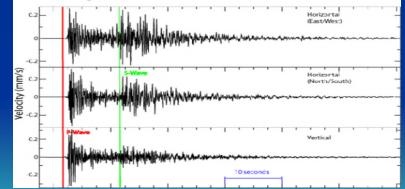
Earthquake! Principles and Hazards





Seismogram for seismic station TMI



Physical Geology - GEOL 100 Ray Rector - Instructor EARTHQUAKE TOPICS

What are Earthquakes?

Where and How do Earthquake Form?

What are the Types of Seismic Waves?

How are Earthquakes Measured? What are the Effects of Earthquakes?

What are the Types of Seismic Hazards?

Can we Predict Earthquakes?

How Can We Prepare for an Earthquake?

Earthquakes Occur Along Active Fault Zones

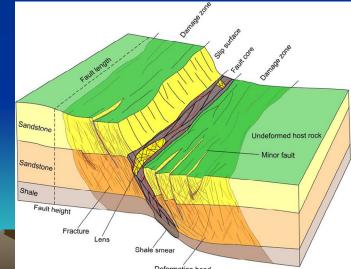
1) Earthquakes are the instant release of built-up elastic strain energy (seismic waves) along faults in the crust as the result of fault rupture (rock fracture and offset)

2) Faults are planar surfaces (zones of weakness) in the upper crust where brittle fracture and offset movement takes place between two crustal blocks

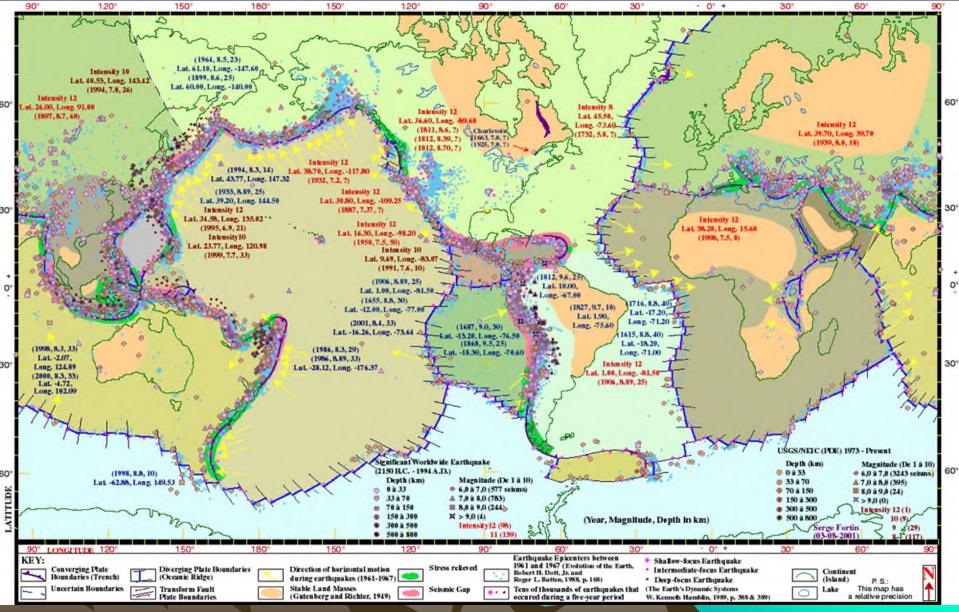
3) Faulting is caused when the built-up of tectonic, magmatic, or hydrologic stress/force in crustal rocks overcomes rock strength, resulting in rock failure.

4) Most active faults and quakes occur at or near tectonic plate boundaries





Major Earthquakes and Associated Fault Zones

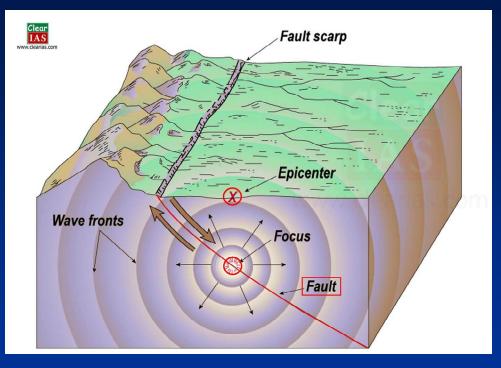


Most earthquakes and faulting occur at tectonic plate boundaries

Faulting and Earthquake Anatomy

Terminology

- 1) Fault
- 2) EQ Focus
- 3) EQ Epicenter
- 4) Seismic Waves
- 5) Fault Rupture Offset
- 6) Fault Line
- 7) Fault Scarp



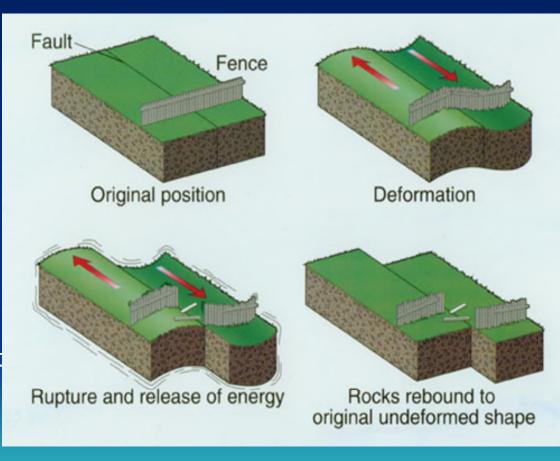
- Earthquakes develop deep in the ground along a rupturing fault
- > The site of origin of an earthquake on a fault is termed the *focus*
- > The ground surface location directly above the fault is termed the *epicenter*
- Seismic energy waves are generated by the rupturing fault (at the focus)
- A fault line is where the fault is traced along the ground surface
- A fault scarp is where a cliff-like feature forms along the fault line

What Causes an Earthquake?

1) Pre-load Period

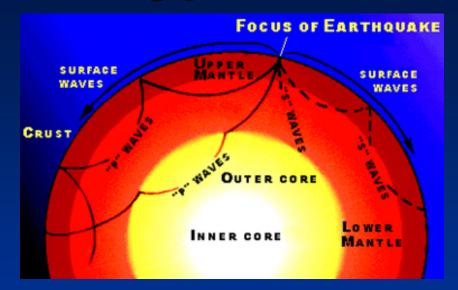
- No Stress
- No Deformation
- 2) Bending Period
 - Slow Stress Loading
 - Elastic Deformation
- 3) Rupture Period
 - Instant Stress Release
 - Brittle Deformation/Offset
- 4) Rebound Period
 - Removal of Bending
 - Stress Relieved

Reid's Elastic Rebound Theory



Four Stages

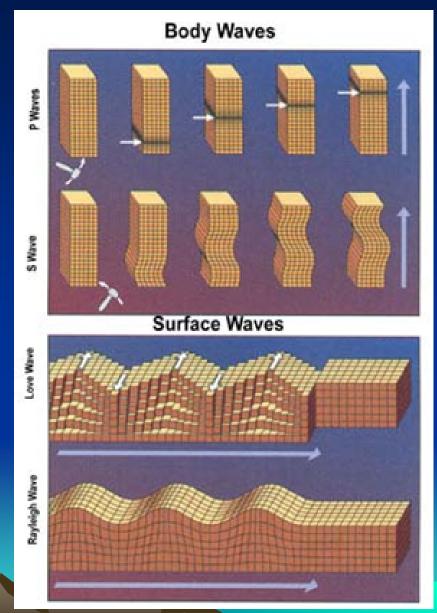
Types of Seismic Waves



- Body Waves Formed at Focus
 - 1) P-waves
 - 2) S-waves

Surface Waves – Formed at Surface

- 1) Love-waves
- 2) Raleigh-waves



Two Types of Seismic Body Waves

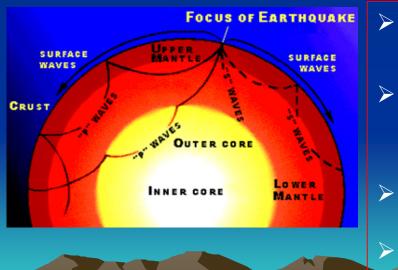
P-waves

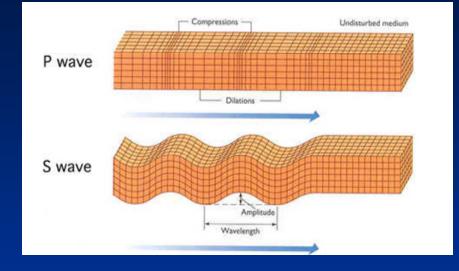
- Compression-dilation behavior of ground when wave passes through
- **Relatively Fast** \geq

S-waves

> Up-down shearing behavior of ground when wave passes through

Relatively Slow

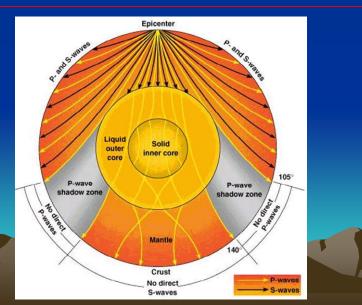


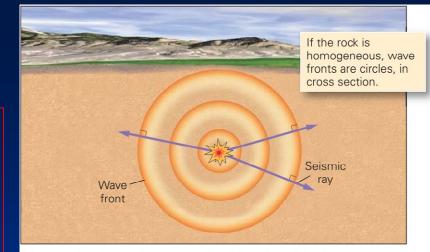


- P- and S-waves form at the site of fault rupture deep in the Earth (quake foci zones)
- Body waves bend when travelling down through \triangleright the Earth due to changes in rock density which affects seismic wave speed
- P-waves travel nearly twice as fast as the S- \triangleright waves
 - P-waves travel through solid and molten rock; Swaves cannot travel through liquid

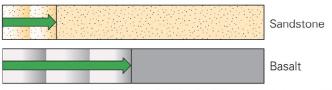
Body Wave Motion Through the Earth

- P- and S-waves travel perpendicular to their wave fronts in al directions from their origin (earthquake foci)
- Body waves change speed when moving from one rock type to another, travelling faster through denser, more solid rock.
- P-waves travel through the entire Earth, whereas S-waves stop at the core - not being able to travel through liquids

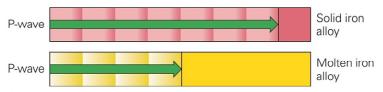




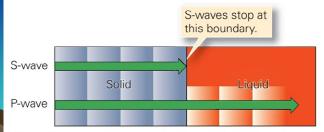
(a) An earthquake sends out waves in all directions. Seismic rays are perpendicular to wave fronts.



(b) Seismic waves travel at different velocities in different rock types. After a given time, the wave will have traveled farther in basalt than in sandstone.



(c) P-waves travel faster in solid iron alloy than in liquid, such as molten iron alloy.

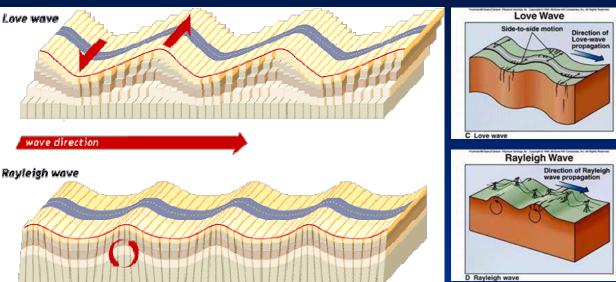


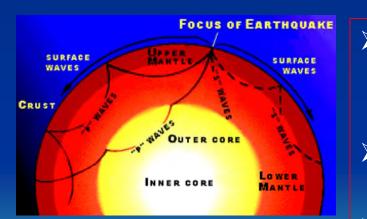
(d) Both P-waves and S-waves can travel through a solid, but only P-waves can travel through a liquid.

Two Types of Seismic Surface Waves

1) Love-waves

- Side-to-side shear motion of ground
- 2) Raleigh-waves
 - Orbital rolling motion of ground

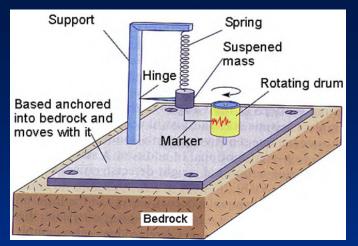




- Love- and Raleigh-waves form at the ground surface as the result of P- and S- body waves striking the ground surface from depth
- Surface waves only travel through the shallow surface layers of the crust
- Surface waves have larger wavelengths and amplitudes than the body waves

Surface waves are more destructive to building and other structures than body waves

Recording Seismic Activity with a Seismometer



A Simplified Seismometer

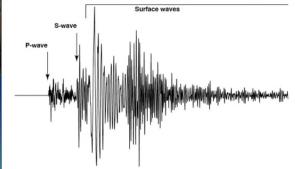
- A seismometer measures and records ground shaking
- A seismometer measures backand-forth, side-to-side, and upand-down ground motion
- A seismometer records seismic wave energy on a rolling drum
- Both body and surface waves of a quake are recorded as a seismogram





A Seismogram

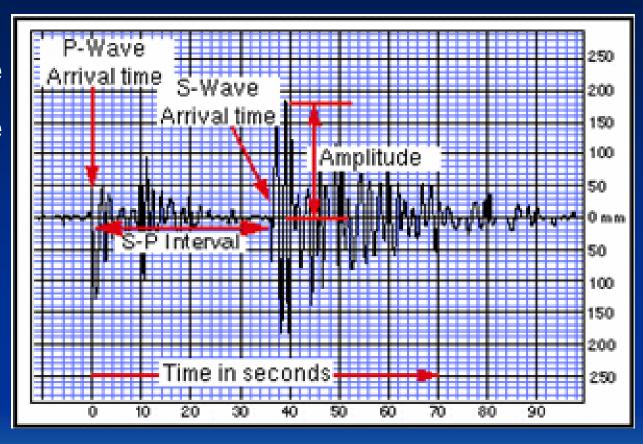
Examples of Seismometers



How does a seismometer work? tps://www.youtube.com/watch?v=geNigkgZDXA

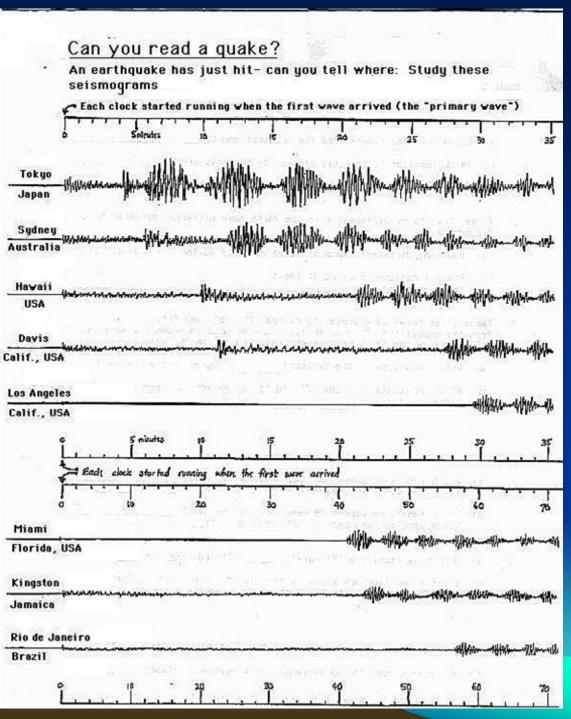
Fundamentals of a Seismogram

- 1) P-wave Arrival time
- 2) S-wave Arrival time
- 3) S-P Interval
- 4) Amplitude

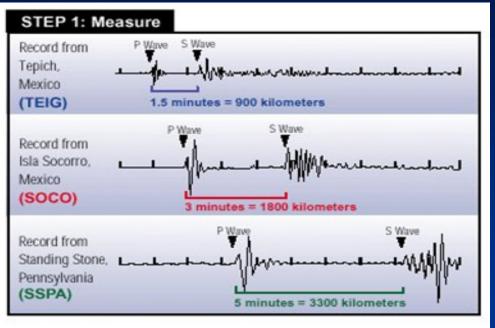


Reading a Seismogram

- 1) P-wave Arrival time
- 2) S-wave Arrival time
- 3) S-P Interval
- 4) Amplitude



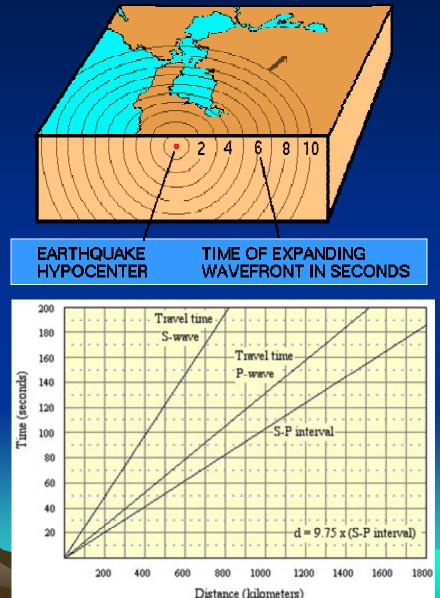
Determining Distance to Epicenter



1) Measure S-P Interval for each station

2) Convert S-P Interval time into ground distance from epicenter using the S-P conversion chart

3) Location of epicenter from seismic station is found somewhere along a circle drawn around station with a radius equal to epicenter distance



Determining Earthquake Epicenter

- 1) Need at least three seismograph stations
- 2) Find distance from station to epicenter for each station

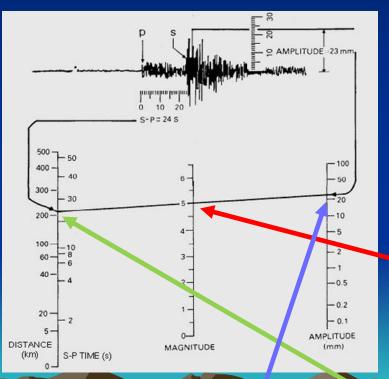
3) Plot distance circles for each station

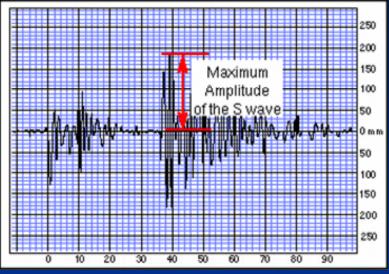
4) Epicenter located where all three circles intersect



Determining Earthquake Magnitude

- 1) Measure amplitude of largest S-wave
- 2) Plot line from distance to amplitude
- 3) Magnitude is read from center scale
- 4) Only need 1 station for determination





Measure the Tallest S-Wave on a Seismogram

Richter Magnitude is found by drawing a line between plotted left and right column points

Plot the distance to epicenter on left column and the height of S-wave on right column of Richter Chart

Earthquake frequency and destructive power

The left side of the chart shows the magnitude of the earthquake and the right side represents the amount of high explosive required to produce the energy released by the earthquake. The middle of the chart shows the relative frequencies.

10 Chile (1960) 9 Great earthquake; near total destruction, massive loss of life Japan (2011) 8 Major earthquake; severe economic impact, large loss of life New Madrid, Mo. (1812) 7 Strong earthquake; damage San Francisco (1906) 6 Moderate earthquake; damage Long Island, N.Y. (1884) 5 Light earthquake; some property damage Long Island, N.Y. (1884) 5 Light earthquake; some property damage Long Island, N.Y. (1884)	Magnitude		Notable earthquakes		(equivalent of explosive)
9 Great earthquake; near total destruction, massive loss of life New Madrid, Mo. (1812) 1 Krakatoa volcanic eruption 4 trillion lb. (1.8 trillion kg) 8 Major earthquake; severe economic impact, large loss of life New Madrid, Mo. (1812) 3 World's largest nuclear test (USSR) 123 billion lb. (56 billion kg) 7 Strong earthquake; damage (\$ billions), loss of life Loma Prieta, Calif. (1989) 20 4 4 billion lb. (56 billion kg) 6 Moderate earthquake; damage Long Island, N.Y. (1884) 200 4 123 million lb. (56 million kg) 5 Light earthquake; some property damage Long Island, N.Y. (1884) 2,000 Average tormado (1.8 million kg)			notable our enquance	Ener BJ eduration to	, 123 trillion lb.
9 Great earthquake; near total destruction, massive loss of life Japan (2011) Krakatoa volcanic eruption (1.8 trillion kg) 8 Major earthquake; severe economic impact, large loss of life San Francisco (1906) 3 World's largest nuclear test (USSR) 123 billion lb. 7 Strong earthquake; damage (\$ billions), loss of life San Prieta, Calif. (1989) 20 Mount St. Helens eruption 4 billion kg) 6 Moderate earthquake; property damage Long Island, N.Y. (1884) 20 20 4 million lb. 5 Light earthquake; some property damage Long Island, N.Y. (1884) 2,000 Average tomado (1.8 million kg)	10 -		Chile (1960)		(56 trillion kg)
9 Great earthquake; near total destruction, massive loss of life Japan (2011) Krakatoa volcanic eruption (1.8 trillion kg) 8 Major earthquake; severe economic impact, large loss of life San Francisco (1906) 3 World's largest nuclear test (USSR) 123 billion lb. 7 Strong earthquake; damage (\$ billions), loss of life San Prieta, Calif. (1989) 20 Mount St. Helens eruption 4 billion kg) 6 Moderate earthquake; property damage Long Island, N.Y. (1884) 20 20 4 million lb. 5 Light earthquake; some property damage Long Island, N.Y. (1884) 2,000 Average tomado (1.8 million kg)	and a		Alaska (1964)		4 trillion lb.
8 Major earthquake; severe economic impact, large loss of life New Madrid, Mo. (1812) 3 World's largest nuclear test (USSR) 123 billion lb. 7 Strong earthquake; damage (\$ billions), loss of life San Francisco (1906) 3 Mount St. Helens eruption 4 billion lb. 6 Moderate earthquake; damage Northridge, Calif. (1994) 20 20 4 billion kg) 6 Moderate earthquake; property damage Long Island, N.Y. (1884) 200 4 million lb. 5 Light earthquake; some property damage Long Island, N.Y. (1884) 2,000 Average tornado (1.8 million kg) 123 colub. 123 colub. 123 colub. 123 colub. 123 colub. 123 colub.	9 -	Great earthquake: near total	Japan (2011) 🜱		
8 Major earthquake; severe economic impact, large loss of life San Francisco (1906) 3 World's largest nuclear test (USSR) 123 billion ib. 7 Strong earthquake; damage (\$ billions), loss of life Loma Prieta, Calif. (1989) 20 4 billion lb. 4 billion kg) 6 Moderate earthquake; property damage Long Island, N.Y. (1884) 200 200 4 million kg) 5 Light earthquake; some property damage Long Island, N.Y. (1884) 2,000 Average tormado (1.8 million kg) 123 200 lb 123 200 lb			New Madrid Mo (1912)	 Krakatoa volcanic eruption 	
Major earthquake; severe economic impact, large loss of life San Francisco (1906) Mount St. Helens eruption (56 billion kg) 7 Strong earthquake; damage (\$ billions), loss of life Loma Prieta, Calif. (1989) 20 4 billion lb. 6 Moderate earthquake; property damage Long Island, N.Y. (1884) 20 20 4 million kg) 5 Light earthquake; some property damage Long Island, N.Y. (1884) 2,000 Average tormado (1.8 million kg)	0 -	desa deboit, massive toss of me		World's largest nuclear test (USSR)	123 billion lb.
7 Strong earthquake; damage (\$ billions), loss of life Kobe, Japan (1995) 20 Northridge, Calif. (1994) 20 20 (1.8 billion kg) 6 Moderate earthquake; property damage Long Island, N.Y. (1884) 200 2,000 Hiroshima atomic bomb 123 million lb. (56 million kg) 5 Light earthquake; some property damage 2,000 Average tomado 12.8 million kg)	0	Major earthquake; severe eco-	San Francisco (1906)		(56 billion kg)
6 Strong earthquake; damage (\$ billions), loss of life Kobe, Japan (1995) 20 (1.8 billion kg) 6 Moderate earthquake; property damage Long island, N.Y. (1884) 200 Hiroshima atomic bomb 123 million lb. (56 million kg) 5 Light earthquake; some property damage Long island, N.Y. (1884) 2,000 Average tomado (1.8 million kg)	-		Loma Prieta, Calif. (1989)		4 billion lb.
6 (\$ billions), loss of life 123 million lb. 6 Moderate earthquake; property damage Long Island, N.Y. (1884) 200 Hiroshima atomic bomb 123 million lb. 5 Light earthquake; some property damage Long Island, N.Y. (1884) 2,000 Average tomado 123 million kg) 10 123 million kg) 123 million kg) 123 million kg)	1-	Strong earthquake; damage	wana' anham (rasa)	1	
6 Moderate earthquake; property damage Long Island, N.Y. (1884) 200 (56 million kg) 5 Light earthquake; some property damage 2,000 Average tomado (1.8 million kg)		(\$ billions), loss of life	woruninge, cam. (1994)	Hireshima atomic bomb	123 million lb
5 Light earthquake; some property damage Long Island, N.Y. (1884) 4 million lb. (1.8 million kg)	6 -	Moderate earthquake:	F 20) -	and a second sec
5 Light earthquake; some property damage (1.8 million kg)					
some property damage	5 -	Light earthquaker	J- 2,00	Average tornado	
some property damage			/	And age to make	and the second second second
12,000 10.	1 -		12.0		12,300 lb.
(36,000 kg)	4	Minor earthquake;			(56,000 kg)
felt by humans	-		/		4 000 lb
3 + 0klahoma City bombing + (1,800 kg)	3 -	-	100,0	00 Oklahoma City bombin	
Moderate lightning bolt	2565			Moderate lightnin	ig bolt
123 lb			1000		
2 1,000,000 (56 kg)	2 -		1,000,		(56 kg)
Humber of earthered as a second durida	1		Number of contheseders	and the found duriday	
Number of earthquakes per year (worldwide)		E	Number of earthquakes	per year (worldwide)	
Source: U.S. Geological Survey	Source	e: LLS. Geological Survey			MCT

Francis ralance

Measuring Ground Shaking

Modified Mercalli Intensity Scale

I Not felt

II Felt only by persons at rest

III-IV Felt by persons indoors only

V–VI Felt by all; some damage to plaster, chimneys

- VII People run outdoors, damage to poorly built structures
- VIII Well-built structures slightly damaged; poorly built structures suffer major damage
- IX Buildings shifted off foundations
- X Some well-built structures destroyed
- XI Few masonry structures remain standing; bridges destroyed
- XII Damage total; waves seen on ground; objects thrown into air

Seismic Hazards

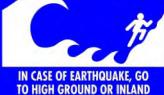
- 1) Ground shaking
- 2) Ground displacement
- 3) Liquefaction
- 4) Landslides
- 5) Building collapse
- 6) Tsunami
- 7) Fires
- 8) Flooding







TSUNAMI HAZARD ZONE

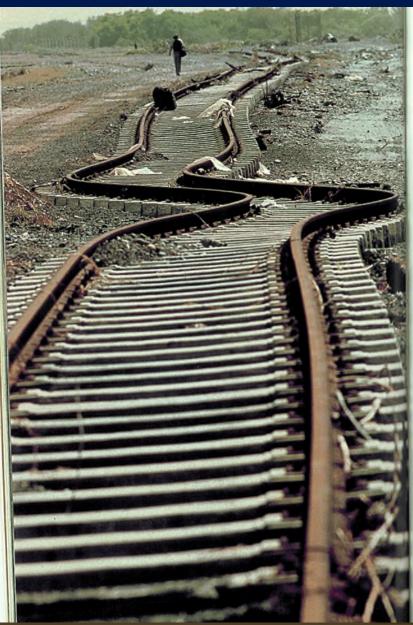


Ground Shaking and Building Motion



Japan Earthquake - Building Shaking Alaska Earhquake - Modeled Building Motion

Surface Displacement Along Active Faults

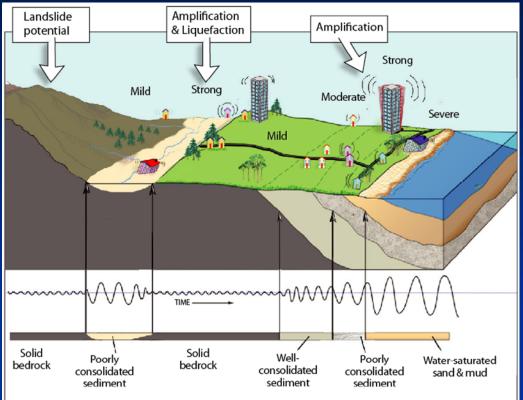


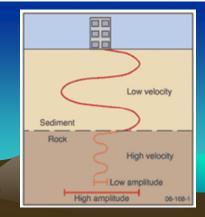




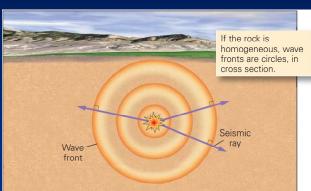
Earthquake Ground Shaking: Variations in Substrate

- Different types of ground materials behave differently to seismic waves
- 2) The softer the material, the greater the shaking
- 3) Solid rock is less shaken than consolidated sediment
- 4) Well-consolidated sediment is less shaken than poorlyconsolidated sediment
- 5) Dry sediment is more stable than water-saturated sediment

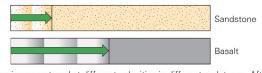




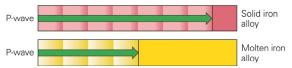
How Ground Shaking Affects Buildings



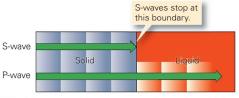
(a) An earthquake sends out waves in all directions. Seismic rays are perpendicular to wave fronts.



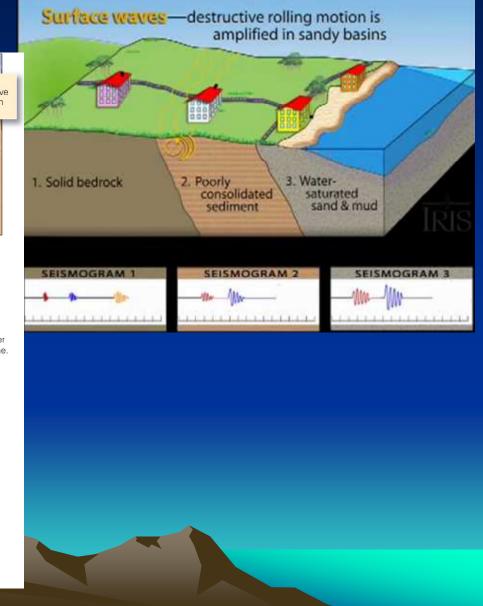
(b) Seismic waves travel at different velocities in different rock types. After a given time, the wave will have traveled farther in basalt than in sandstone.



(c) P-waves travel faster in solid iron alloy than in liquid, such as molten iron alloy.



(d) Both P-waves and S-waves can travel through a solid, but only P-waves can travel through a liquid.



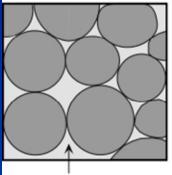
Liquifaction!

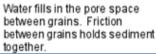


Liquifaction!



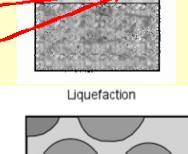
Water-Saturated Sediment

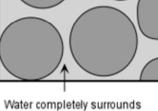




Video 1

Video 2





Water completely surrounds all grains and eliminates all grain to grain contact. Sediment flows like a fluid.

Exhumed p







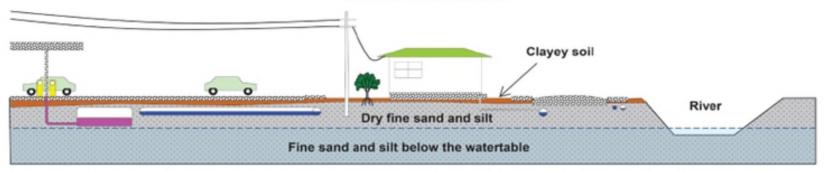


Liquifaction

Liquefaction and its Effects

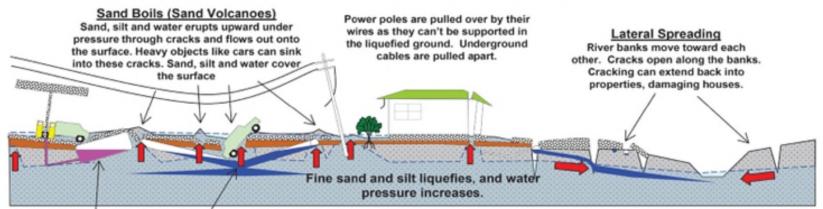
Before the Earthquake

Areas of flat, low lying land with groundwater only a few metres below the surface, can support buildings and roads, buried pipes, cables and tanks under normal conditions.



During and after the Earthquake

During the earthquake fine sand, silt and water moves up under pressure through cracks and other weak areas to erupt onto the ground surface. Near rivers the pressure is relieved to the side as the ground moves sideways into the river channels.



Tanks, pipes and manholes float up in the liquefied ground and break through the surface. Pipes break, water and sewage leaks into the ground.

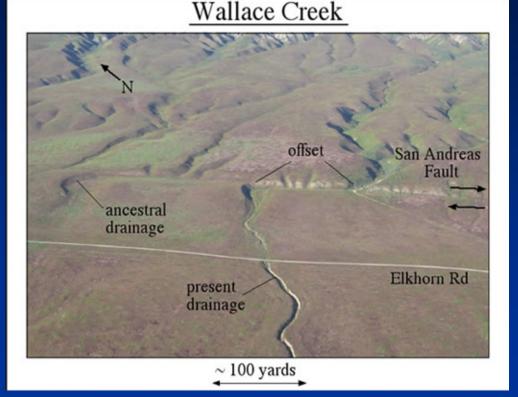
Using Aerial Photos to Interpret Fault Movement

1) Recognizing the offset of linear surface features

- ✓ Drainage channels
- ✓ Ridgelines
- ✓ Geologic formations

2) Relative direction of offset feature shows the relative movement direction

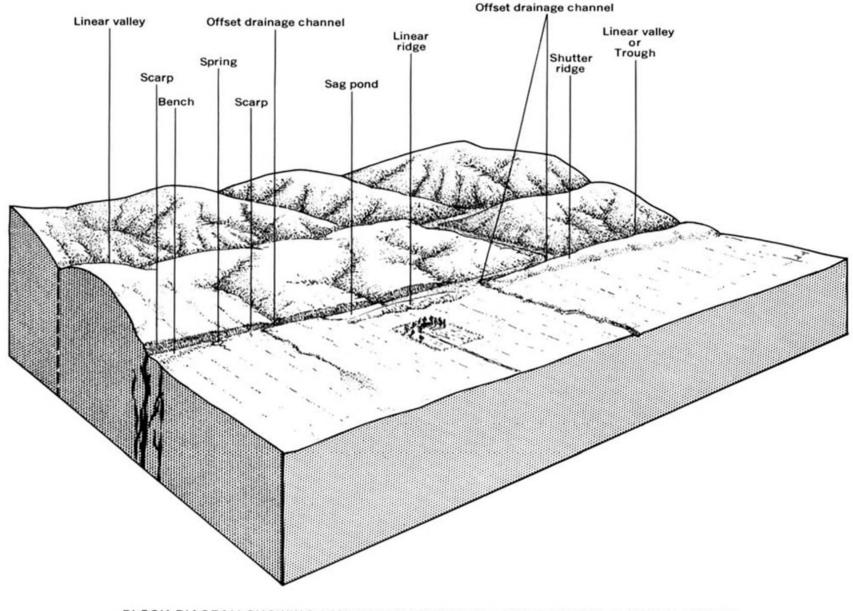
3) Amount of offset along disturbed feature shows the amount of fault movement



Surface Displacement Along San Andreas Fault

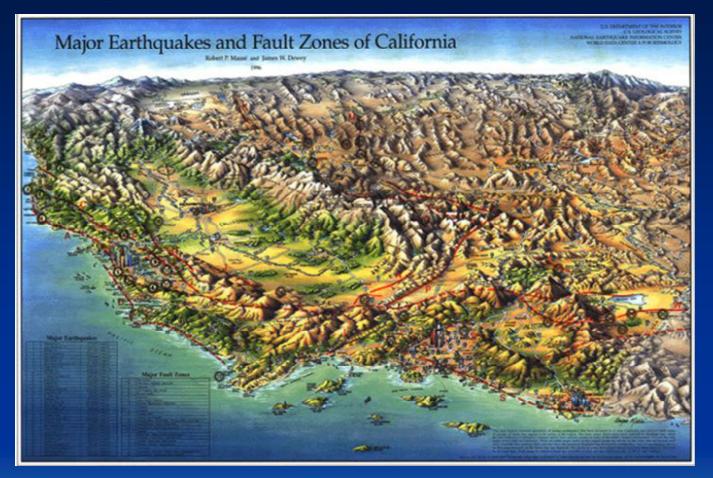
4) Age of offset feature gives averaged rate of displacement

Active Fault Features



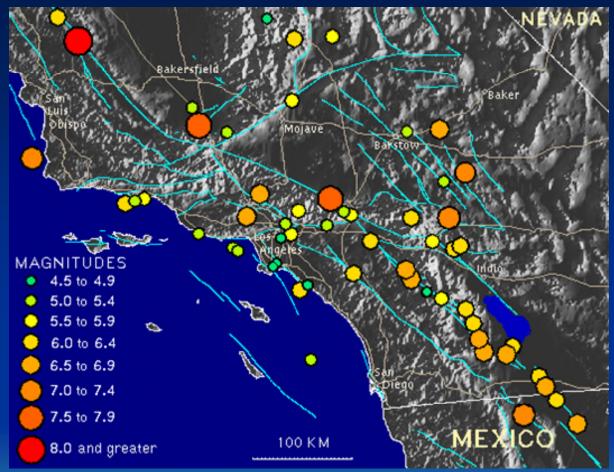
BLOCK DIAGRAM SHOWING LANDFORMS PRODUCED ALONG RECENTLY ACTIVE FAULTS

Major Fault Zones of California



The majority of California's abundance of faults are part of the San Andreas Fault Zone – a transform boundary fault system

Largest Earthquakes of Southern California



The San Andreas Fault is capable of up to 8.0 M earthquakes. The most active fault in So Cal is the San Jacinto Fault

Most Recent Earthquakes in California

1) Most fault activity is associated with the San Andreas Fault Zone

2) The other zone is the Eastern Sierra region

3) The most active in Southern California are the San Jacinto and Elsinore faults

4) Short range quake prediction does not exist at this time

 6

 5

 4

 3

 2

 1

 2

 1

 2

 1

 2

 1

 2

 1

 2

 1

 2

 1

 2

 1

 2

 1

 2

 1

 2

 1

 2

 1

 2

 1

 2

 1

 2

 1

 2

 1

 2

 1

 1

 2

 1

 2

 1

 1

 1

 1

 1

 1

 1

 1

 1

 1

 1

 1

 1

 1

 <td

5) Where will the next "Big One" (> 7.5M) hit?

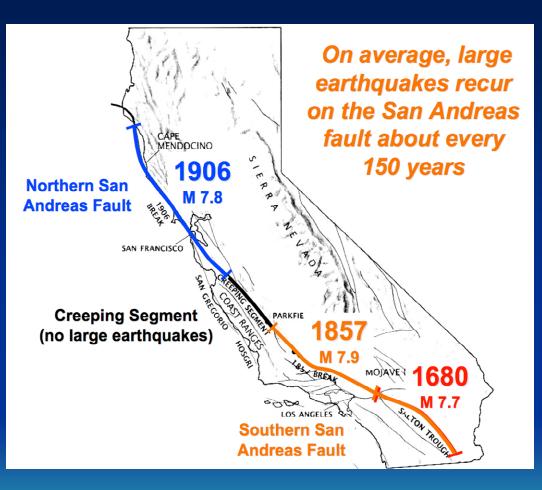
"Big Ones" on the San Andreas

1) Three Big Ones in the last 500 years on the SAF

2) Last Big One was on the Northern California segment in 1906

3) Last Big One on the Southern California segment was in 1680

4) A "Big One" occurs about every 400 years on each of the SAF segments

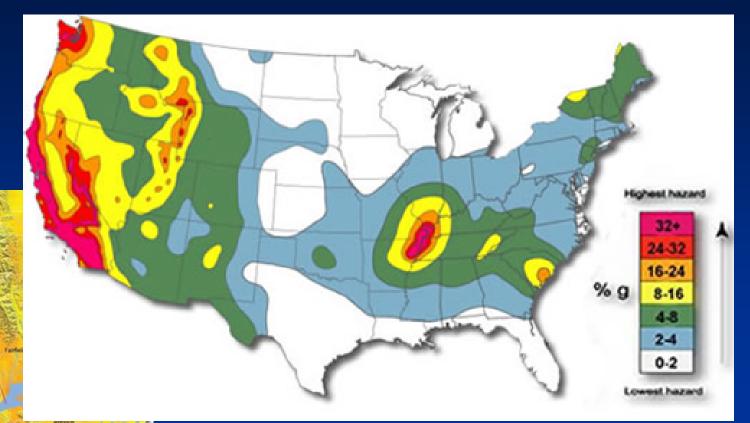


5) Based on this map, where will the next "Big One" on the SAF most likely strike?

Earthquake Probability in USA

1)

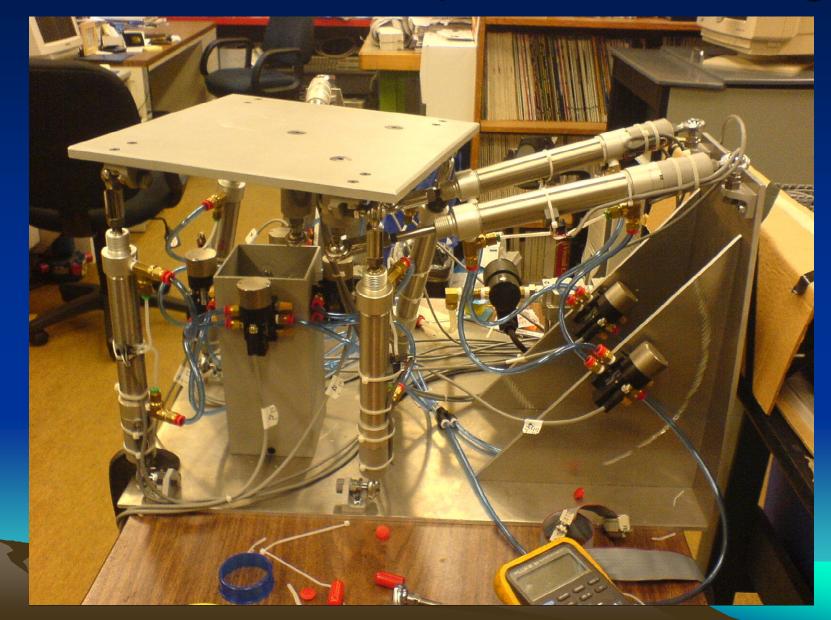
THE NEXT BIG ONE 2



Geologists cannot predict an earthquake at the present time

2) Geologists can make statisticallybased probability estimates for a given faults's chances of rupture

Advanced Earthquake Modeling



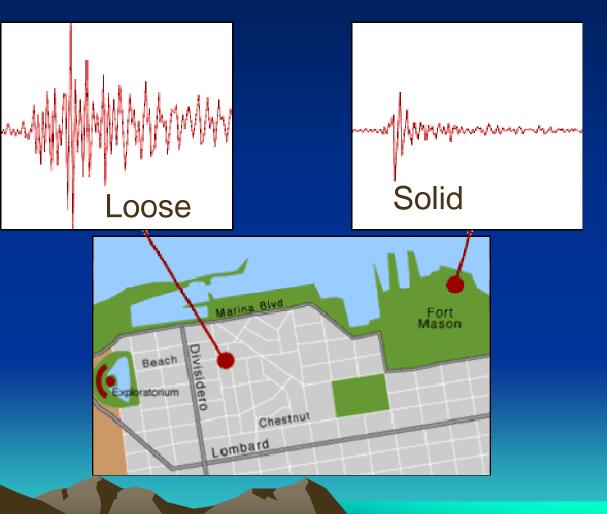
Bay Area Earthquake Analysis

Comparing Substrate Type with Observed Ground Motion

1) Solid Rock

2) Dry Loose Sediment

3) Watersaturated Loose Sediment



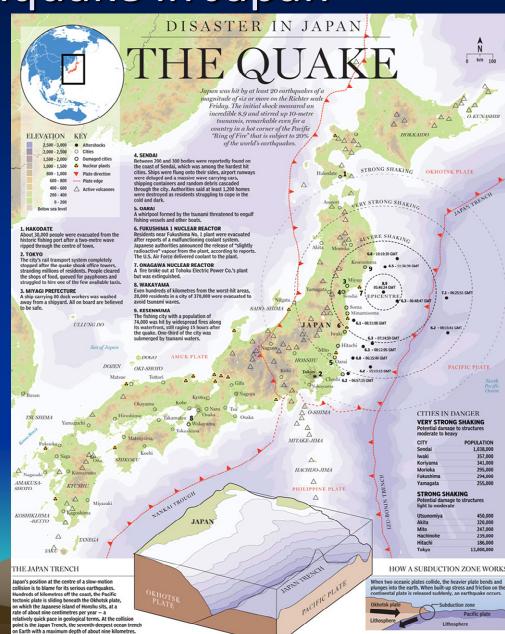
Recent Earthquake in Japan

1) Measured 9.0 on Richter Scale and lasted for over 4 minutes

2) One of the largest earthquakes ever recorded – biggest ever measured in Japan

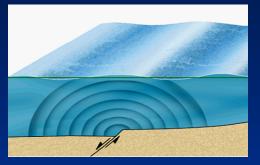
 Centered offshore along subduction zone thrust fault

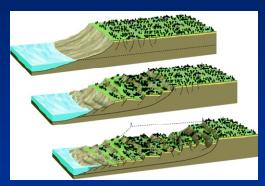
4) Caused super destructive tsunami waves



Origin of Tsunami Tsunami can be generated by several means:

1) Seismic event





2) Coastal landslide

3) Volcanic eruption



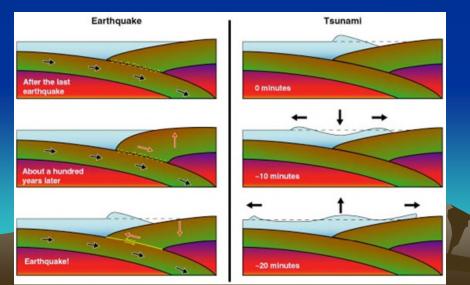
4) Bolide ocean impact

Formation of Seismic Sea Waves

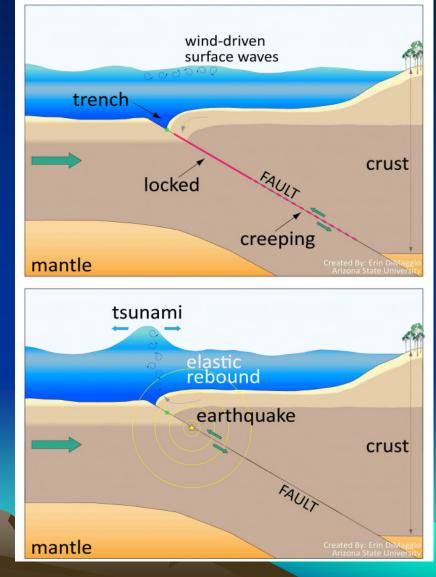
□ A seismic sea wave is generated by a rapid vertical displacement of the sea bottom during an earthquake

Overlying water column is equally displaced, either up or down, depending on direction of the ruptured seafloor

□ The influence of gravity on the ocean surface anomaly will cause water column oscillation resulting in a set of outwardly moving concentric tsunami waves



How a tsunami is generated by an earthquake at a subduction zone

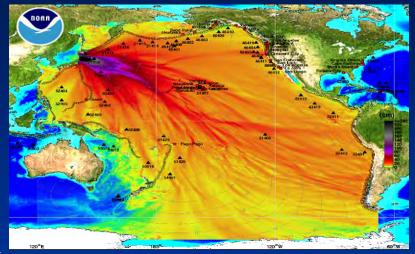


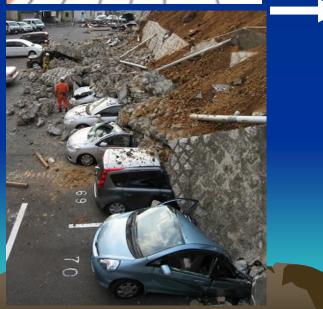
Pacific Rim – Tsunami Factory



Earthquake-Tsunami Combo The Deadly One-Two Punch









Tsunami = Godzilla Wave?



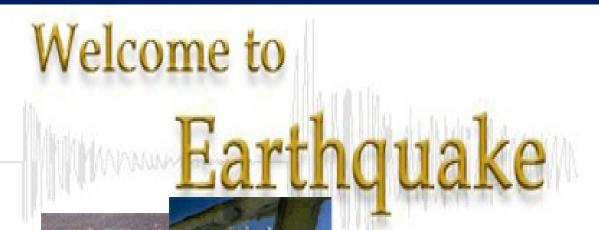
https://www.youtube.com/watch?v=23 VflsU3kZE https://www.youtube.com/watch?v=F1 ZewAPI7L0

Steps For Earthquake Preparedness

Preparation and Identify potential hazards in your home and begin to fix them! Mitagation 1 2 Create a disaster preparedness plan. 3 Prepare disaster supply kits. Identify your building's potential weaknesses and begin to fix them. Protecing yourself during earthquake 5 shaking-DROP, COVER AND HOLD ON After the earthquake, check for for injuries and damage. When safe, continue to follow **DROP! COVER!** your disaster preparedness plan.

Earthquake

Earthquake Epicenter and Magnitude Internet Exercise



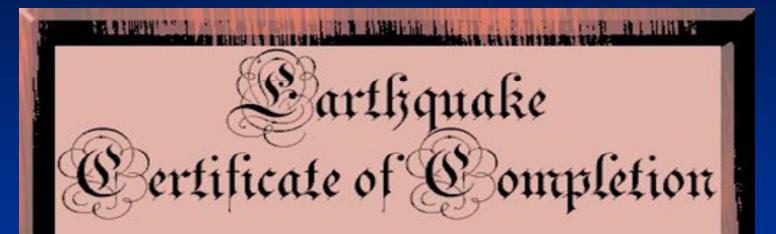






Virtual Earthquake Internet Exercises

Virtual EQ Certificate



Joe ShakeRattleRoll

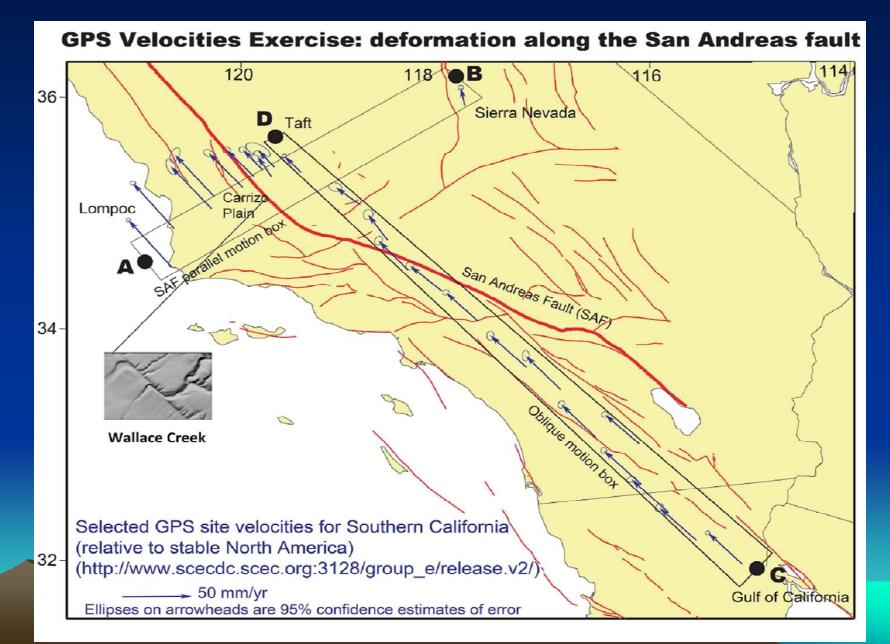
Friday, November 07, 2014

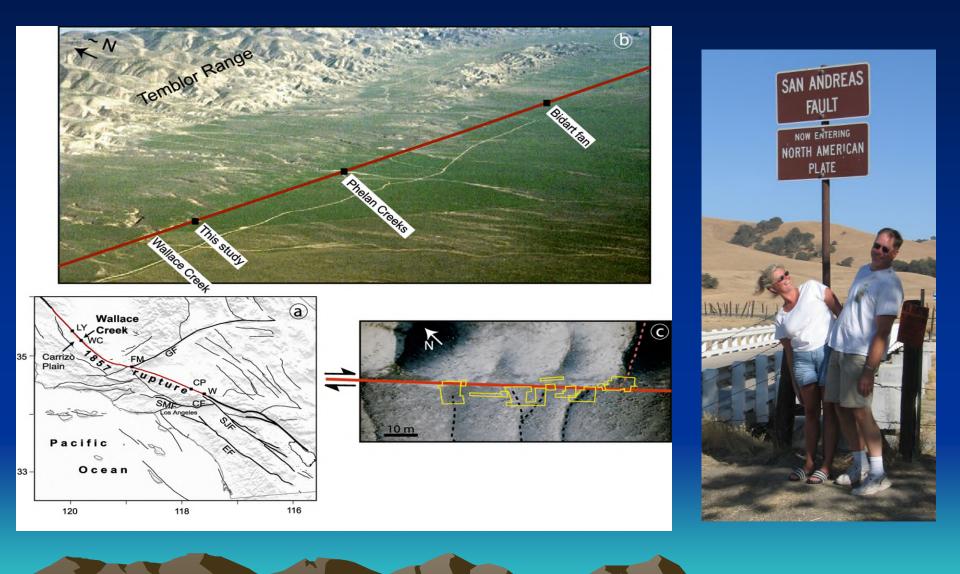
The above named researcher has successfully completed the listed activities of the EARTHQUAKE activity and will soon be a VIRTUAL SEISMOLOGIST.

By Authority of the Virtual Courseware Project

Copyright 2001

1 1 1 111



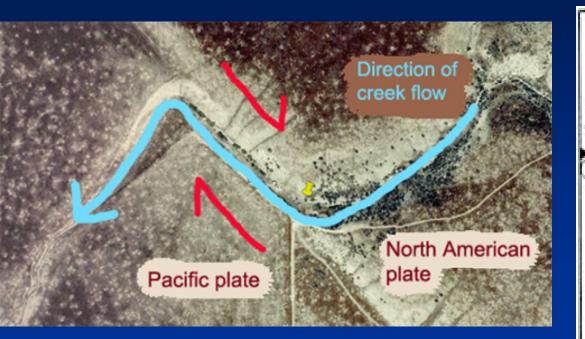






Wallace Creek

Dry Valley



Dextral Fault Movement as Shown by Apparent Creek Offset



Using Trenching to Interpret Faulting History

1) Trench perpendicular to active fault zone along a stream channel

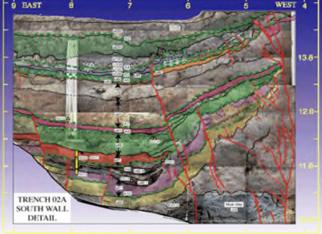
2) Trace and record all rupture surfaces and offset bedding and rock units

3) Date ruptured stream deposits using carbon 14 method on charcoal grains

4) Correlate offset events to ruptured layers using cross-cutting principle and C-14 dates.







Fault Trenching Studies

Head's-Up for Next Week's Lab Structural Geology and Geologic Maps Next Week's Lab Activities 1) Analyze structural block diagrams

- 2) Construct structural diagrams
- 3) Take compass bearing

Preparation

Recommended Pre-Lab Web Activities (Click on Link)

- 1) Construction of topographic and bathymetric profiles
- 2) Plotting map locations and taking bearings

3) World ocean bottom features and Tectonic plate boundaries