Indian Institute of Technology, Kanpur
Department of Earth Sciences

ESO213A: Fundamentals of Earth Sciences

Lecture 33. Earthquakes - II

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Experimental Rock Deformation Laboratory

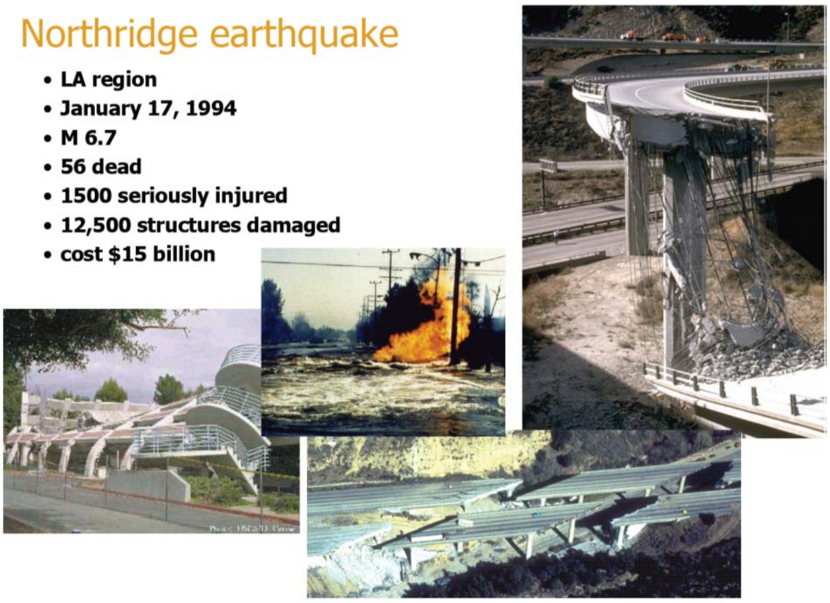
Aims of this lecture

- Visualization of rupture
- Seismic Waves
- Focal Mechanism
- Magnitudes

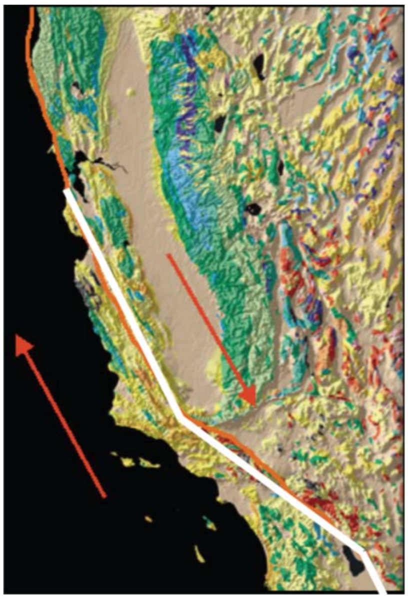
Faulting – how do we see the process

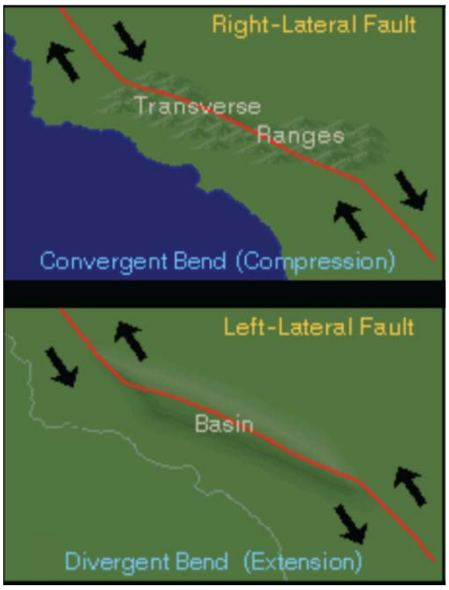
Northridge earthquake

- LA region
- January 17, 1994
- M 6.7
- 56 dead
- 1500 seriously injured
- 12,500 structures damaged
- cost $15 billion



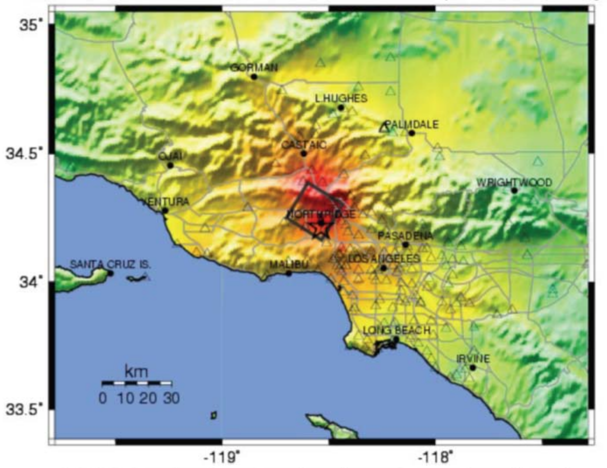
The bend



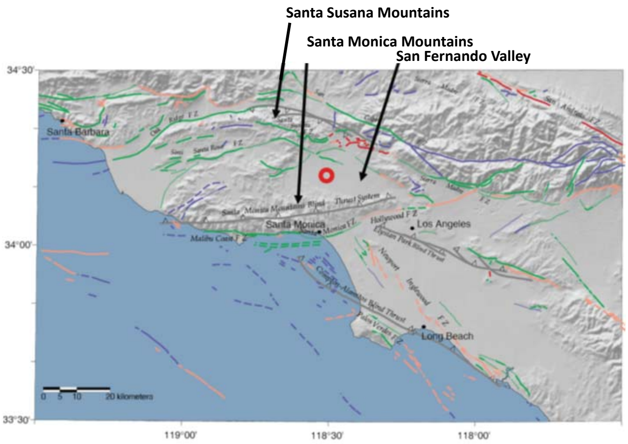


How Faulting Generates Earthquakes?

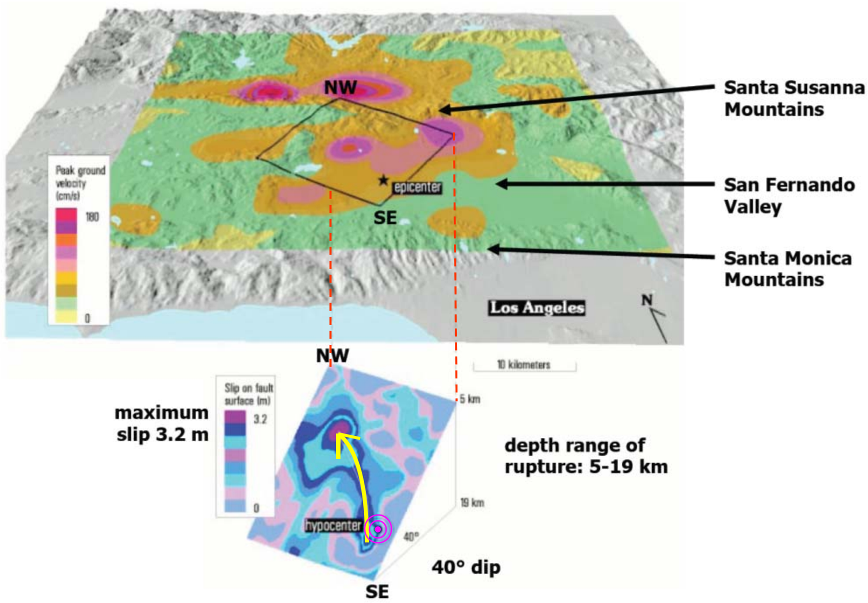
CISN Rapid Instrumental Intensity Map for Northridge Earthquake
Mon Jan 17, 1994 04:30:55 AM PST M 6.7 N34.21 W118.54 Depth: 18.0km ID:Northridge



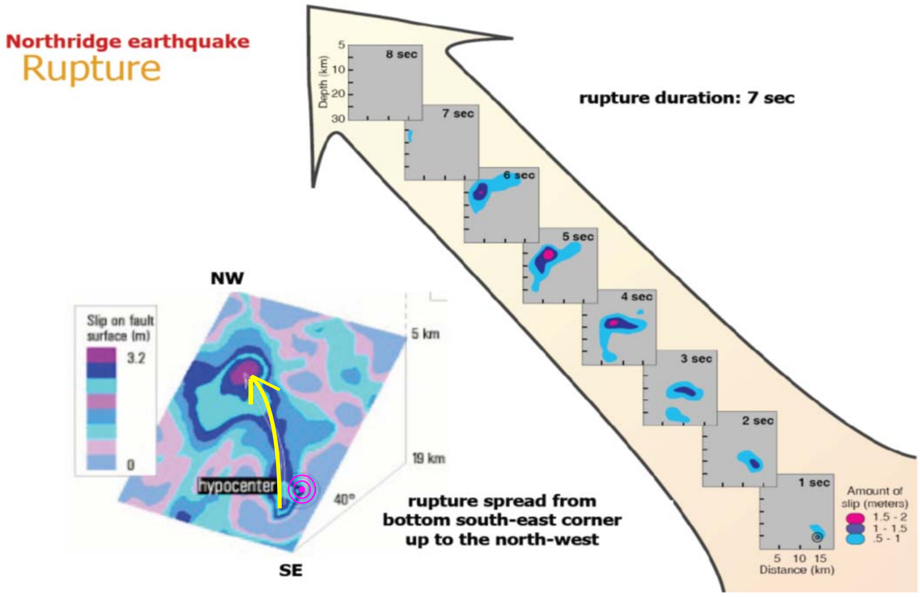
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



Ground motion map

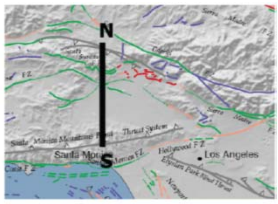


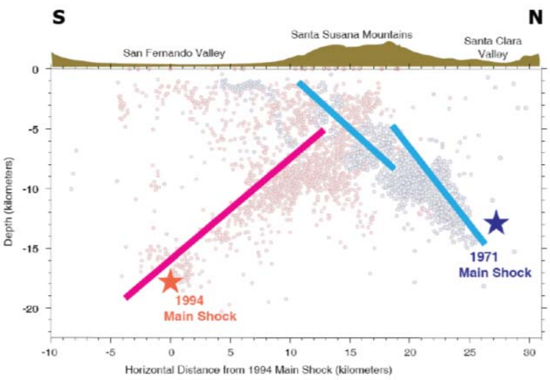
Rupture propagation



Thrust Fault

Compressional setting (NS)





Summary

Photo: Pilar Vilamore, Zabe Bruce and S. Misra

Summary

Photo: Tim Little

Summary

Photo source: Otago University Archive, NZ

Summary

Areal photo: GNS Science, New Zealand

Summary

Areal photo: GNS Science, New Zealand

Summary

Do you a pattern in the fracture?

Can you suggest the stress direction?

Photo: S Misra

Summary

Liquefaction

Photo: S Misra

Summary

Liquefaction

Photo: S. Elis

Summary

Liquefaction

Photo: S Elis

Summary

Landslide

Photo: Z Bruce

Summary

Rock-fall

Photo: J Thomson

Seismic Waves

- **How does the Earth Vibrate?**

Equations of motion
($F = ma$)

Elasticity relations
($\sigma_{ij} = \lambda \varepsilon_{ij} \delta_{ij} + 2\mu \varepsilon_{ij}$)

Elastic wave equations, describing the motion of waves through the Earth

Body waves (P and S)

Surface waves (Love and Rayleigh)

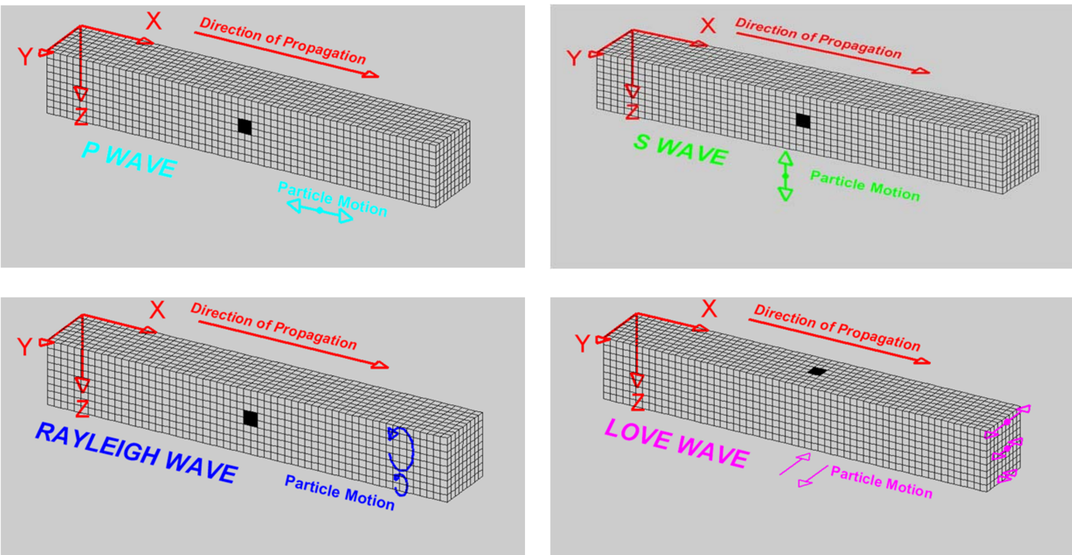
Normal modes (torsional and spheroidal)

$$V_P = \alpha = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}} \qquad V_S = \sqrt{\frac{\mu}{\rho}}$$

Seismic Waves

Known Elastic Constants	E	ν	μ	κ	λ
Shear modulus μ, Bulk modulus κ	$\frac{9\kappa\mu}{3\kappa+\mu}$	$\frac{3\kappa-2\mu}{6\kappa+2\mu}$	μ	κ	$\frac{3\kappa-2\mu}{3}$
Young's modulus E, Poisson's ratio ν	E	ν	$\frac{E}{2(1+\nu)}$	$\frac{E}{3(1-2\nu)}$	$\frac{E\nu}{(1+\nu)(1-2\nu)}$
Young's modulus E, Shear modulus μ	E	$\frac{E-2\mu}{2\mu}$	μ	$\frac{E\mu}{3(3\mu-E)}$	$\frac{\mu(E-2\mu)}{3\mu-E}$
Young's modulus E, Bulk modulus κ	E	$\frac{3\kappa-E}{6\kappa}$	$\frac{3\kappa E}{9\kappa-E}$	κ	$\frac{3\kappa(3\kappa-E)}{9\kappa-E}$
Shear modulus μ, Lame's constant λ	$\frac{\mu(3\lambda+2\mu)}{\lambda+\mu}$	$\frac{\lambda}{2(\lambda+\mu)}$	μ	$\frac{3\lambda+2\mu}{3}$	λ

Seismic Waves



http://web.ics.purdue.edu

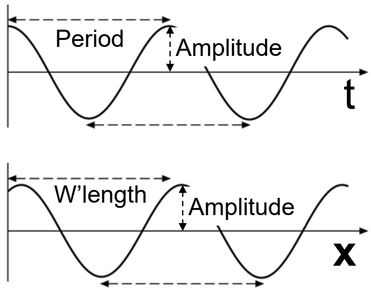
Wavelength, Period and frequency

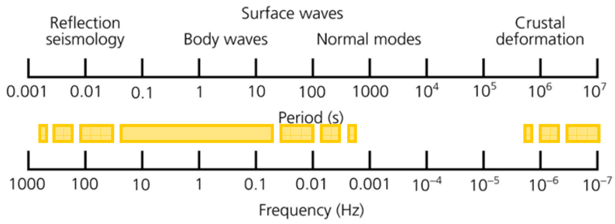
Wavelength (metres, m)
The distance between successive peaks/troughs

Period (seconds, s)
The time between successive peaks/troughs passing a point

Frequency (Hertz, Hz = s^{-1})
The number of oscillations in a fixed time

Amplitude (metres, m)
The wave height measured with respect to the rest position

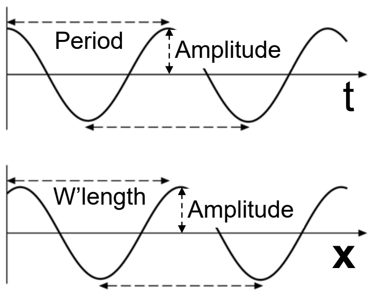




Harmonic wave parameters

Parameter	Symbol	Units	Key relationships
Frequency	f	Hz	$f = \omega/2\pi = 1/T$
Period	T	s	$T = 1/f = 2\pi/\omega$
Wavelength	λ	m	$\lambda = v/f$
Velocity	v	m s^{-1}	$v = f\lambda$
Angular frequency	ω	s^{-1}	$\omega = 2\pi f = 2\pi/T$
Angular wavenumber	k	m^{-1}	$k = \omega/v$

Shearer (1999; Table 3.1)



How to record earthquake generated seismic waves

- **<u>Challenges</u>**

How do we measure ground motion using an instrument that is itself attached to the ground, and moving?

How do we make reliable measurements of motion occurring over a very wide range of frequencies and amplitudes?

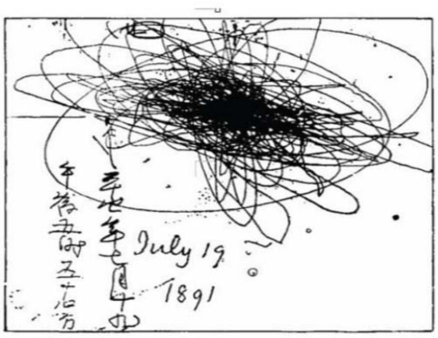
How to record earthquake generated seismic waves

Pendulum seismometer

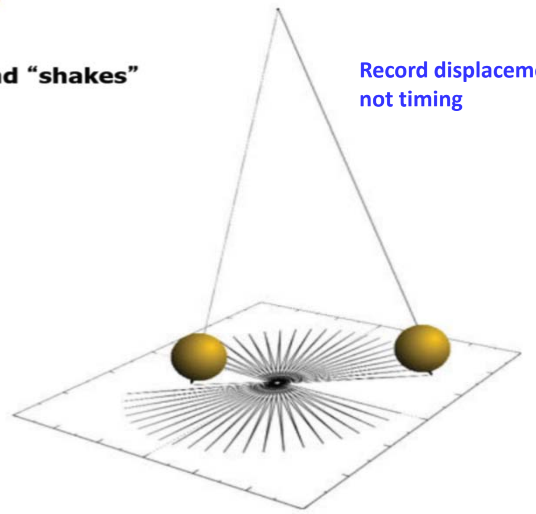
Mass stays still while ground "shakes"

[concept of *inertia*]

Record displacements only, not timing



Earthquake recording



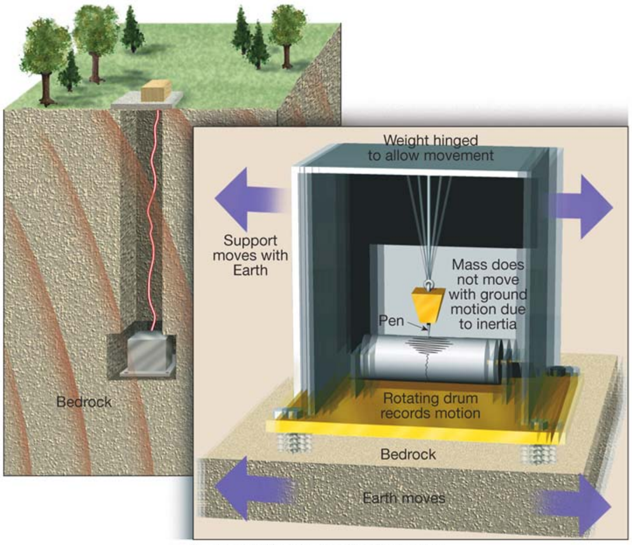
Initial direction of swing is dependent on the direction of the earthquake

How to record earthquake generated seismic waves

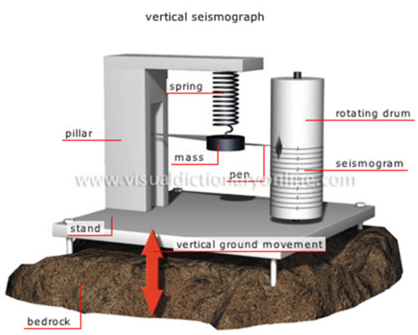
Zhang Heng
(78-139 AD)

Zhang Heng's seismoscope (Model)

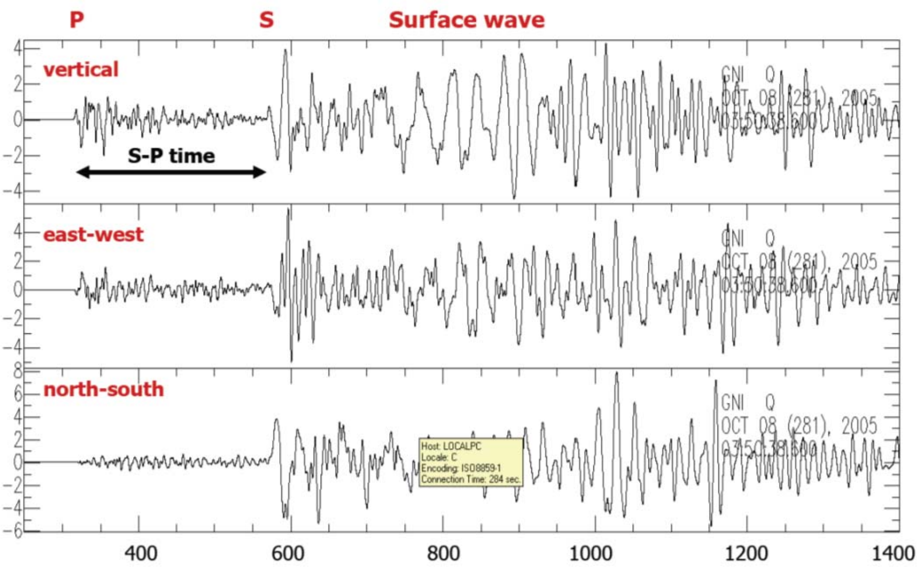
How to record earthquake generated seismic waves



OK. This one only can measures HORIZONTAL ground motions. What about the VERTICAL ones?

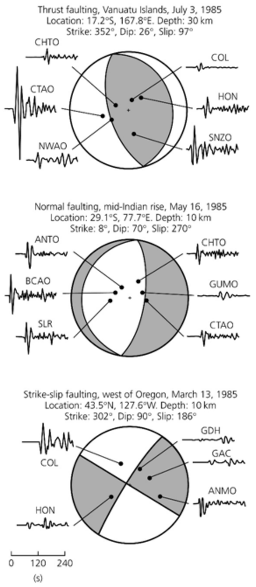


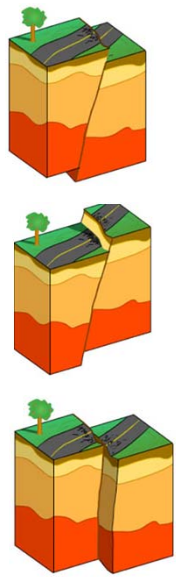
Typical Seismograms



Focal Mechanism - I

- **REVERSE FAULT**
- **NORMAL FAULT**
- **STRIKE-SLIP FAULT**

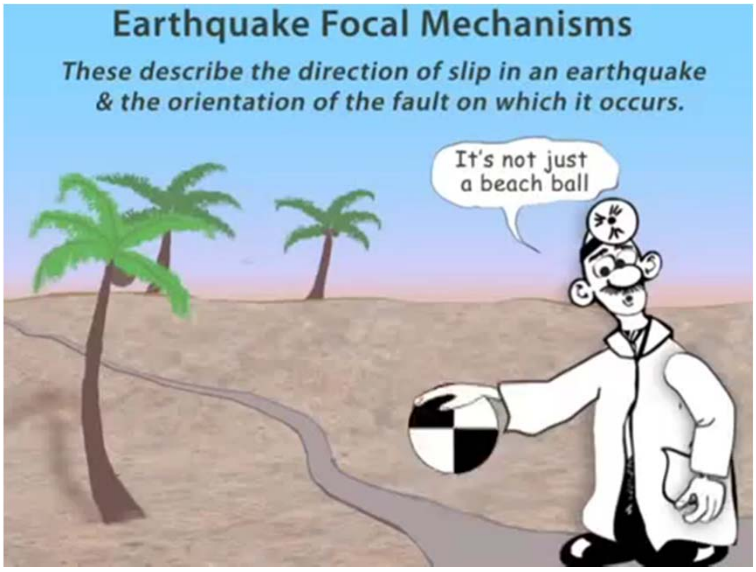




Remember, without other information (geological maps, aftershock patterns, geodetic information,...) it is not possible to distinguish the fault and auxiliary planes

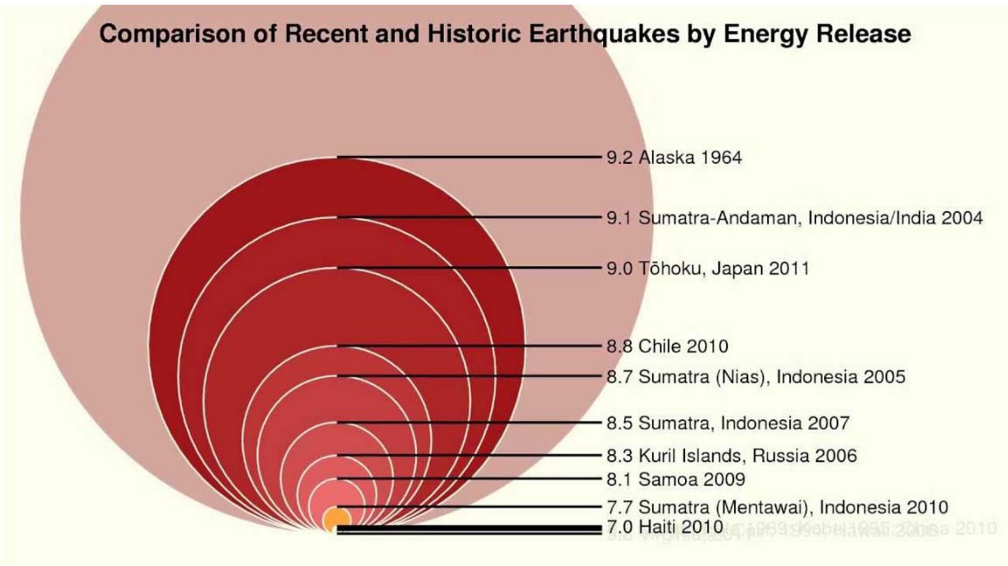
Focal Mechanism - II

- **Summary**



Shall upload the slide separately

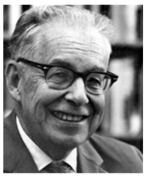
Magnitude of an earthquake



Magnitude of an earthquake

- **Richter Scale**

  A formula based on amplitude of the largest wave recorded on a specific type of seismometer and the distance between the earthquake and the seismometer.



C. F. Richter (CalTech)

$M_L = \log_{10}A - \log_{10}A_0(\delta) = \log_{10}[A/A_0(\delta)]$

A: maximum amplitude of seismograph (*Wood-Anderson Seismograph, 100 km distance from epicenter*),
A_0: empirical function of the epicenter distance (δ)

- **Modified Richter Scale**

  Beno Gutenberg modified the scale to include earch quakes of distant (>100 km) locations.

B. Gutengerg (CalTech)

Magnitude of an earthquake

- **Moment Magnitude Scale**

  The orientation, direction of fault movement and size of an earthquake can be described by the fault geometry and seismic moment. The differing shapes and directions of motion of the waveforms recorded at different distances and azimuths from the earthquake are used to determine the fault geometry, and the wave amplitudes are used to compute moment. The seismic moment is related to fundamental parameters of the faulting process

H. Kanamori (CalTech)

$M_0 = \mu S d$

μ: shear strength of the faulted rock; S: affected area of the fault plane; d: average displacement; **UNIT: dyne.cm**

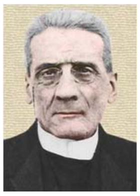
$M_w = 2/3 \log_{10}(M_o) - 10.7$

The two largest reported moments are 2.5 X 10^{30} dyn·cm (dyne·centimeters) for the 1960 Chile earthquake (M_S 8.5; M_W 9.6) and 7.5 X 10^{29} dyn·cm for the 1964 Alaska earthquake (M_S 8.3; M_W 9.2). M_S approaches it maximum value at a moment between 10^{28} and 10^{29} dyn·cm.

Magnitude of an earthquake

Mercalli Intensity Scale

Measures the released energy by taking into account of surface shaking.



Giuseppe Mercalli
Italy

I. Not felt	Not felt except by a very few under especially favorable conditions.
II. Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
III. Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV. Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V. Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI. Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII. Very Strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII. Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX. Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X. Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
XI. Extreme	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII. Extreme	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Next Lecture

VOLCANOES