MEASUREMENT OF EARTHQUAKE STRENGTH

- **EARTHQUAKE MAGNITUDE** IS A MEASURE OF THE STRENGTH OF AN EARTHQUAKE, OR THE AMOUNT OF STRAIN THAT ROCKS IN EARTH'S CRUST RELEASE WHEN AN EARTHQUAKE OCCURS.
- **THE RICHTER SCALE** AND THE **MOMENT MAGNITUDE SCALE** ARE USED TO MEASURE THE MAGNITUDE OF EARTHQUAKES.
- **RICHTER SCALE**, METHOD OF RANKING THE STRENGTH OR SIZE OF AN EARTHQUAKE.
- THE RICHTER SCALE, ALSO KNOWN AS THE LOCAL MAGNITUDE SCALE, WAS DEvised IN 1935 BY THE AMERICAN SEISMOLOGIST CHARLES F. RICHTER TO RANK EARTHQUAKES OCCURRING IN CALIFORNIA.
- RICHTER AND HIS ASSOCIATES LATER MODIFIED IT TO APPLY TO EARTHQUAKES ANYWHERE IN THE WORLD.
- THE RICHTER SCALE RANKS EARTHQUAKES BASED ON HOW MUCH THE GROUND SHAKES 100 KM (60 MI) FROM THE EARTHQUAKE'S EPICENTER, THE SITE ON THE EARTH'S SURFACE DIRECTLY ABOVE THE EARTHQUAKE'S ORIGIN.
- **THE RICHTER SCALE IS A LOGARITHMIC SCALE**—EACH INCREASE OF 1 ON THE RICHTER SCALE REPRESENTS A TENFOLD INCREASE IN MOVEMENT.
- THUS, AN EARTHQUAKE REGISTERING 7 ON THE SCALE IS 10 TIMES AS STRONG AS AN EARTHQUAKE REGISTERING 6, AND THE EARTH MOVES 10 TIMES AS FAR.

# MEASUREMENT OF EARTHQUAKE STRENGTH



# DAMAGE FROM EARTHQUAKES

- LARGE EARTHQUAKES CAN DISPLACE ROCK AND ALTER THE EARTH'S SURFACE. MOST EARTHQUAKE FATALITIES AND INJURIES OCCUR WHEN FALLING STRUCTURES CRUSH PEOPLE. STRUCTURAL DAMAGE, INJURY, AND DEATH DEPEND ON THE MAGNITUDE OF THE QUAKE, ITS PROXIMITY TO POPULATION CENTERS, ROCK AND SOIL TYPES, TOPOGRAPHY, AND THE QUALITY OF CONSTRUCTION IN THE REGION.
- **CONSTRUCTION DESIGN AND EARTHQUAKE DAMAGE**
- A MAGNITUDE 6.4 EARTHQUAKE STRUCK CENTRAL INDIA IN 1993, KILLING 30,000 PEOPLE. IN CONTRAST, THE 1994 MAGNITUDE 6.6 QUAKE IN NORTHRIDGE (NEAR LOS ANGELES) KILLED ONLY 55. THE TREMENDOUS MORTALITY IN INDIA OCCURRED BECAUSE BUILDINGS WERE NOT ENGINEERED TO WITHSTAND EARTHQUAKES.
- SOME COMMON FRAMING MATERIALS USED IN BUILDINGS, SUCH AS WOOD AND STEEL, BEND AND SWAY DURING AN EARTHQUAKE BUT RESIST FAILURE. HOWEVER, BRICK, STONE, CONCRETE, ADOBE (DRIED MUD), AND OTHER MASONRY PRODUCTS ARE BRITTLE AND LIKELY TO FAIL DURING AN EARTHQUAKE.



# DAMAGE FROM EARTHQUAKES

## ➤ FIRE

EARTHQUAKES COMMONLY RUPTURE BURIED GAS PIPES AND ELECTRICAL WIRES, LEADING TO FIRE, EXPLOSIONS, AND ELECTROCUTIONS. WATER PIPES MAY ALSO BREAK, SO FIRE FIGHTERS CANNOT FIGHT THE BLAZES EFFECTIVELY.



## ➤ LANDSLIDES

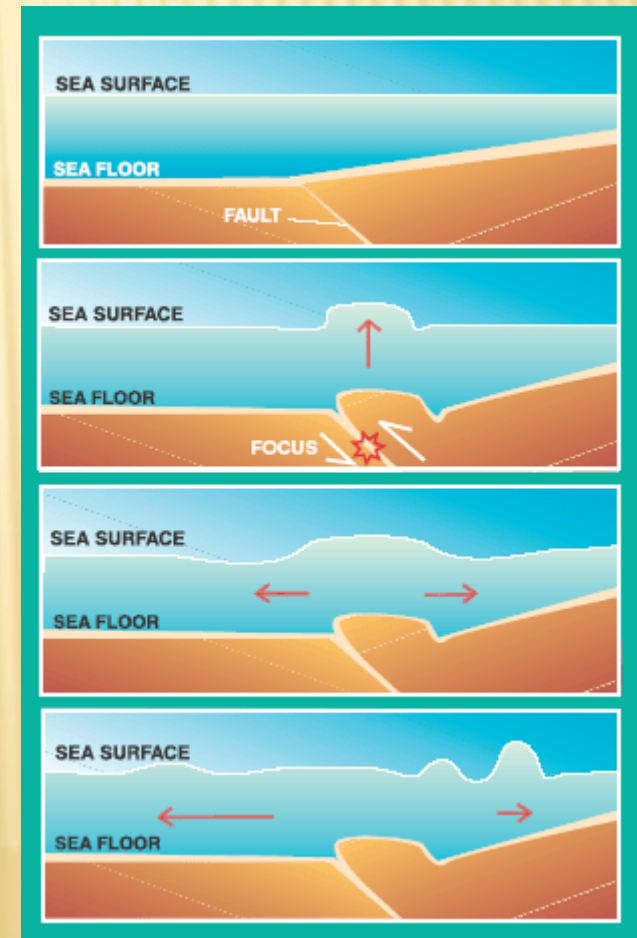
LANDSLIDES ARE COMMON WHEN THE EARTH TREMBLES. THEY OCCUR MOSTLY WHEN EARTHQUAKE OCCURS IN A HILLY REGION.



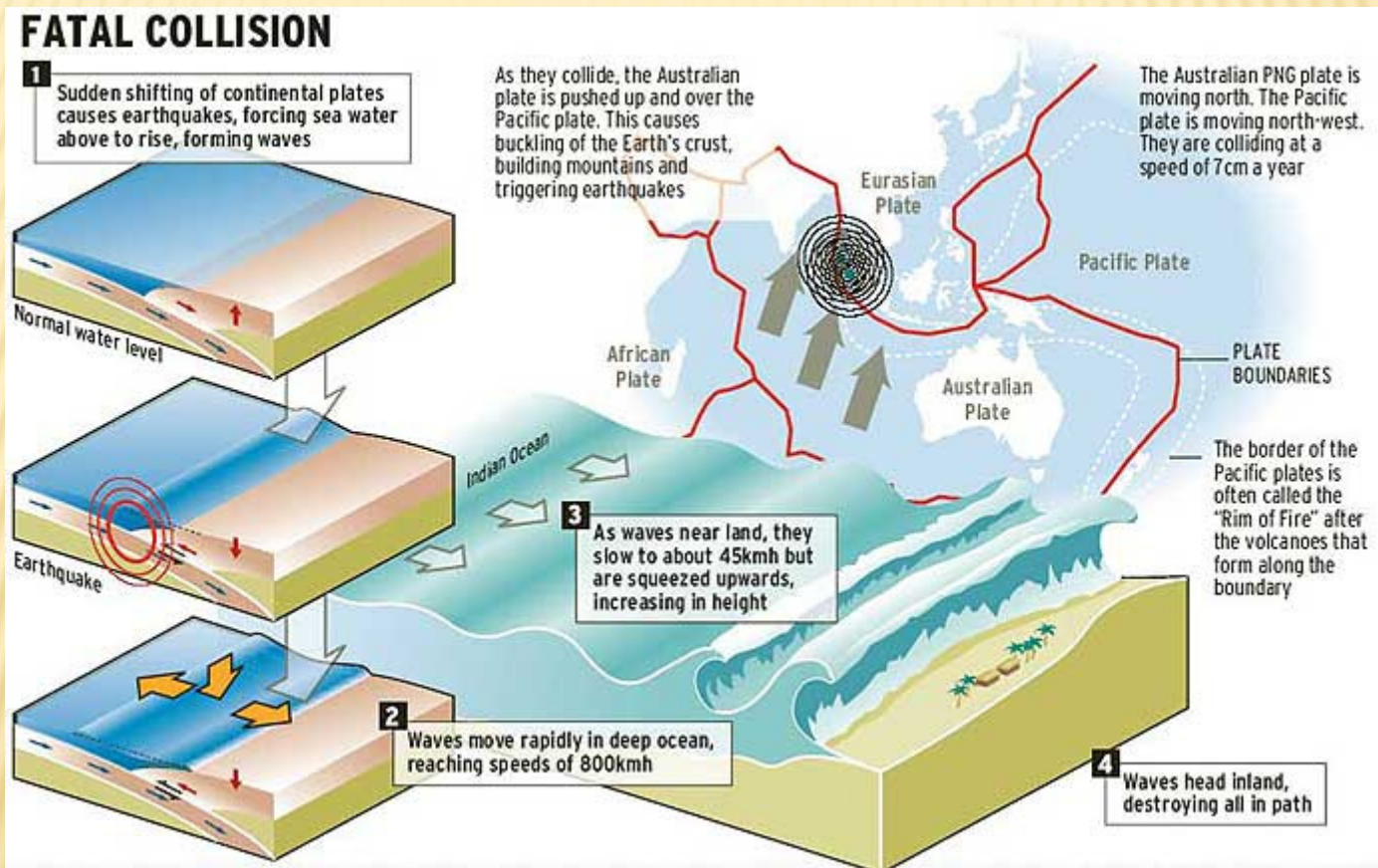
# DAMAGE FROM EARTHQUAKES

## TSUNAMIS

- WHEN AN EARTHQUAKE OCCURS BENEATH THE SEA, PART OF THE SEA FLOOR RISES OR FALLS AND WATER IS DISPLACED IN RESPONSE TO THE ROCK MOVEMENT, FORMING A WAVE.
- SEA WAVES PRODUCED BY AN EARTHQUAKE ARE OFTEN CALLED TIDAL WAVES, BUT THEY HAVE NOTHING TO DO WITH TIDES.
- THEREFORE, GEOLOGISTS CALL THEM BY THEIR JAPANESE NAME, **TSUNAMI**.
- IN THE OPEN SEA, A TSUNAMI IS SO FLAT THAT IT IS BARELY DETECTABLE. TYPICALLY, THE CREST MAY BE ONLY 1 TO 3 METERS HIGH, AND SUCCESSIVE CRESTS MAY BE MORE THAN 100 TO 150 KILOMETERS APART.
- HOWEVER, A TSUNAMI MAY TRAVEL AT 750 KILOMETERS PER HOUR.
- WHEN THE WAVE APPROACHES THE SHALLOW WATER NEAR SHORE, THE BASE OF THE WAVE DRAGS AGAINST THE BOTTOM AND THE WATER STACKS UP, INCREASING THE HEIGHT OF THE WAVE. THE RISING WALL OF WATER THEN FLOWS INLAND.

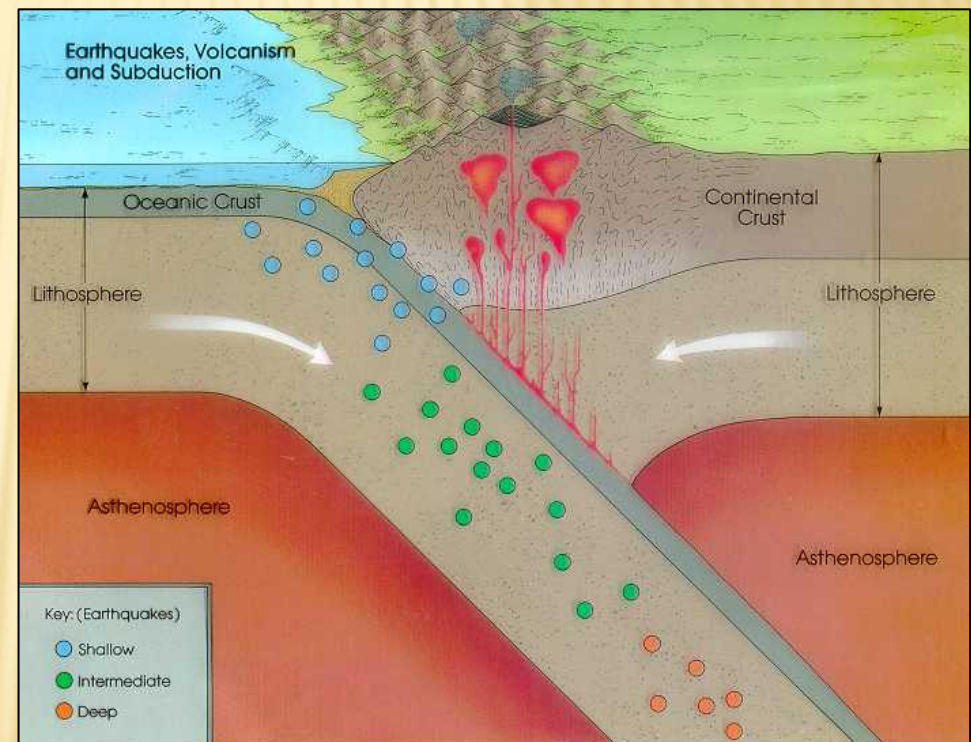


# FORMATION OF A TSUNAMIS



# DEPTH OF EARTHQUAKES

- EARTHQUAKES CAN OCCUR ANYWHERE BETWEEN THE EARTH'S SURFACE AND ABOUT 700 KILOMETERS BELOW THE SURFACE. FOR SCIENTIFIC PURPOSES, THIS EARTHQUAKE DEPTH RANGE OF 0 - 700 KM IS DIVIDED INTO THREE ZONES: SHALLOW, INTERMEDIATE, AND DEEP.
- **SHALLOW EARTHQUAKES** ARE BETWEEN 0 AND 70 KM DEEP;
- **INTERMEDIATE EARTHQUAKES:** 70 - 300 KM DEEP; AND
- **DEEP EARTHQUAKES:** 300 - 700 KM DEEP.
- IN GENERAL, THE TERM "DEEP-FOCUS EARTHQUAKES" IS APPLIED TO EARTHQUAKES DEEPER THAN 70 KM.
- ALL EARTHQUAKES DEEPER THAN 70 KM ARE LOCALIZED WITHIN GREAT SLABS OF SHALLOW LITHOSPHERE THAT ARE SINKING INTO THE EARTH'S MANTLE.

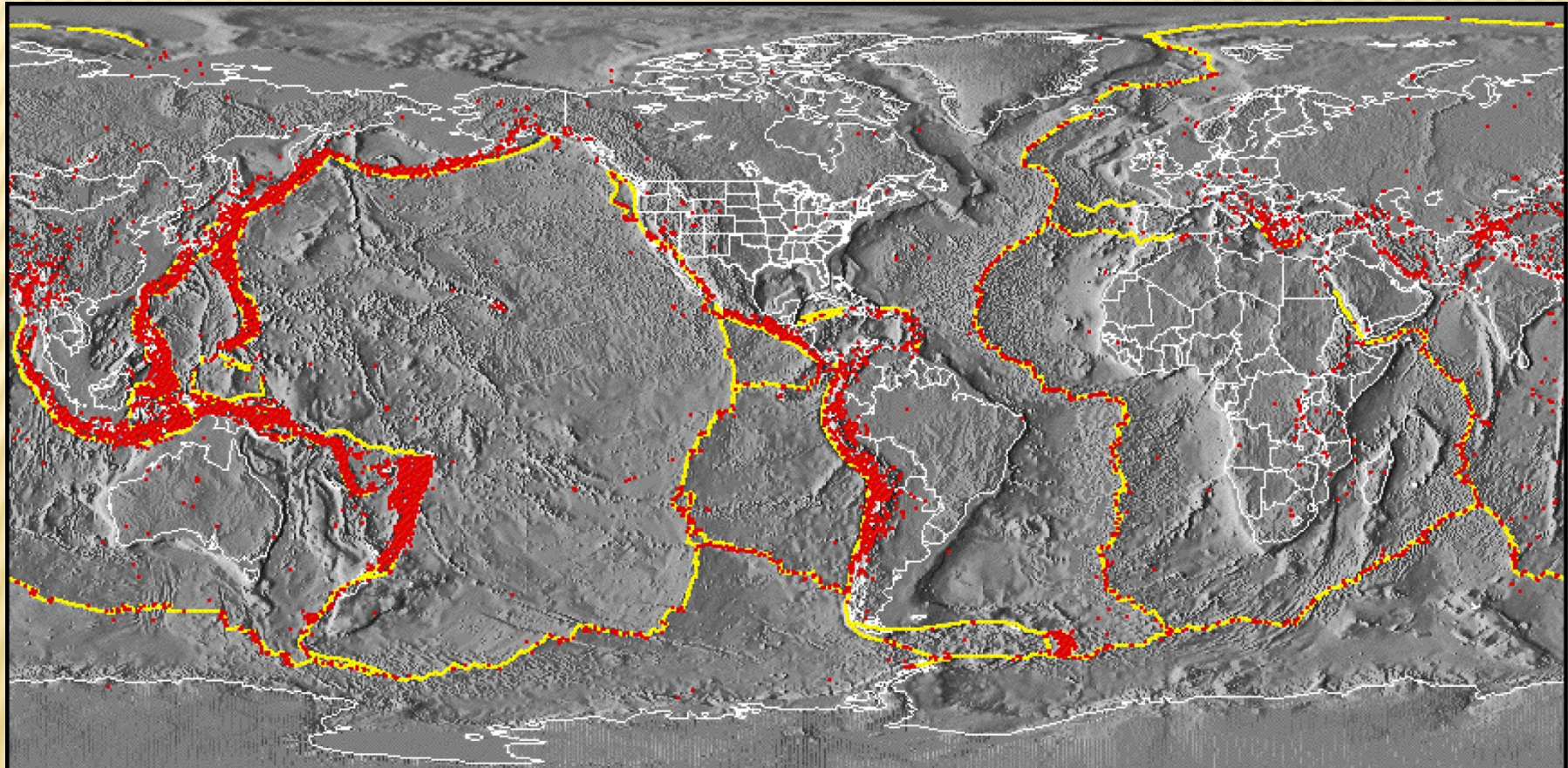


# EARTHQUAKE AND TECTONIC PLATE BOUNDARIES

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- ALTHOUGH MANY FAULTS ARE LOCATED WITHIN TECTONIC PLATES, THE LARGEST AND MOST ACTIVE FAULTS ARE THE BOUNDARIES BETWEEN TECTONIC PLATES.
- THEREFORE, EARTHQUAKES OCCUR MOST FREQUENTLY ALONG PLATE BOUNDARIES.
- **EARTHQUAKE OCCURS AT ALL THE THREE TYPE OF PLATE BOUNDARIES** THAT IS THE DIVERGENT PLATE BOUNDARIES, CONVERGENT PLATE BOUNDARIES AND TRANSFORM PLATE BOUNDARIES.
- HOWEVER ONLY **SHALLOW EARTHQUAKES OCCUR ALONG THE MID-OCEANIC RIDGE** (DIVERGENT PLATE BOUNDARY) BECAUSE HERE THE ASTHENOSPHERE RISES TO WITHIN 20 TO 30 KILOMETERS OF THE EARTH'S SURFACE AND IS TOO HOT AND PLASTIC TO FRACTURE.

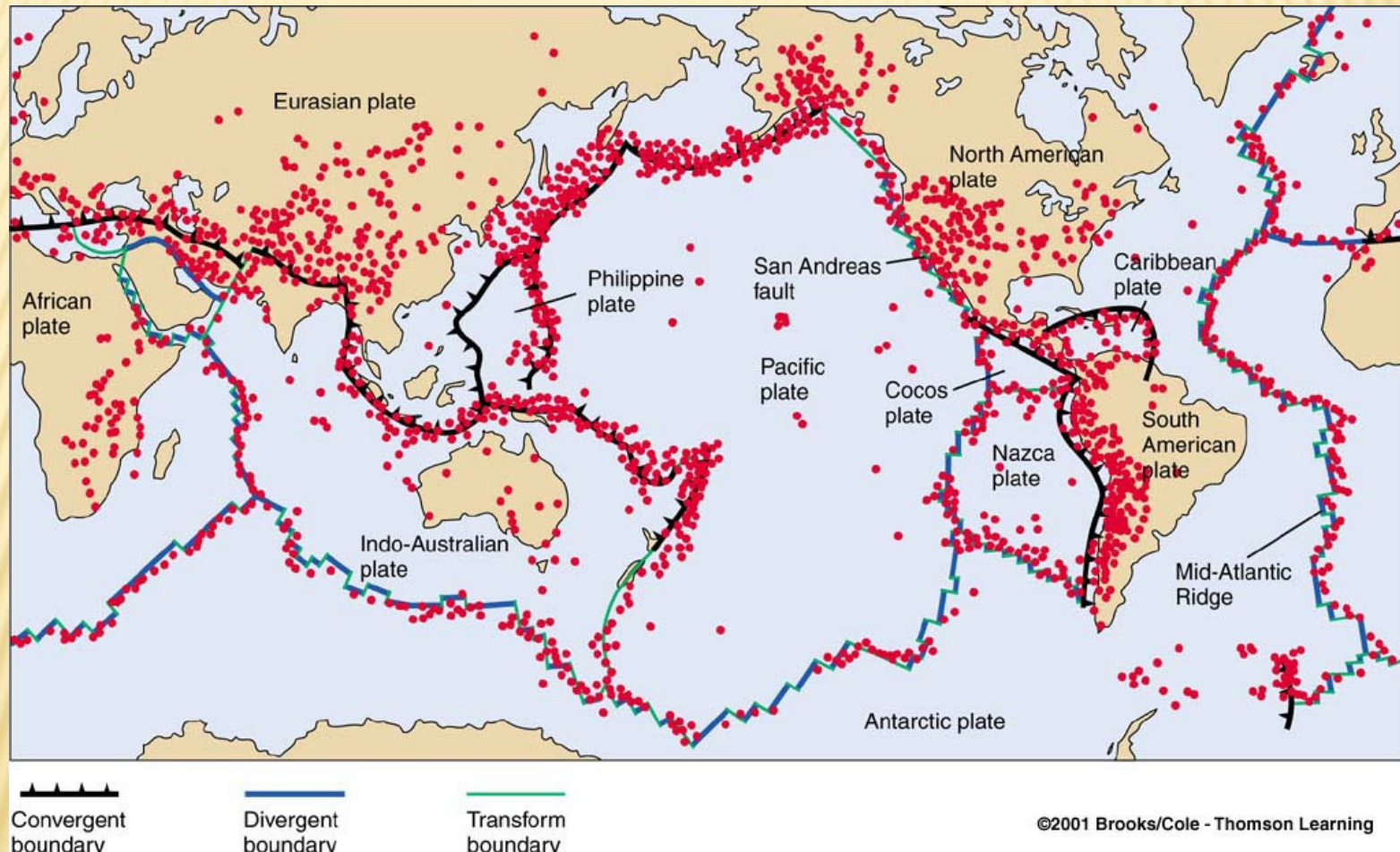
# EARTHQUAKE AND TECTONIC PLATE BOUNDARIES



Crustal Plate Boundaries  
Coastlines, Political Boundaries

Earthquake Epicenters,  $M > 5$ , 1980-1990  
Image courtesy of NOAA

# 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

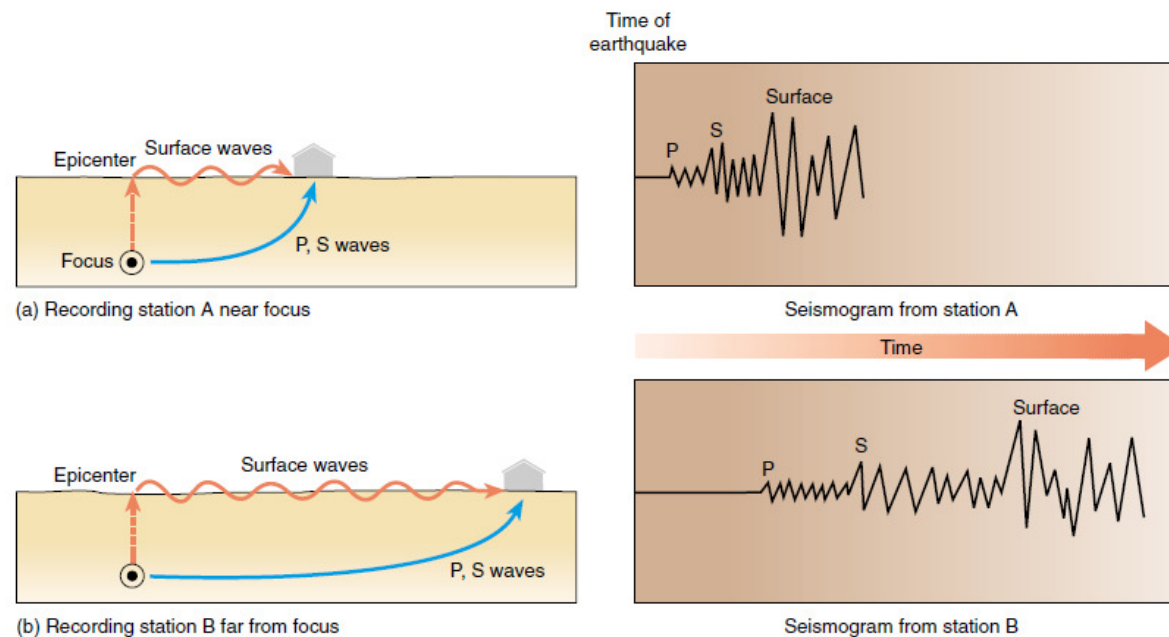
# EARTHQUAKE PREDICTION

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- **LONG TERM PREDICTION:** EARTHQUAKES OCCUR OVER AND OVER IN THE SAME PLACES BECAUSE IT IS EASIER FOR ROCKS TO MOVE ALONG AN OLD FRACTURE THAN FOR A NEW FAULT TO FORM IN SOLID ROCK.
- MANY OF THESE FAULTS LIE ALONG TECTONIC PLATE BOUNDARIES.
- THEREFORE, LONG-TERM EARTHQUAKE PREDICTION RECOGNIZES THAT EARTHQUAKES HAVE RECURRED MANY TIMES IN A SPECIFIC PLACE AND WILL PROBABLY OCCUR THERE AGAIN.
- **SHORT-TERM PREDICTION** IS BASED ON OCCURRENCES OF FORESHOCKS, RELEASE OF RADON GAS, CHANGES IN THE LAND SURFACE, THE WATER TABLE, ELECTRICAL CONDUCTIVITY, AND ERRATIC ANIMAL BEHAVIOR.

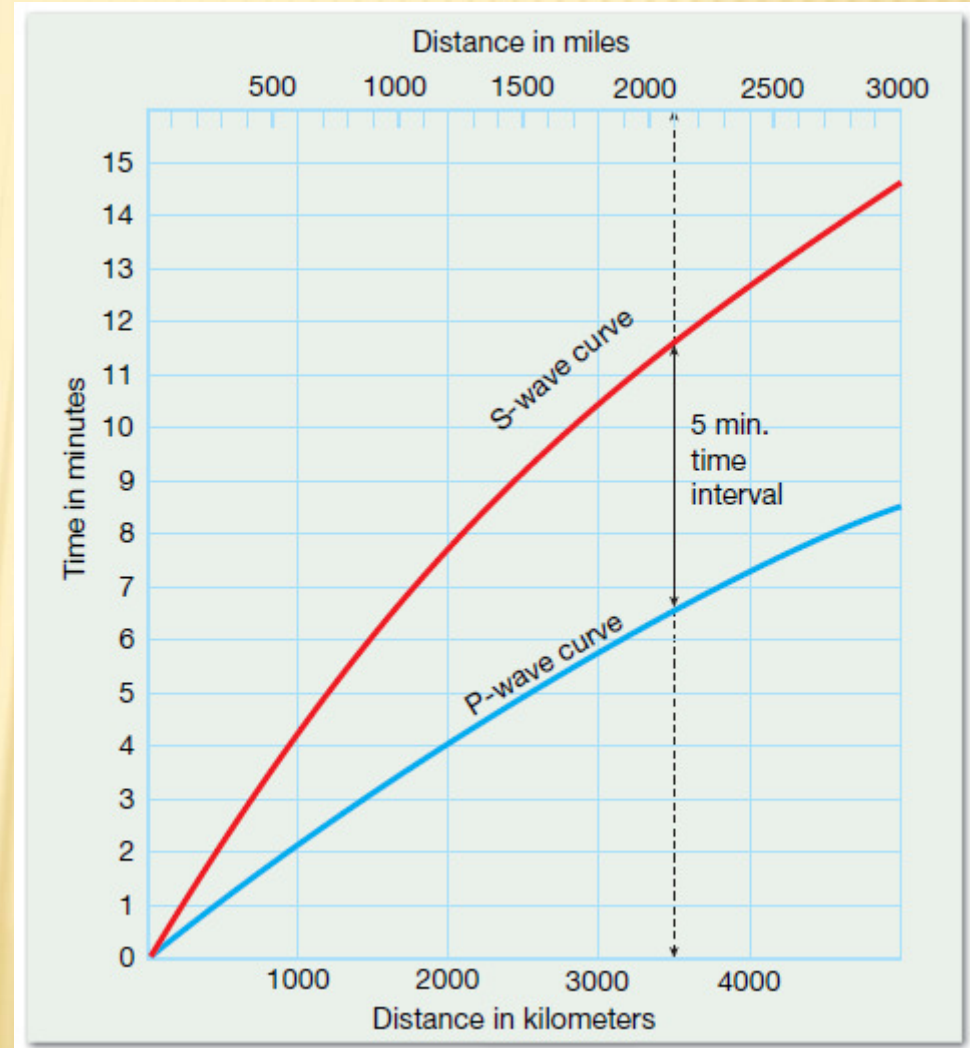
# LOCATING THE SOURCE OF AN EARTHQUAKE

- **P WAVES TRAVEL FASTER THAN THE S WAVES AND THE SURFACE WAVES ARE THE SLOWEST.**
- IF A SEISMOGRAPH IS LOCATED CLOSE TO AN EARTHQUAKE EPICENTER, THE DIFFERENT WAVES WILL ARRIVE IN RAPID SUCCESSION.
- ON THE OTHER HAND, IF A SEISMOGRAPH IS LOCATED FAR FROM THE EPICENTER, THE S WAVES ARRIVE AT CORRESPONDINGLY LATER TIMES AFTER THE P WAVES ARRIVE, AND THE SURFACE WAVES ARE



# LOCATING THE SOURCE OF AN EARTHQUAKE

- GEOLOGISTS USE A TIME-TRAVEL CURVE TO CALCULATE THE DISTANCE BETWEEN AN EARTHQUAKE EPICENTER AND A SEISMOGRAPH.
- TO MAKE A TIME-TRAVEL CURVE, A NUMBER OF SEISMIC STATIONS AT DIFFERENT LOCATIONS RECORD THE TIMES OF ARRIVAL OF SEISMIC WAVES FROM AN EARTHQUAKE WITH A KNOWN EPICENTER AND OCCURRENCE TIME. THEN A GRAPH IS DRAWN.
- THE FIGURE ON THE RIGHT SHOWS US THAT IF THE FIRST P WAVE ARRIVES 5 MINUTES BEFORE THE FIRST S WAVE, THE RECORDING STATION IS ABOUT 3400 KILOMETERS FROM THE EPICENTER.



# LOCATING THE SOURCE OF AN EARTHQUAKE

- BUT THIS DISTANCE DOES NOT INDICATE WHETHER THE EARTHQUAKE ORIGINATED TO THE NORTH, SOUTH, EAST, OR WEST.
- TO PINPOINT THE LOCATION OF AN EARTHQUAKE, GEOLOGISTS COMPARE DATA FROM THREE OR MORE RECORDING STATIONS.
- IF A SEISMIC STATION IN DARWIN RECORDS AN EARTHQUAKE WITH AN EPICENTER 4900 KILOMETERS AWAY, GEOLOGISTS KNOW THAT THE EPICENTER LIES SOMEWHERE ON A CIRCLE 4900 KILOMETERS FROM DARWIN.
- THE SAME EPICENTER IS REPORTED TO BE 8200 KILOMETERS FROM A SEISMIC STATION IN PARIS AND 3400 KILOMETERS FROM ONE IN NAGPUR, INDIA.
- IF ONE CIRCLE IS DRAWN FOR EACH RECORDING STATION, THE ARCS INTERSECT AT THE EPICENTER OF THE QUAKE.

