Regional Training Workshop on Pacific Tsunami Warning Center
Enhanced Tsunami Products for ICG/CARIBE EWS
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Cartagena, Colombia

TWC Operations: Real-Time Earthquake Detection and Fast Source Characterization – Methods to determine Magnitude and Fault Mechanism

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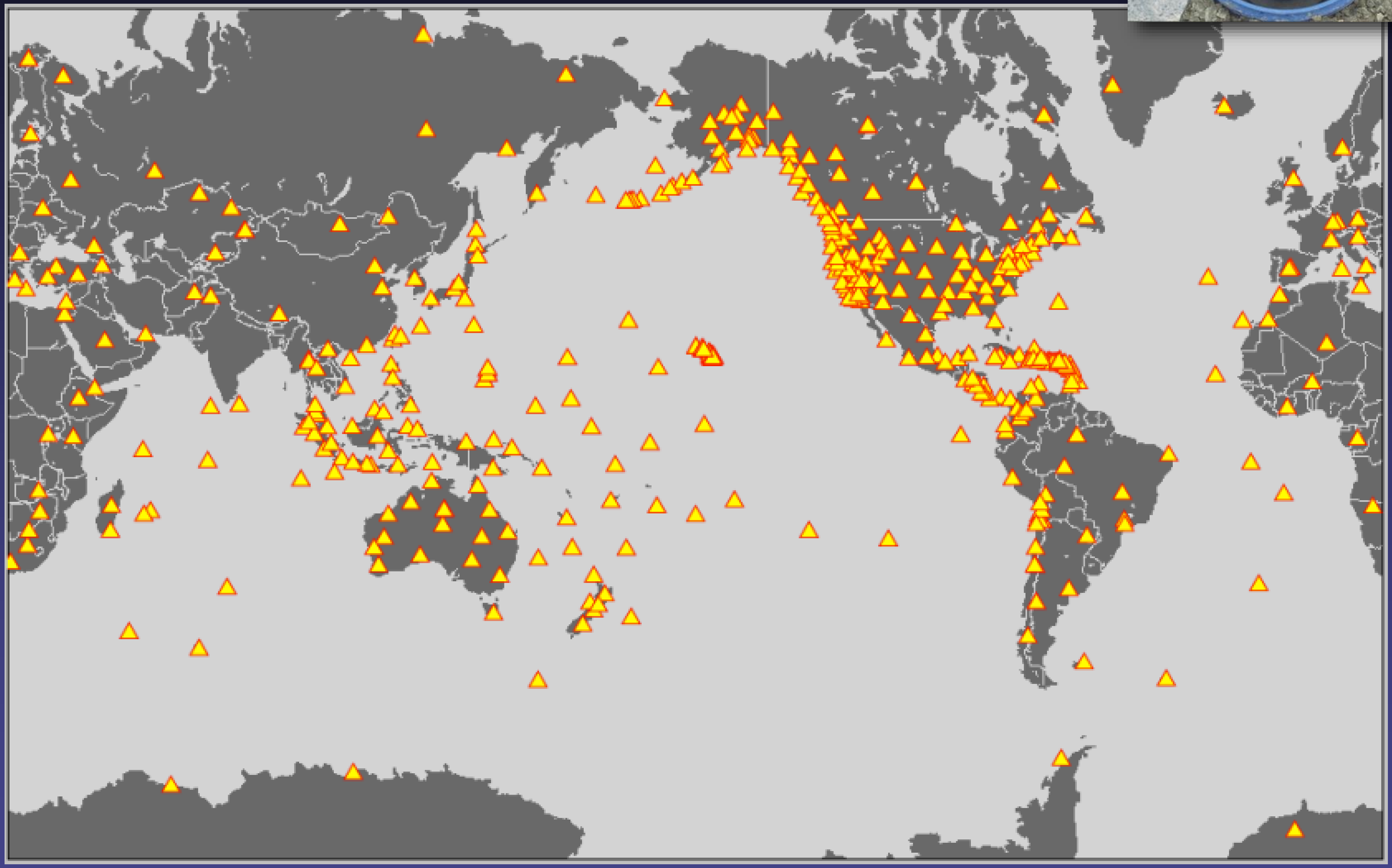
Locating Earthquakes

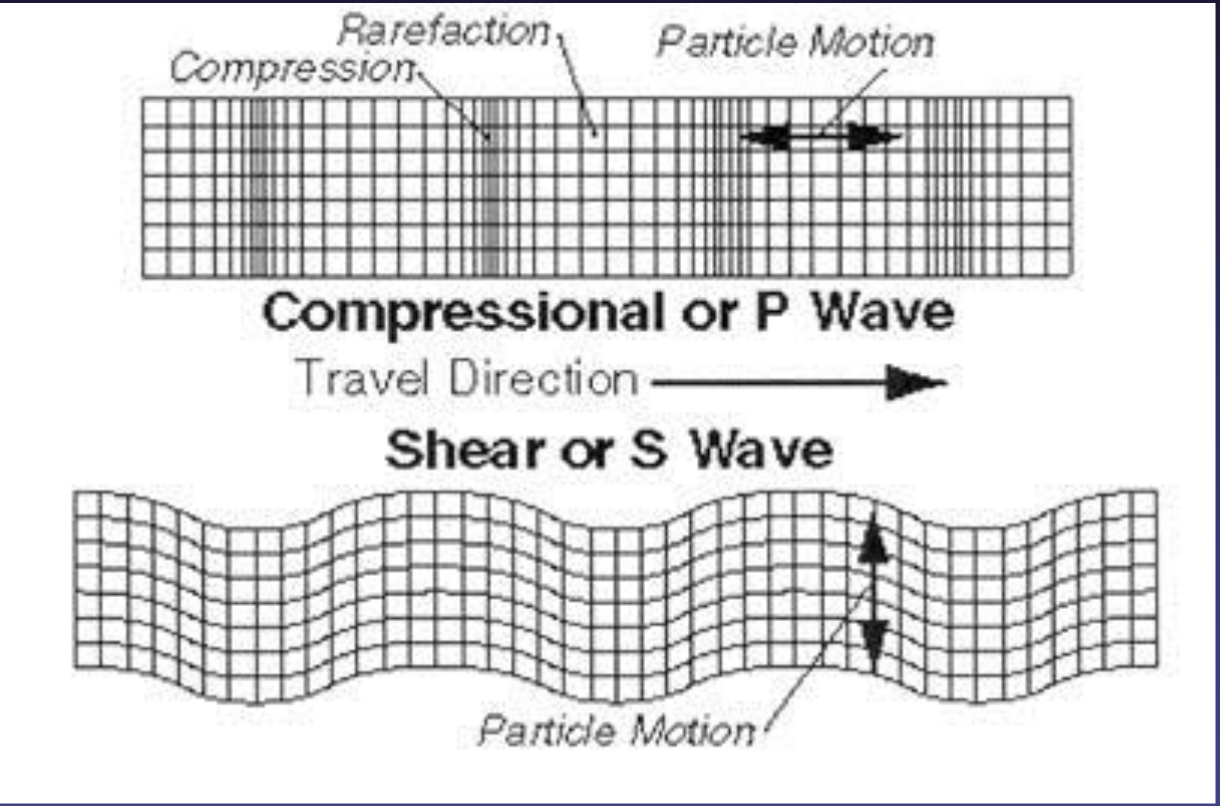
Seismic stations received by PTWC

(Global Seismic Network, USNSN, International Monitoring System, etc.)



Basic Types of Seismic Waves

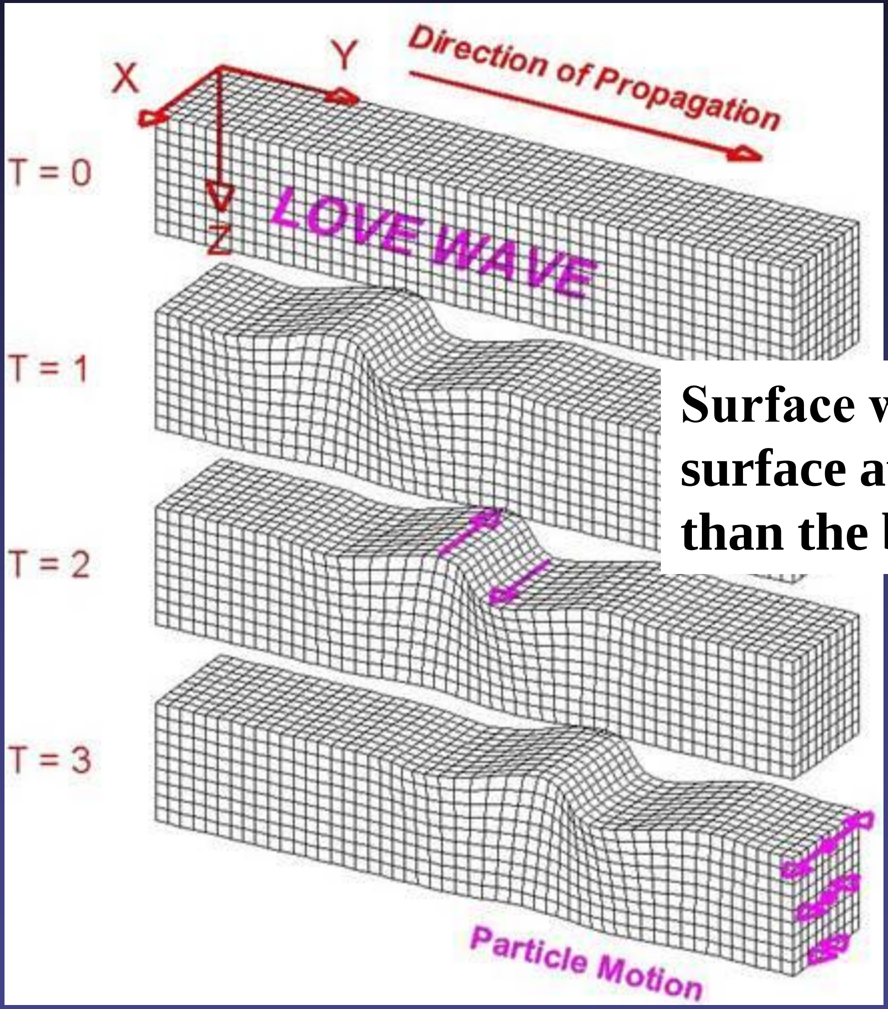
P and S Waves (also called body waves)



P waves are faster and travel at speeds of 6 – 14 km/s

Basic Types of Seismic Waves

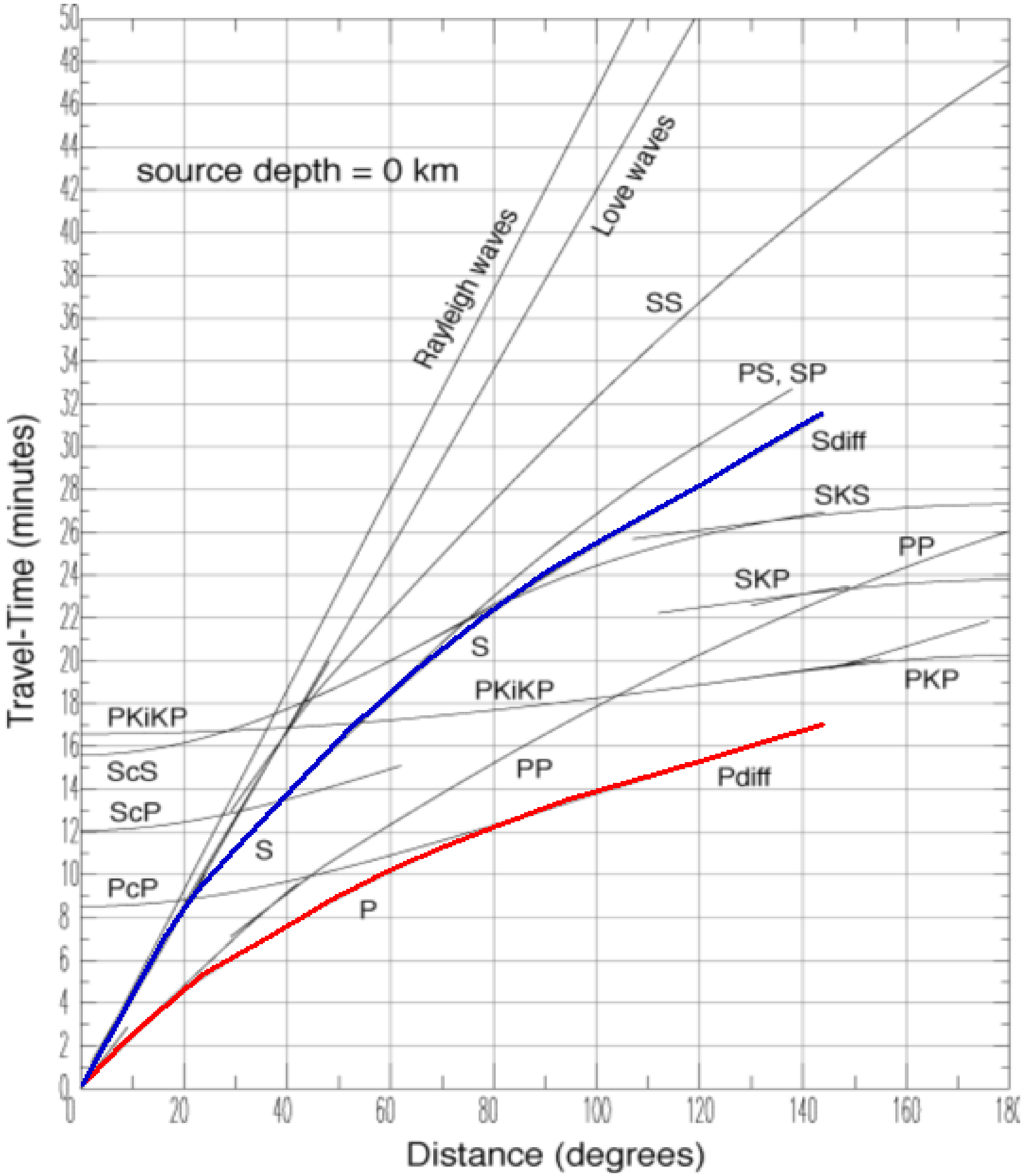
Surface Waves
(They do not travel through the earth)



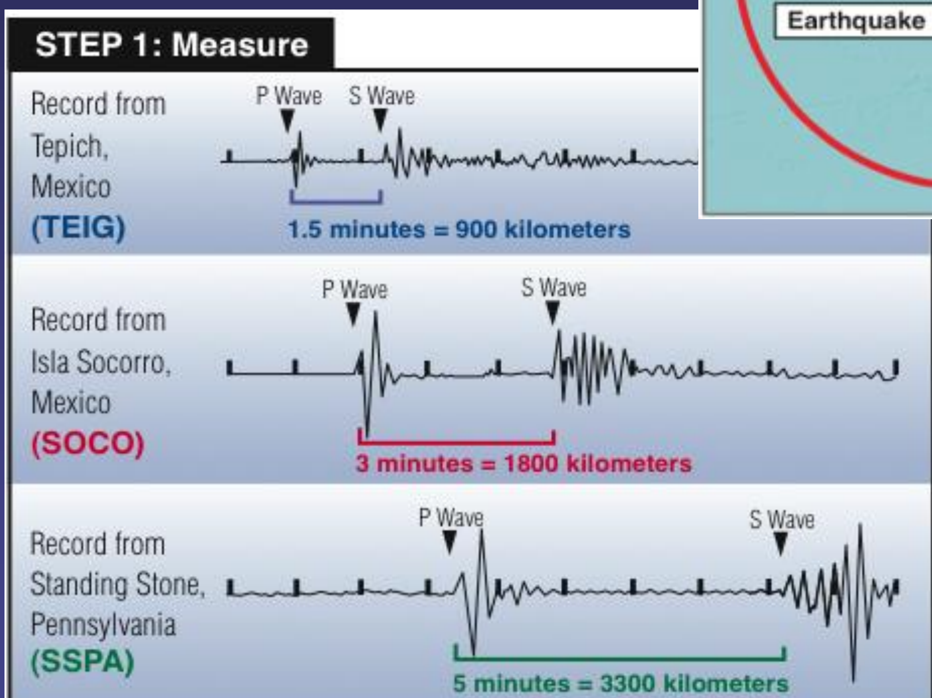
Surface waves travel along the Earth's surface at speeds of ~ 3/km/sec, slower than the body waves.

The two basic types of body waves, P &S travel at different speeds. Hence If you know elapsed time between the P & S wave you can use the Travel Time table to find how far you are from the earthquake.

Its analogous to using the time between seeing the lightning bolt and the thunderclap to determine how far you are from the lightning strike.



Locate the earthquake



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Faulting

Types of Earthquake Faulting - Tectonic

- Normal fault
- Thrust or reverse fault
- Lateral slip or strike-slip fault

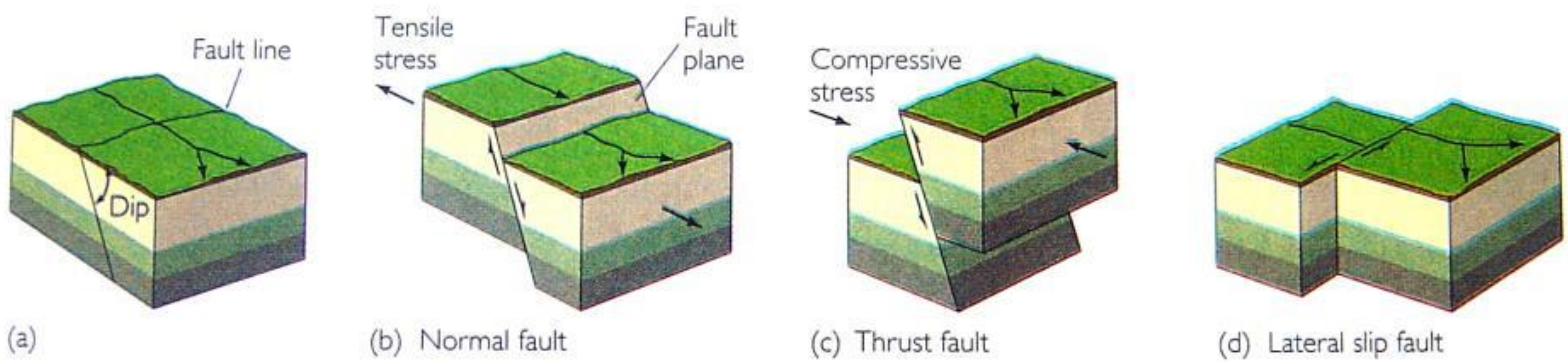


FIGURE 18.12 The three main types of fault movements that initiate earthquakes, and the stresses that cause them: (a) situation before movement takes place; (b) normal fault due to tensile stress; (c) thrust (or reverse) fault due to compressive stress; (d) lateral slip (or strike-slip) fault due to shearing stress.

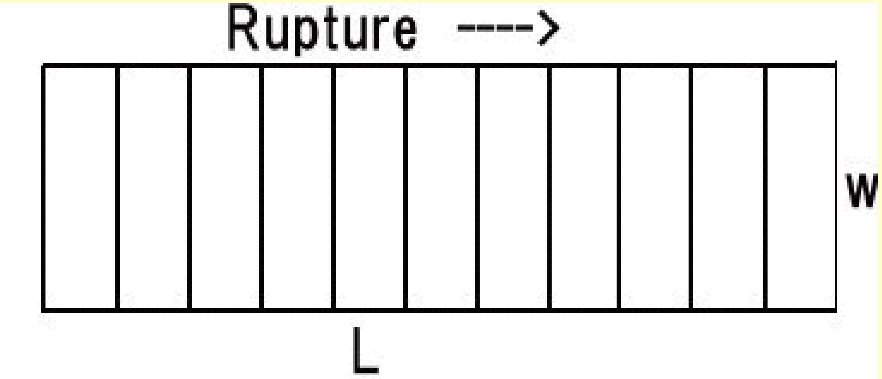
Earthquake Rupture complexity

Great Earthquakes

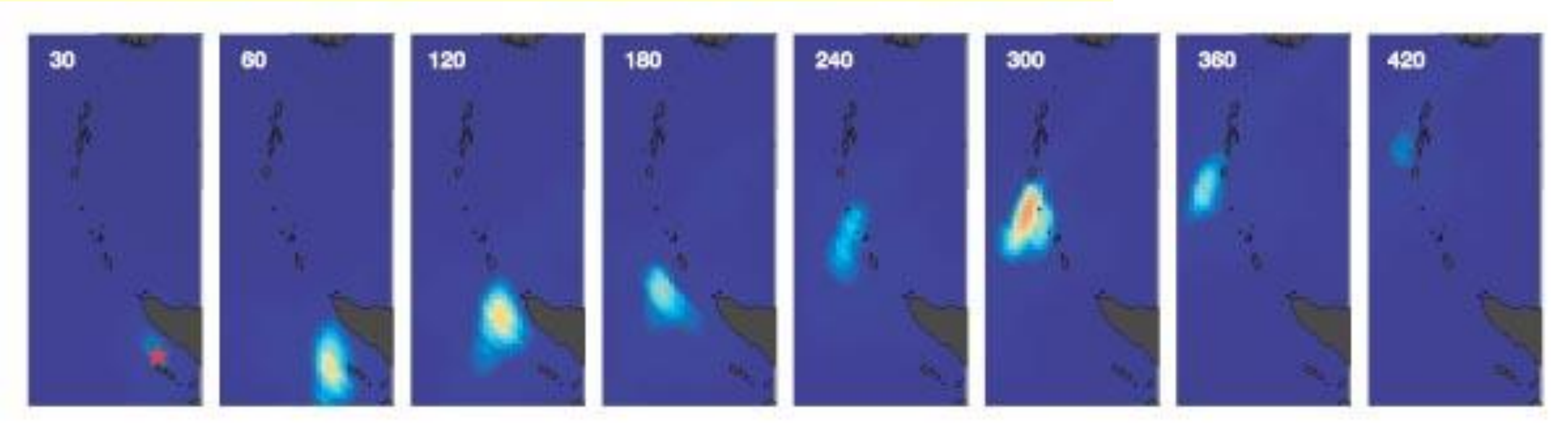
- **Shake for a long time (10s sec to 2-3 minutes)**
- **Rupture for 100s miles**

2004 Sumatra earthquake

Haskell Line Source
Dislocation Source



Energy Release imaged by Japan HINET Array



Ishii et al., 2005

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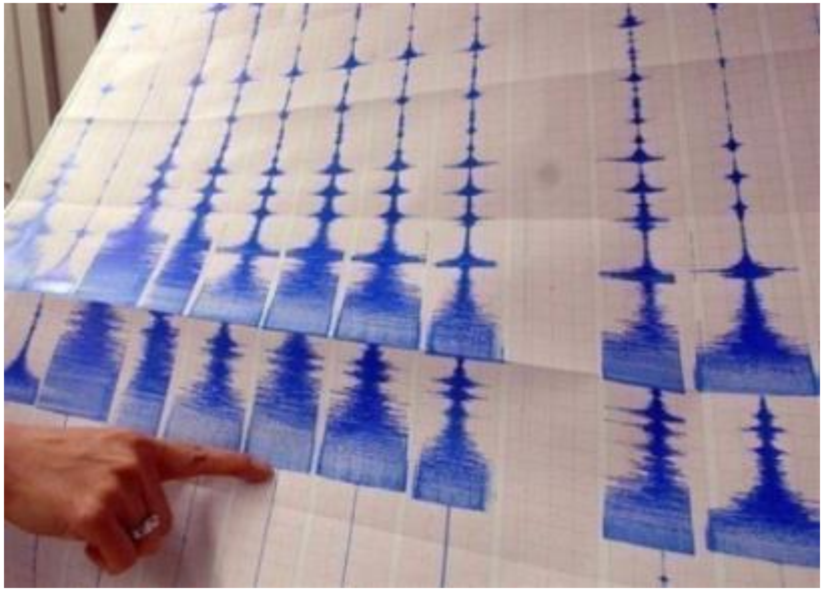
Earthquake Magnitude & Energy

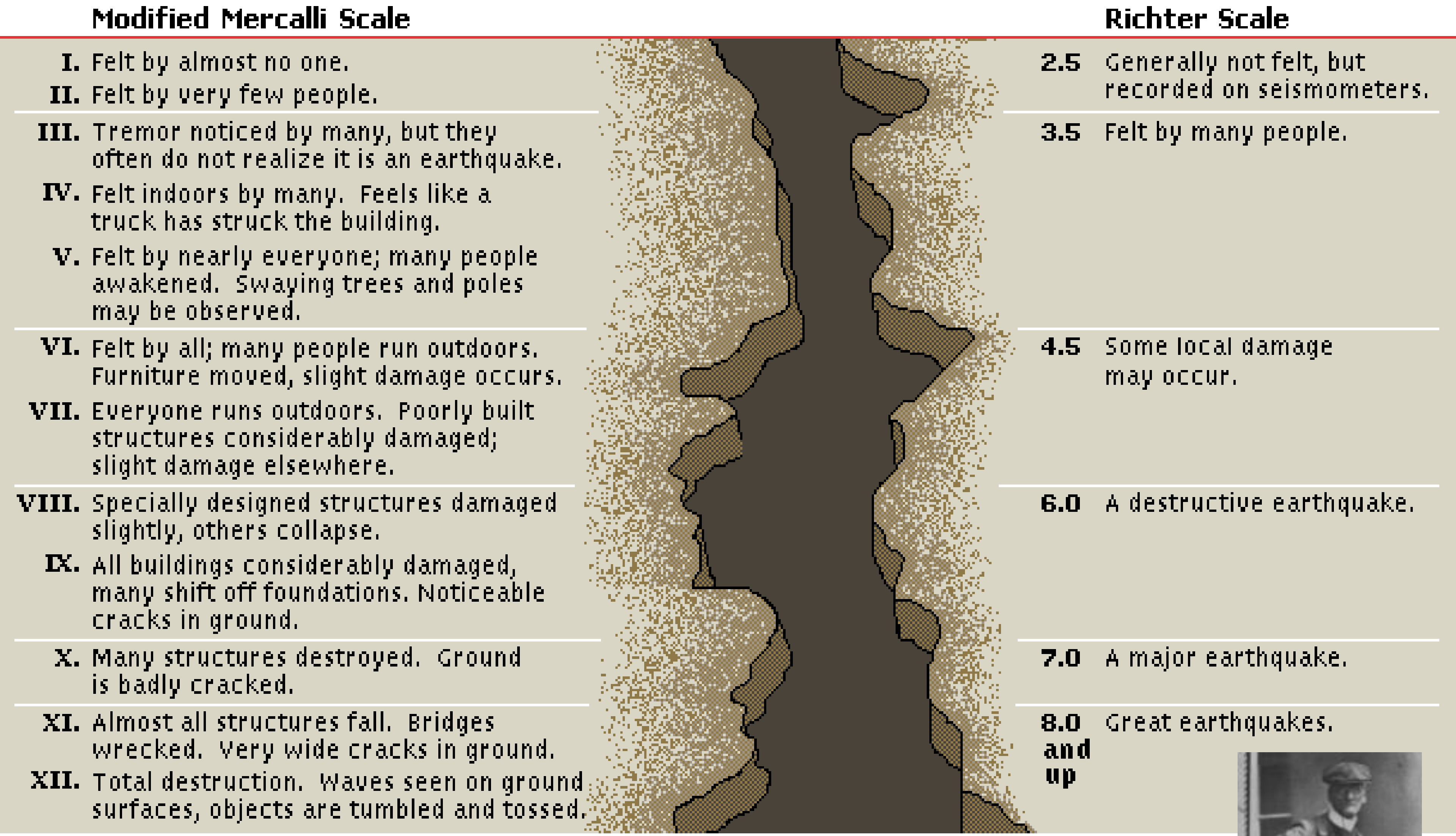
M7, PNG earthquake



Measuring Earthquake size

- **Historical measures (Macroscopic)**
  - Fatalities
  - Maximum shaking
  - Area of intense shaking
- **Do not correlate well from one quake to next**
  - Because the damage and devastation produced by an earthquake will depend on
    - its location, the distance from the epicenter
    - the building designs,
    - surface material (rock or dirt) the buildings rest on
    - depth
    - proximity to populated regions, as well as its "true" size.

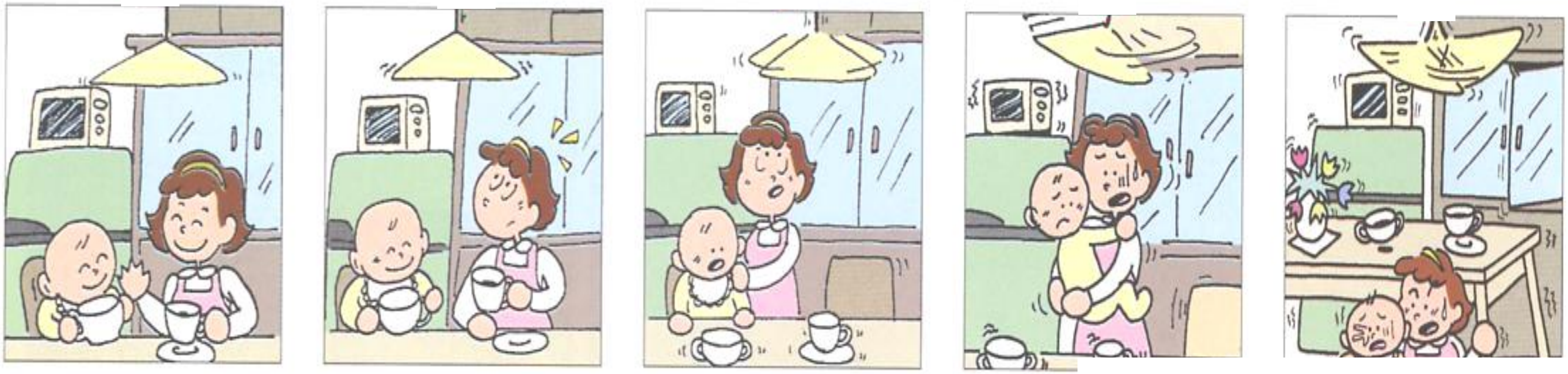
Measuring Earthquake size (macroscopic)
Modified Mercalli Intensity



http://encarta.msn.com/media_461531420/earthquake_scales_modified_mercalli_and_richter.html

Giuseppe Mercalli
(1850-1914)

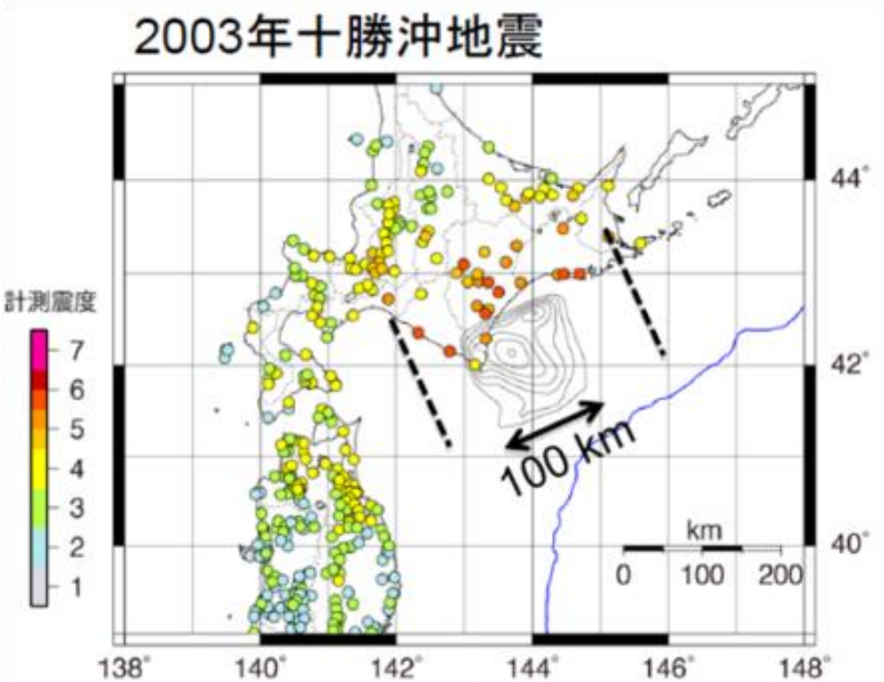
JMA Seismic Intensity Scale

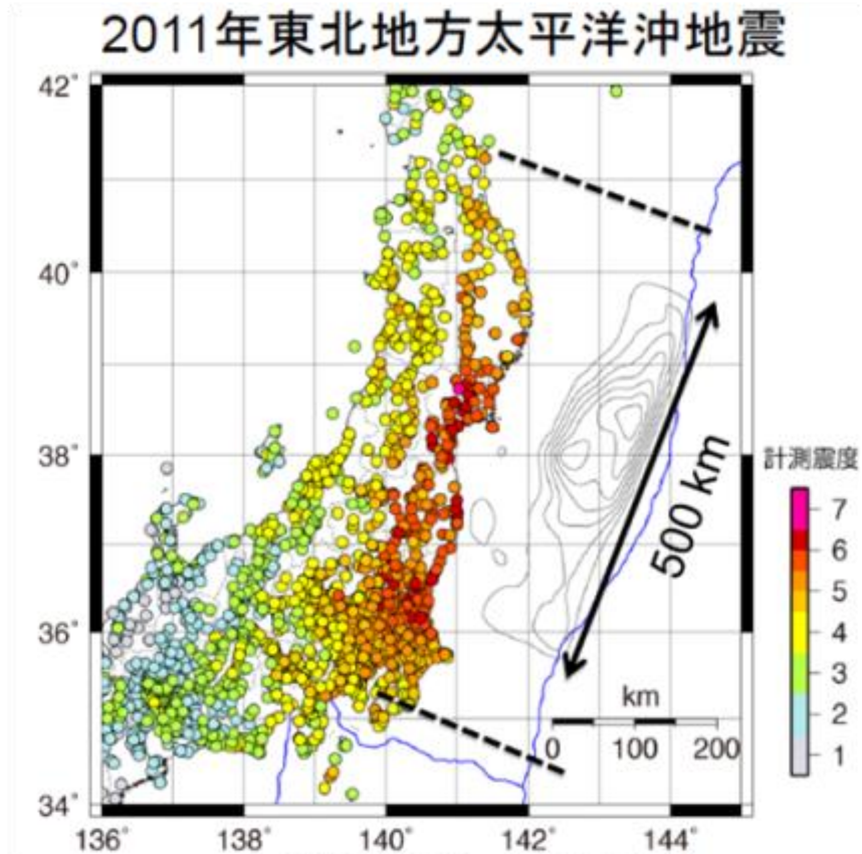


MMI VI VII

MMI VIII IX X XI XII

Magnitude and Intensity



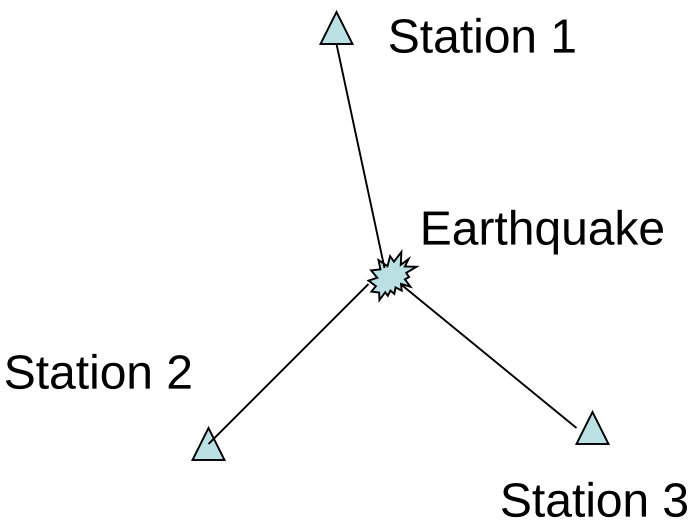


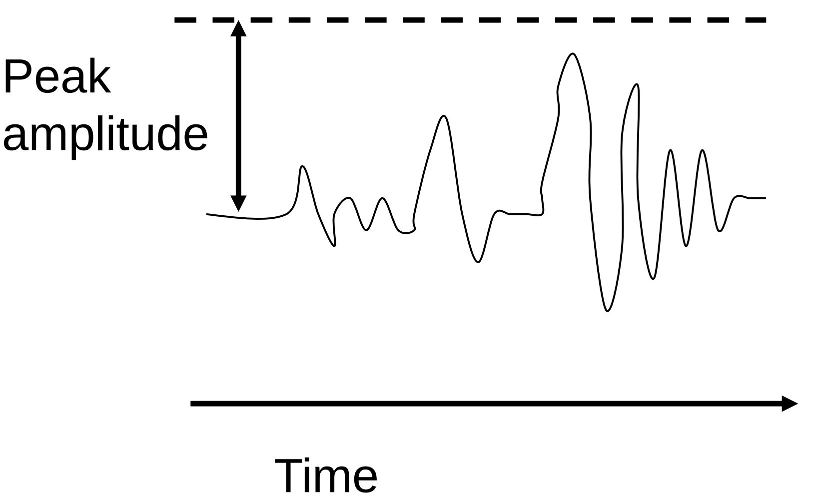
M:8.0

M: 9.0

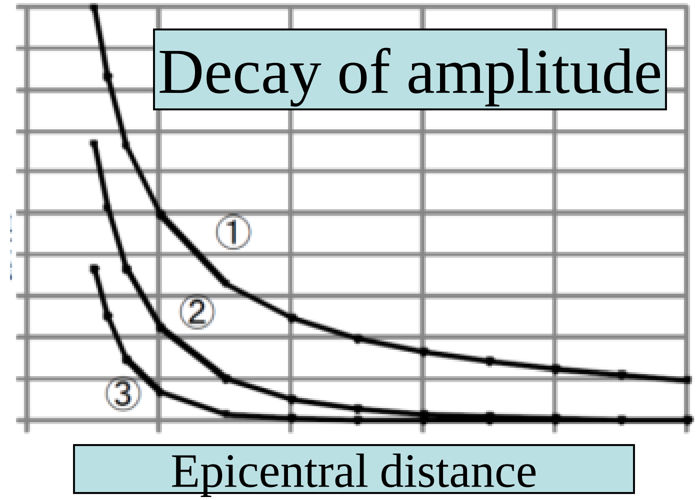
Instrumental Magnitude measures

- Originally derived as size based on seismograms, e.g., maximum or "peak" ground motion measured
- Measure of amount of energy released by earthquake
- Base-10 logarithmic scale
- 1st magnitude scale by Charles Richter (1935) to measure California earthquakes..
- Now, many scales for various observational conditions.





Earthquake Magnitude



General form of Magnitude scales:

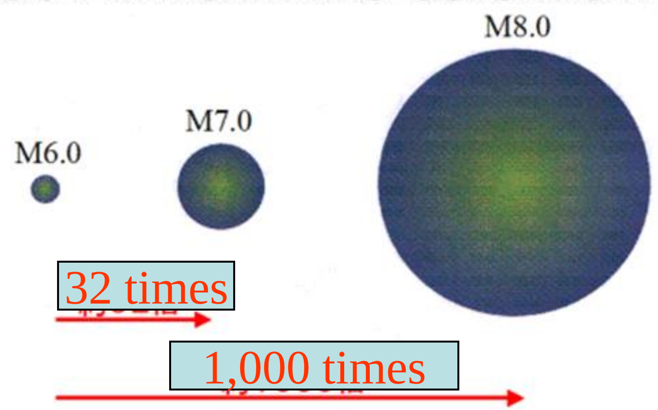
$$M = \log(A/T) + F(h, \Delta) + C$$

A is the amplitude of the signal

T is its dominant period

F is a correction for the variation of amplitude with the earthquake's depth h and distance Δ from the seismometer

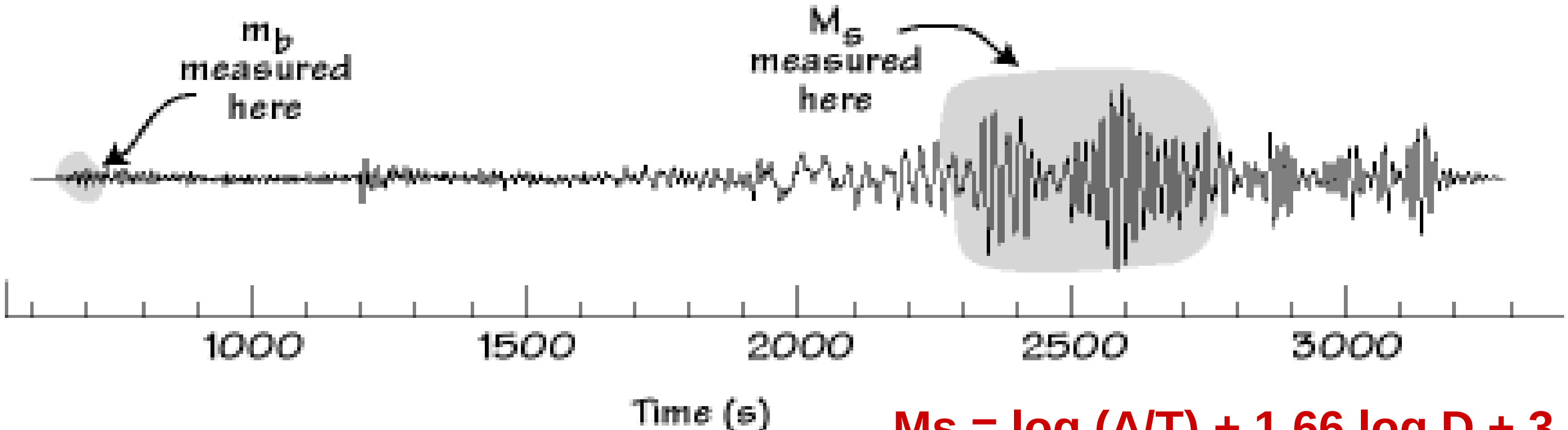
C is a regional scale factor



Richter and Gutenberg's

Tele-seismic (distant) earthquake magnitudes

Body wave Magnitude mb and Surface wave and M_S



mb = log (A/T) +Q(D,h)

T, the period in seconds, is restricted to 0.1 <= T <= 3.0

A, the ground amplitude in micrometers, is not necessarily the maximum in the P wave group.

Q is a function of distance (**D**) and depth (**h**)

where D >= 5°.

Ms = log (A/T) + 1.66 log D + 3.3

A is the maximum ground amplitude in micrometers (microns) of the vertical component of the surface wave within the period range 18 <= **T** <= 22.

D is the distance in geocentric degrees (station to epicenter) and 20° <= D <= 160°.

No depth corrections are applied, and Ms magnitudes are not generally computed for depths greater than 50 kilometers.

Types of Magnitude Scales

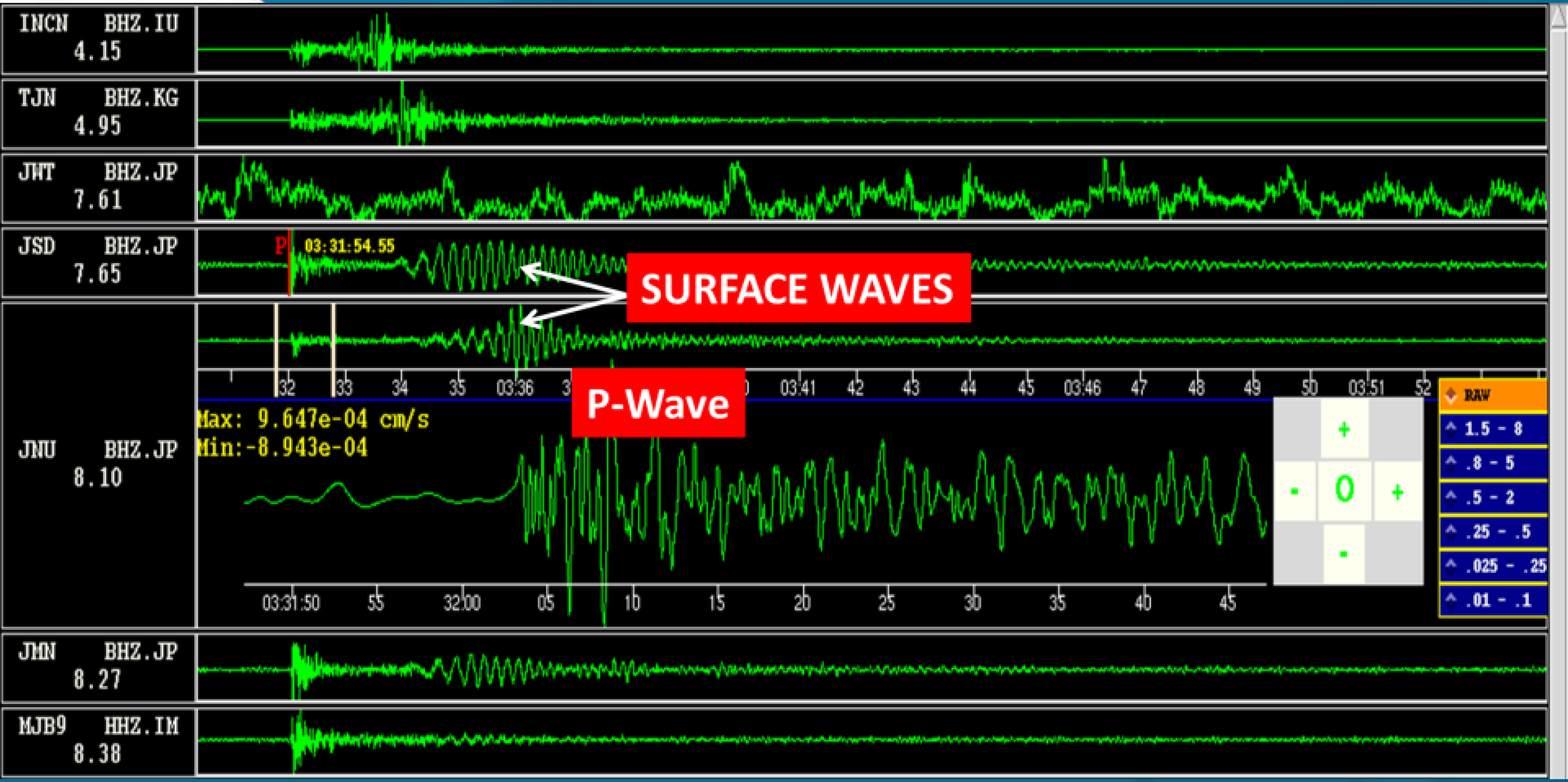
			Period Range
M_L	Local magnitude (California)	regional S & surface waves	0.1-1 sec
M_j	JMA (Japan Meteorol. Agency)	regional S & surface waves	5-10 sec
m_b	Body wave magnitude	teleseismic P waves	1-5 sec
M_s	Surface wave magnitude	teleseismic surface waves	20 sec

The methods below overcome the effects of Saturation:

Mwp	P-wave moment magnitude	teleseismic P waves	10-60 sec
M_w	Moment magnitude	teleseismic surface waves	> 200 sec
M_m	Mantle magnitude	teleseismic surface waves	> 200 sec

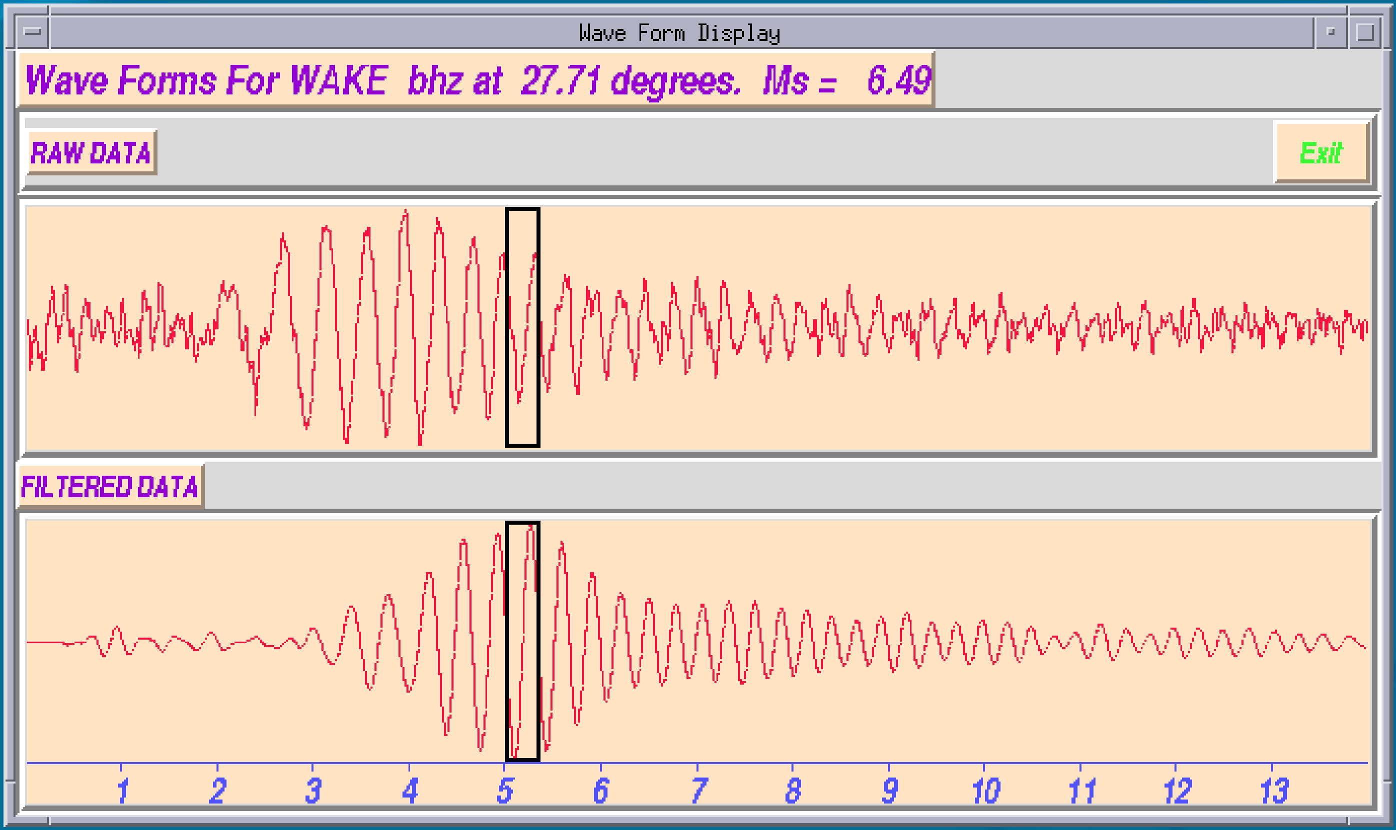
Ref: USGS Seismology and Tsunami Warnings, 2006 (Earthquake Source)

Korea Nuclear Explosion



Mb = 6.3, Ms = 4.9

DISPLAY
TO
REVIEW
SURFACE
WAVE
MAGNITUDE

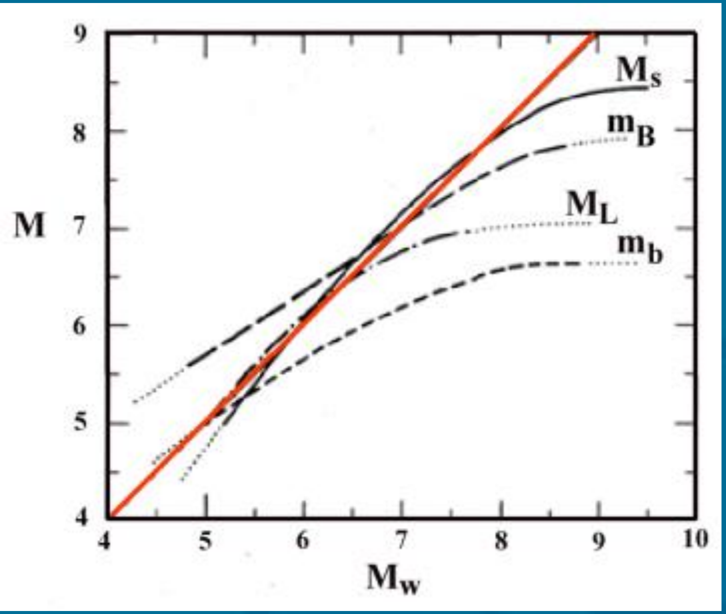


Saturation

- Ml, Ms and mb all suffer from saturation.
- Occurs for 2 reasons:

Time window saturation:
Magnitude is calculated for time window that is less than duration of rupture
(particularly affects mb)

Spectral saturation:
Wavelength of wave too short to "see" all of rupture
(affects mb, Ml, and Ms)



Kanamori 1983

Saturation

How do we overcome saturation?

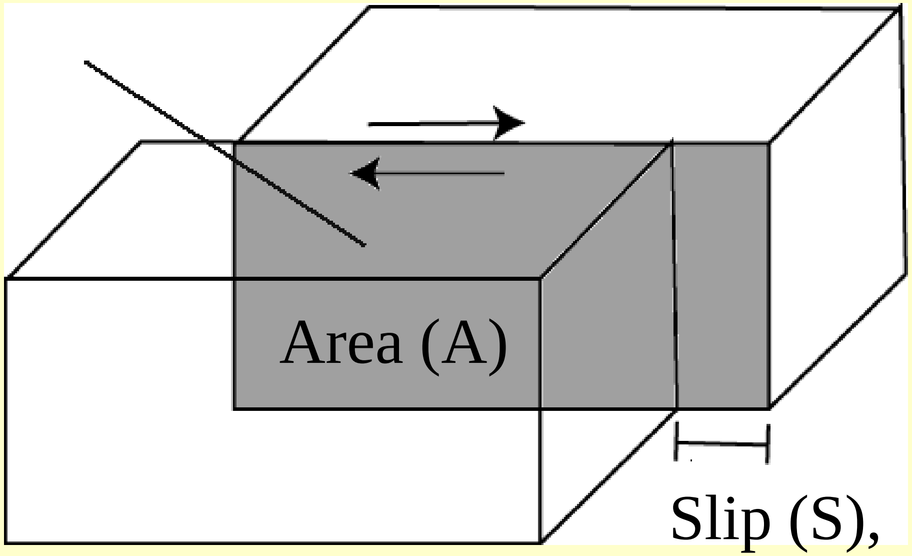
=> Examine Longer Period Waves!

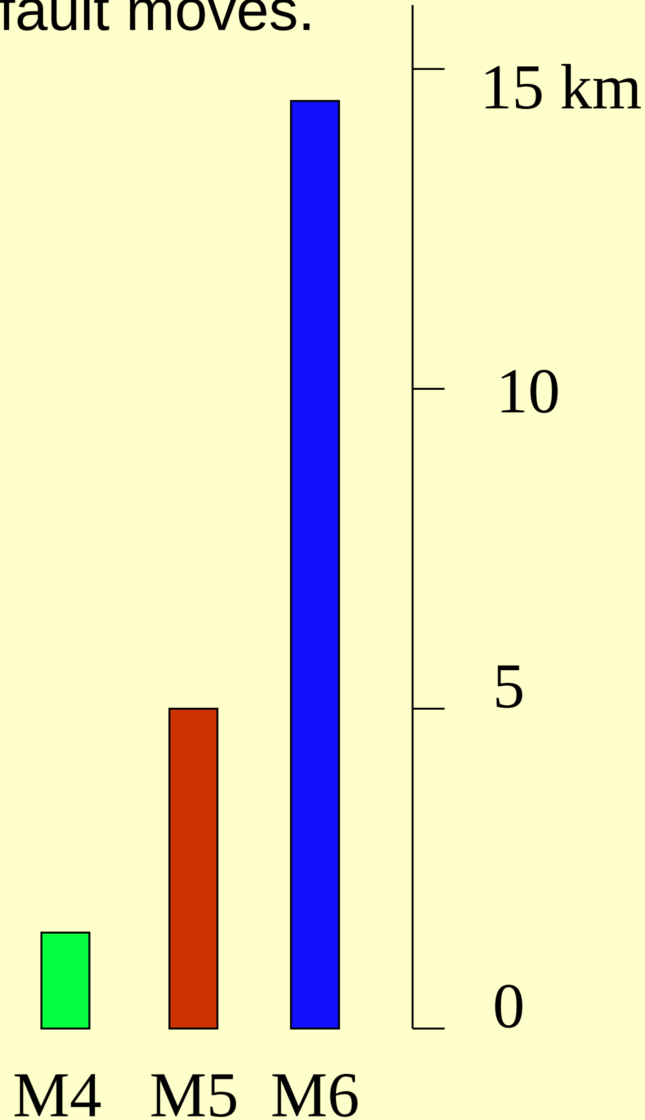
Enter Mwp, Mantle Magnitude
And
The CMT

Earthquake size - Seismic Moment, M_0

Mechanical measure of EQ size

Mathematically, how big an area and how far fault moves.





Seismic Moment = (Rigidity)(Area)(Slip)

$$M_0(t) = \mu \cdot S \cdot \Delta u(t)$$

Mw=2/3logMo – 10.7

Moment Magnitude

Moment magnitude scale Mw

- Introduced in 1979 by Hanks and Kanamori based on seismic moment.

$$Mw = \frac{2}{3}(\log \frac{Mo}{N*m} - 9.1) = \frac{2}{3}(\log \frac{Mo}{dyne*cm} - 16.1)$$

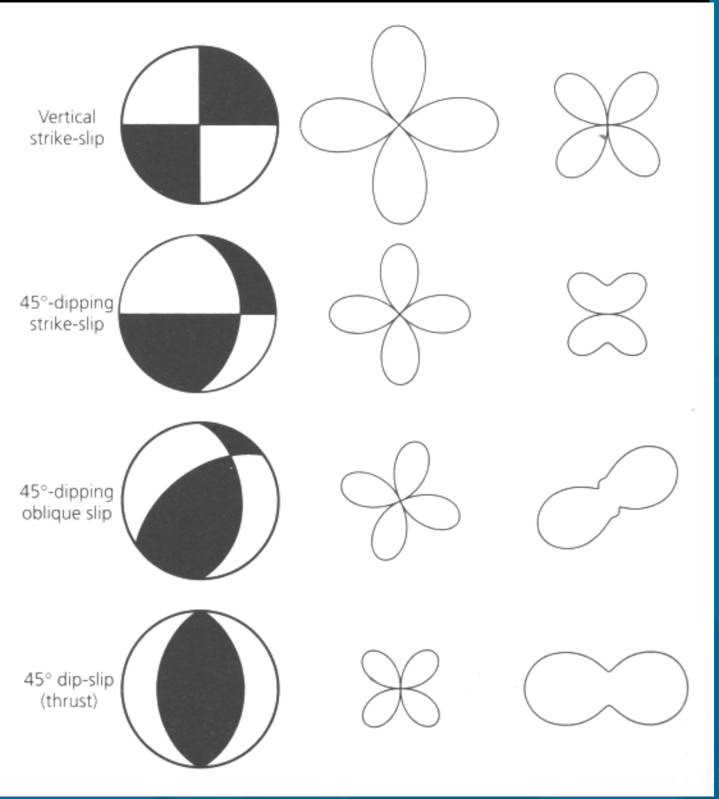
- Based on source parameter (**Mo**) that is not frequency dependent. e.g., unlike other magnitude scales, does not saturate at upper end.
- Mw used estimate of large earthquake magnitudes.

Moment Magnitude - Mw

- **Calculated from seismic moment (Mo). Therefore *related to fault slip* not energy released as waves. More relevant for tsunamis, less relevant for damage from ground shaking.**

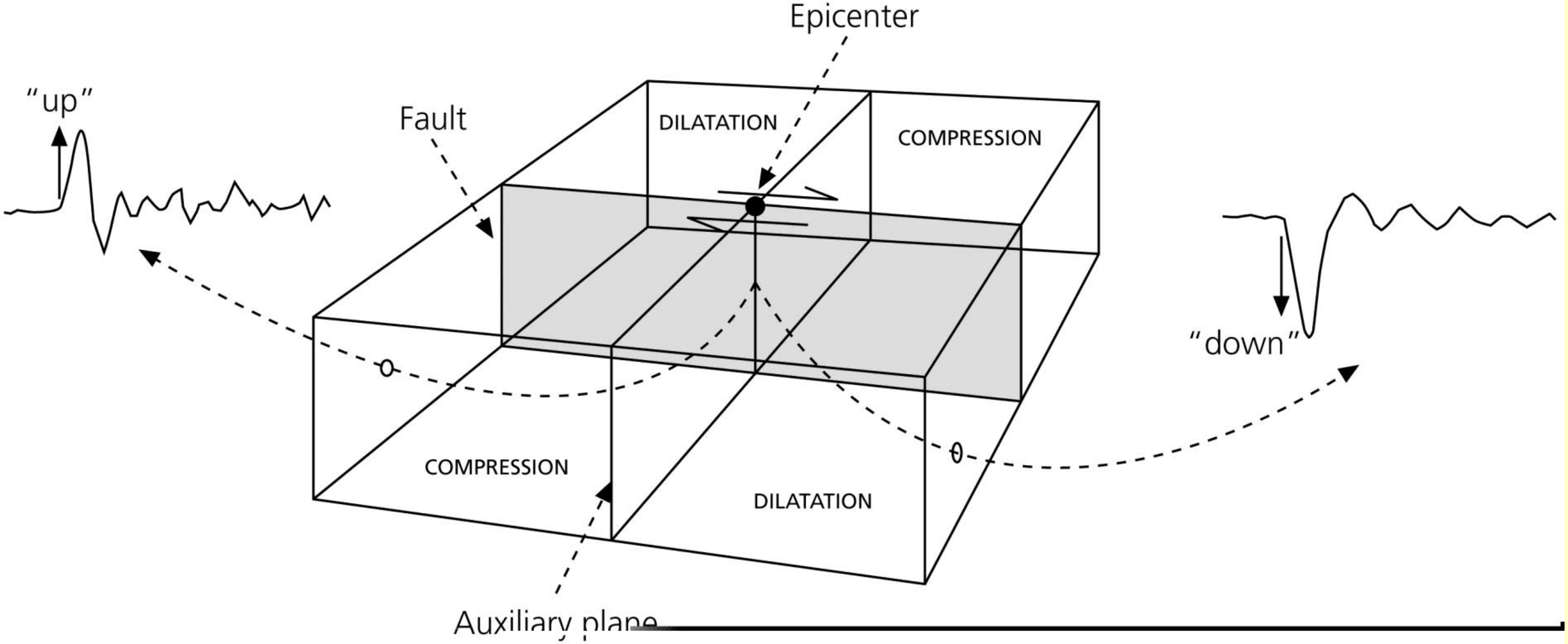
- **Harvard CMT and NEIC calculate Mw from the moment tensor solution.**

- **Fit shape and amplitude of long period surface waves to synthetics to model moment tensor and Mo.**

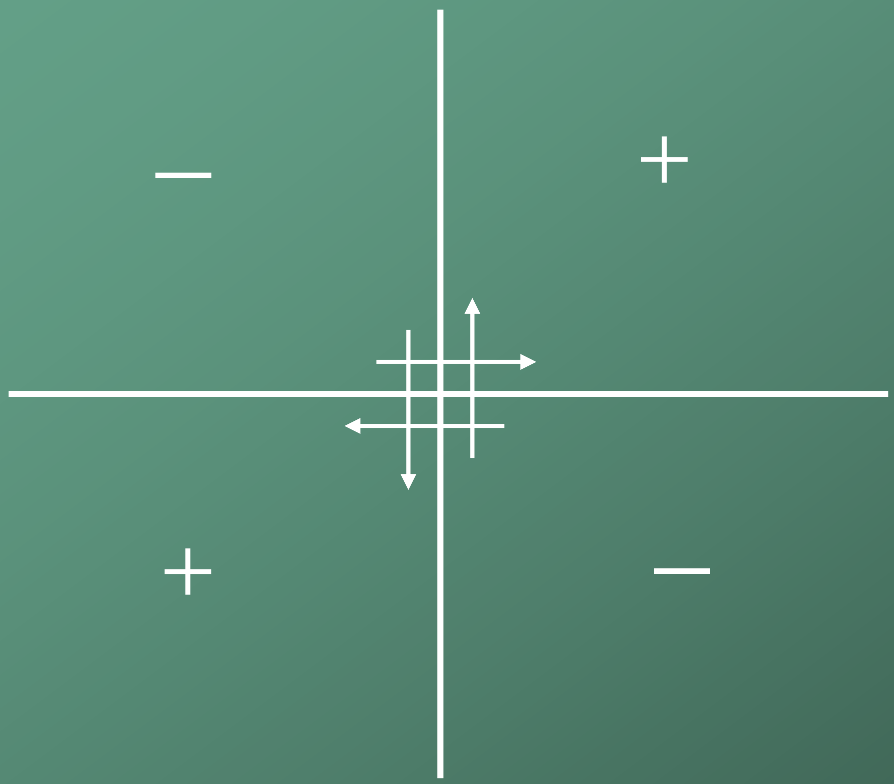


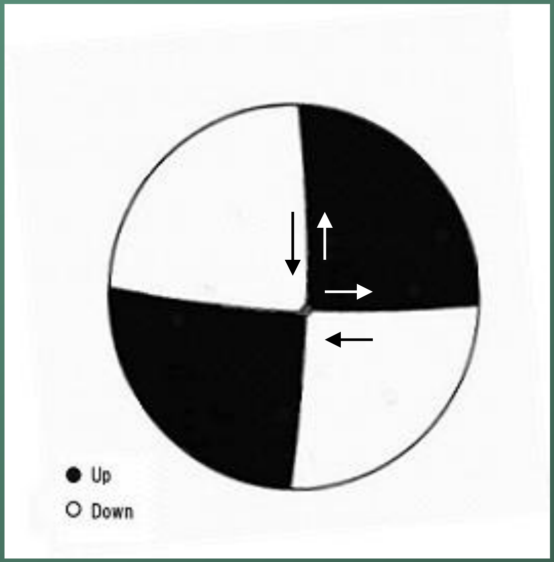
Stein and Wysession, "An Introduction to seismology, earthquakes and Earth structure"

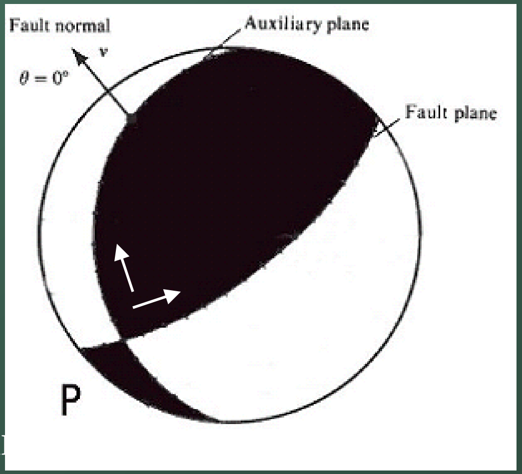
Figure 1.1-7: First motions in relation to fault orientation.



P-wave first motions







Gives the fault geometry, but not the magnitude

USGS
science for a changing world

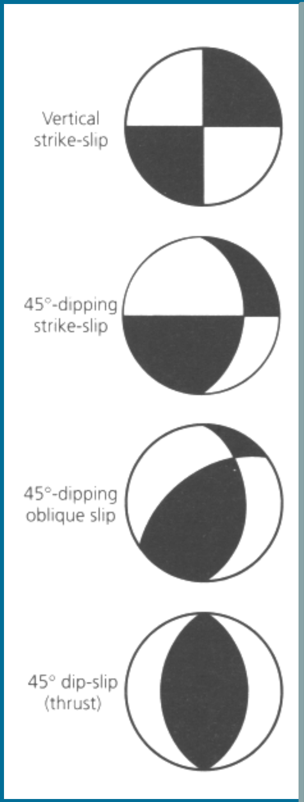
This type more likely to produce la

Earthquake Focal Mechanisms

These describe the direction of slip in an earthquake & the orientation of the fault on which it occurs.

Centroid Moment Tensor (CMT)

- The CMT characterizes the geometry of the earthquake and can be used to compute the surface deformation.
- Fits shape and amplitude of seismic waves to synthetics to model moment tensor and energy released.
- Usually based on longer period and very slow surface waves. CMT required ~90 minutes of wait until there was enough data to compute.



Strike-Slip
Pure horizontal motion

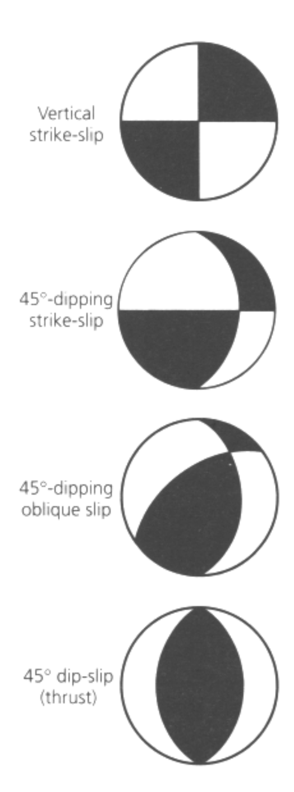
Oblique, motion has horizontal and vertical components

Thrust
Pure Vertical Motion

Centroid Moment Tensor (CMT)

- **Problem with using CMT for tsunami hazard:**

  => It took too long.
- **That changed with the introduction of the W-phase CMT by Kanamori and Rivera in 2008. W-phase travels several times faster than surface waves.**



Strike-Slip
Pure horizontal motion

Oblique, motion has horizontal and vertical componen

Thrust
Pure Vertical Mot

W-phase CMT method gives both the fault geometry and an authoritative magnitude 20-25 minutes after the earthquake. It is the primary reason why PTWC can now quickly issue a reliable forecast.

CMT via Wphase Inversion Japan 2011, Mw=9.1

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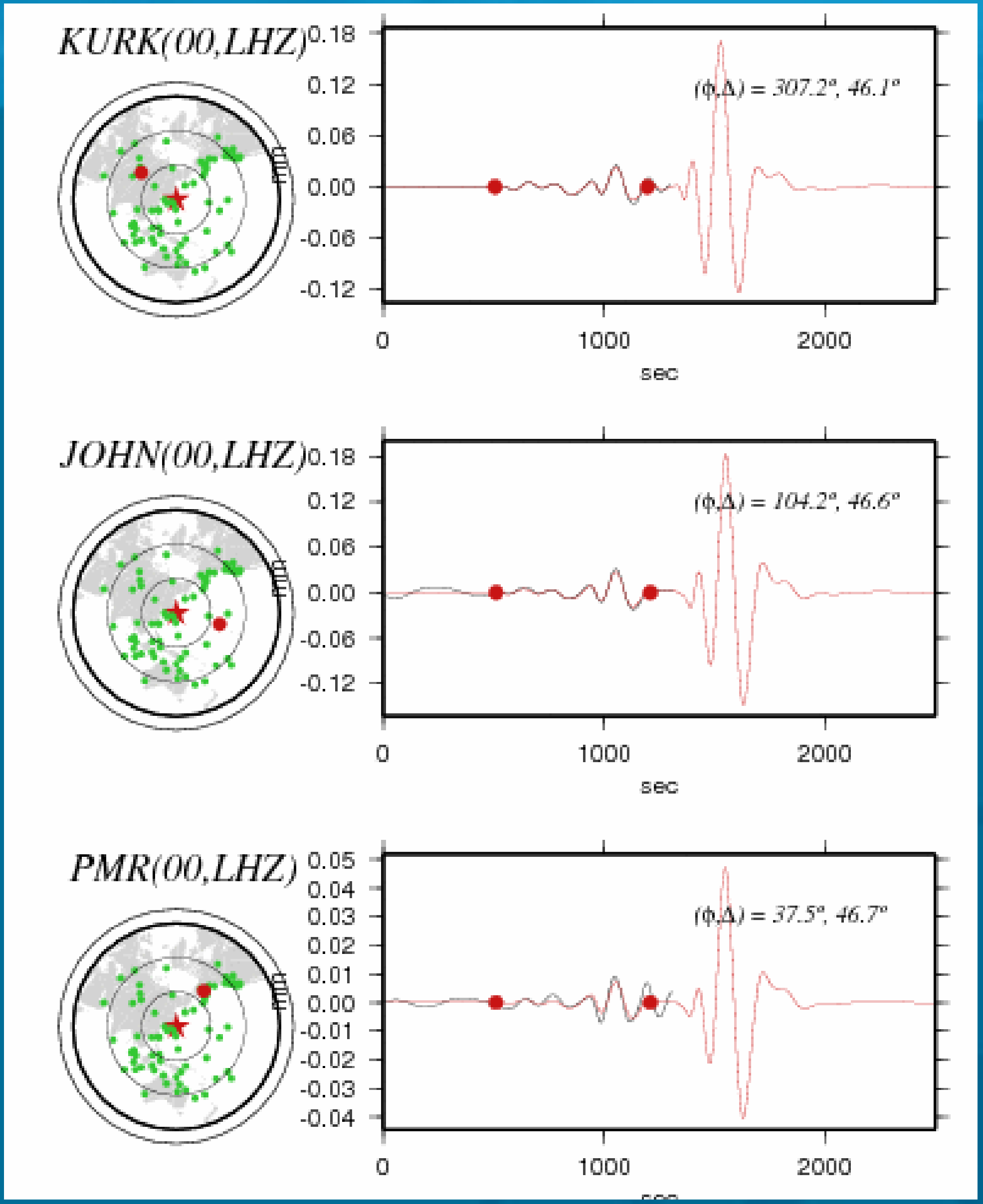


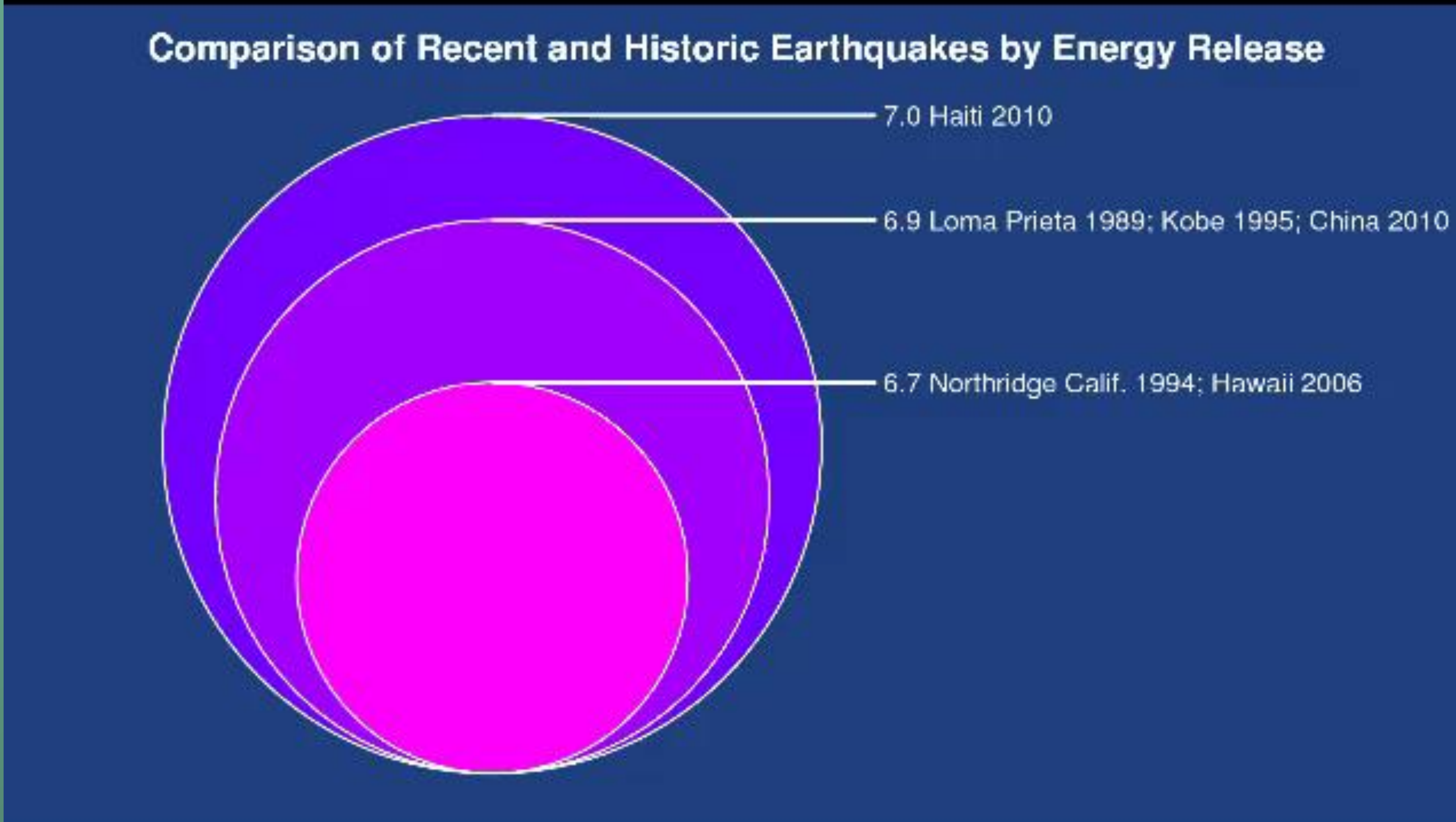
EARTHQUAKE ENERGY

Use Mw to find real energy release

- Incr of 1 in magnitude:
  $10^{1.5}$ = 31.6 times incr energy
- Incr of 2 in magnitude:
  10^{3} = 1000 times incr in energy

Magnitude versus ground motion and energy

Magnitude	Ground Motion	Energy
1.0	10.0 times	about 32 times
0.5	3.2 times	about 5.5 times
0.3	2.0 times	about 3 times
0.1	1.3 times	about 1.4 times


Comparison of Recent and Historic Earthquakes by Energy Release
7.0 Haiti 2010
6.9 Loma Prieta 1989; Kobe 1995; China 2010
6.7 Northridge Calif. 1994; Hawaii 2006

However, it takes time to determine seismic moment and magnitude of very large events

Magnitudes for 2004 Sumatra Earthquake

Scale	Mag	Data	time to announce	number of stations
mb	7.0	1 sec P wave		131 stations
Mwp	8.0 / 8.5	60 sec P waves	11 minutes / 1 hour	
Ms	8.0-8.8	20 sec surface waves		118 stations
Mw	8.9-9.0	300 sec surface waves	5 hours	
Mw	9.1-9.3	3000 sec free oscillations	days	

Magnitude Summary for TWCs

- **Magnitudes are engineer scale. No physical meaning.**
- **Magnitude measurements not precise.**
  - For 1 EQ, get different M using different scale.
  - M saturate for large earthquakes.
  - Takes long time to find true size of great EQ
- **Moment is measure of EQ energy. Directly related to size.**
  Want to know Moment (fault area / size) but takes long time (hours) to collect surface wave / free oscillation data for Mw
- mb (P waves) fast, but underestimates moment
  - If have time (hours), determine Mm (mantle waves) or Mw (long period surface waves)
  - For quick M (sec to min), determine Mwp from P waves
- **For great EQ, TWCs must quickly 'guess-timate' size since still rupturing => wave forecast ~ underestimates**

Gracias, Thank You

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