UNESCO Intergovernmental Oceanographic Commission

UNESCO-IOC / NOAA ITIC Training Program in Hawaii (ITP-TEWS Hawaii)
TSUNAMI EARLY WARNING SYSTEMS
AND THE PACIFIC TSUNAMI WARNING CENTER (PTWC) ENHANCED PRODUCTS
TSUNAMI EVACUATION PLANNING AND UNESCO IOC TSUNAMI READY PROGRAMME
15-26 September 2025, Honolulu, Hawaii

# Tsunami Warning Center Operations:
# Real-Time Earthquake Detection and Fast Source Characterization – Locating Earthquakes & Estimating Magnitude

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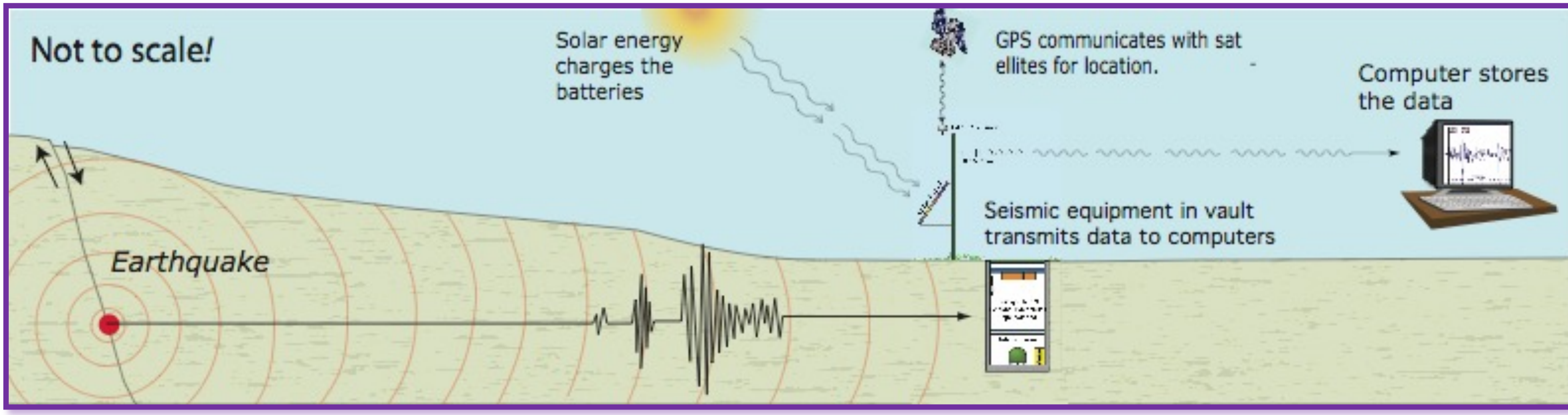
Pacific Community
Communauté du Pacifique

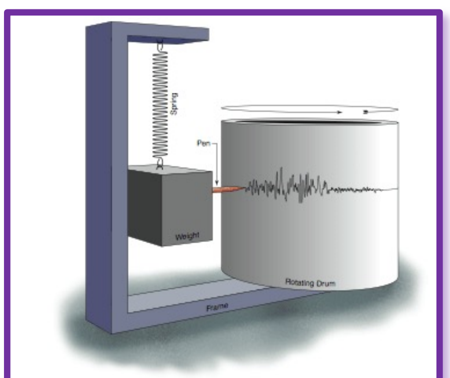
# Locating Earthquakes

# How do we measure earthquakes?

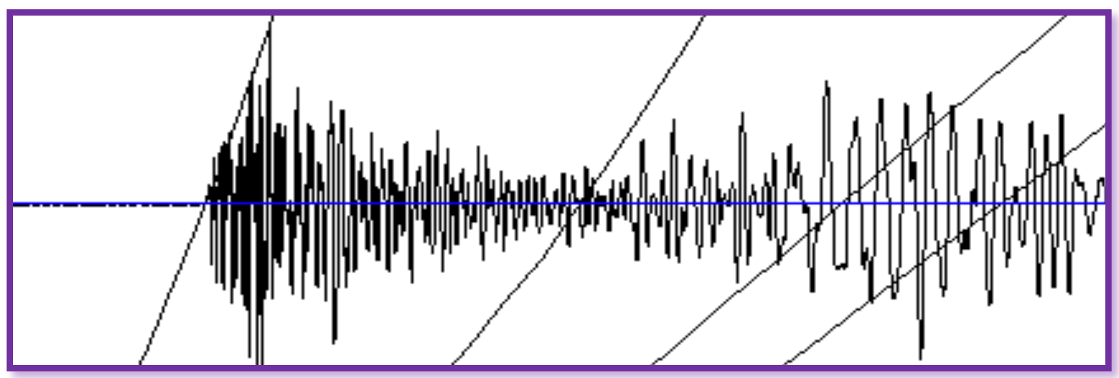



When an earthquake occurs, the seismic waves travel through the Earth to the seismic station where the information is transmitted to distant computers.

A **seismograph** detects and records earthquakes



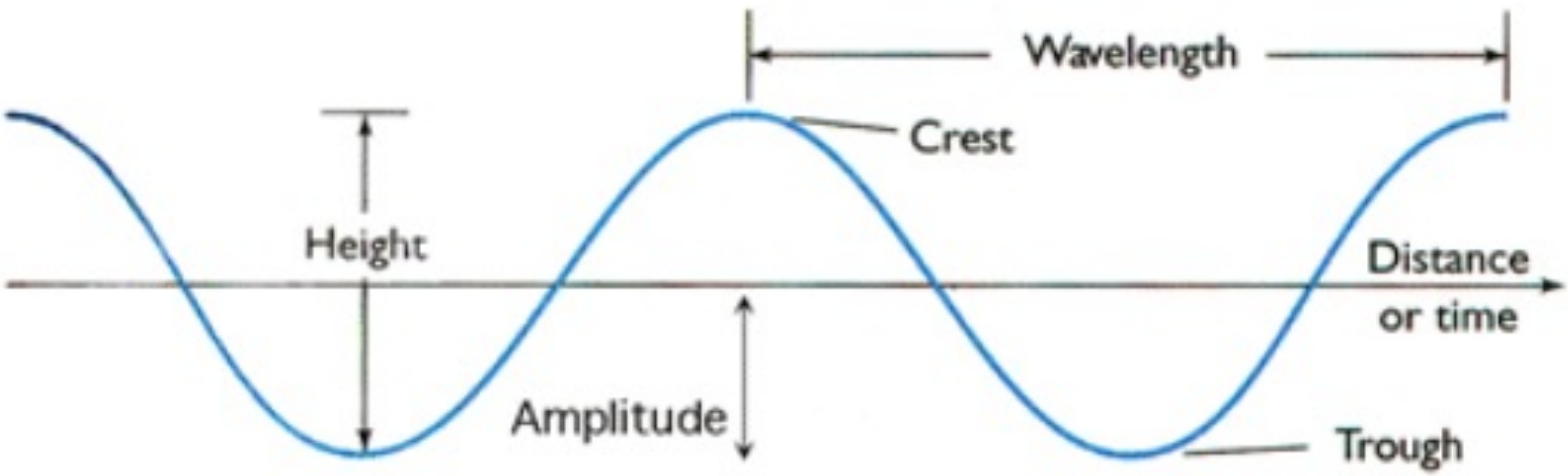
A **seismogram** is the earthquake record



# Global Seismic Network

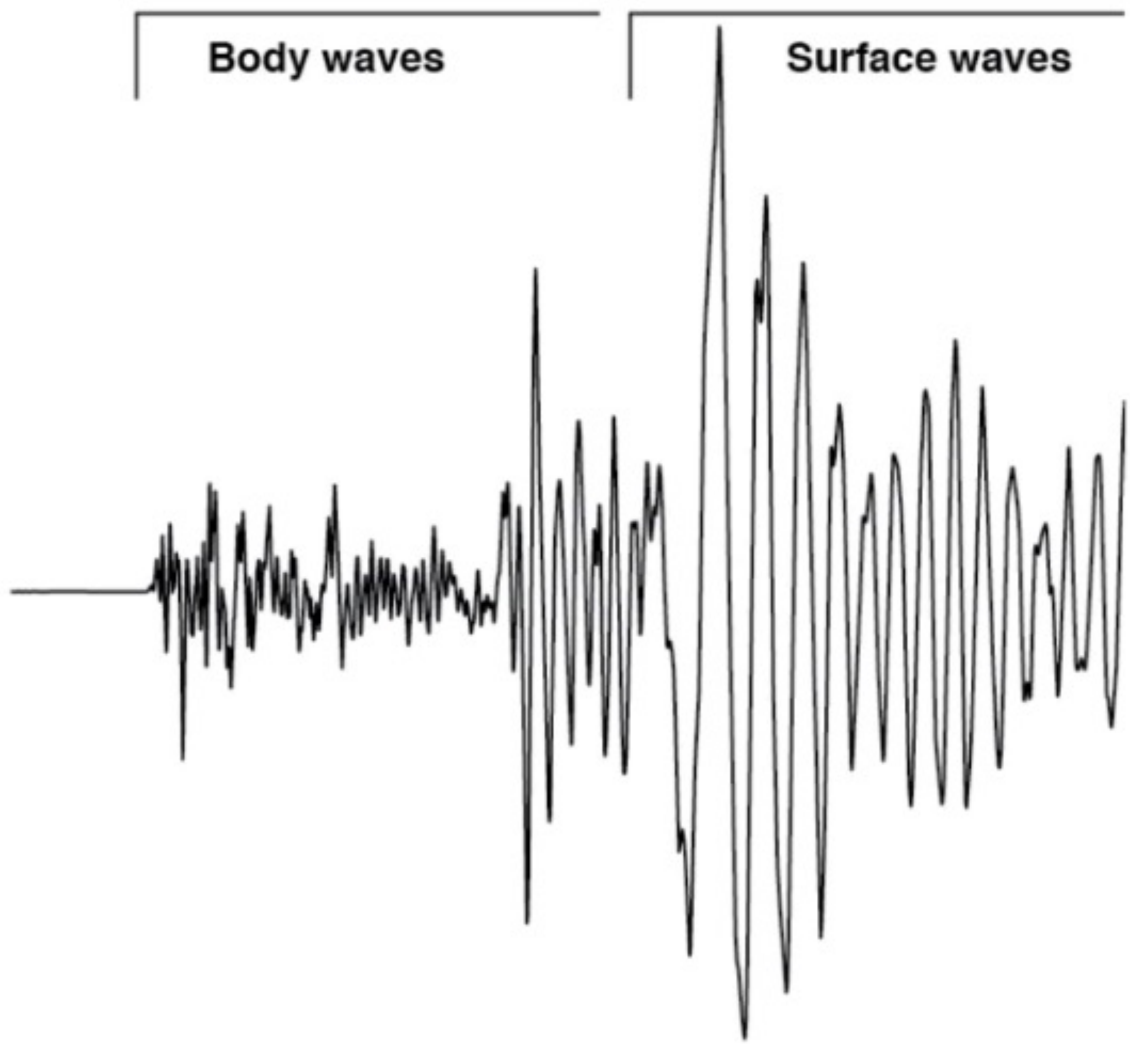

PTWC monitors >800 seismic stations worldwide

# Basic (Seismic) Wave Properties




- Wavelength - distance between successive crests of the wave
- Wave period - time it takes for the wave to travel one wavelength

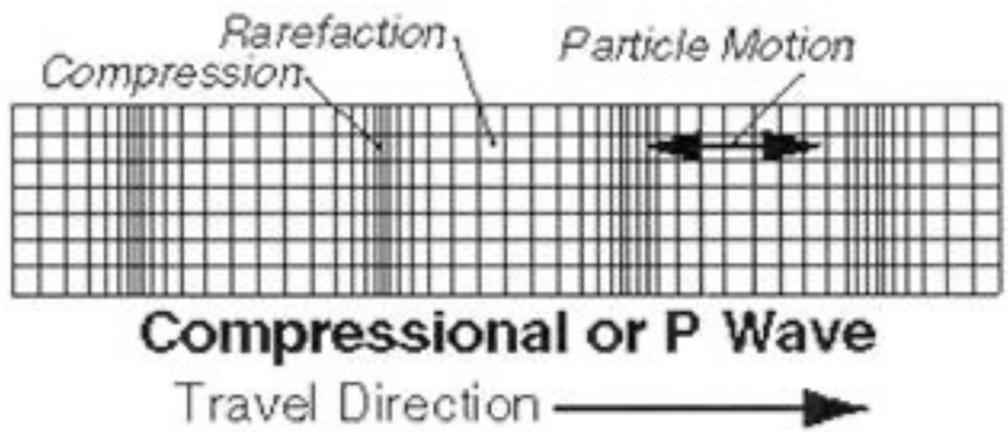
# Basic Types of Seismic Waves

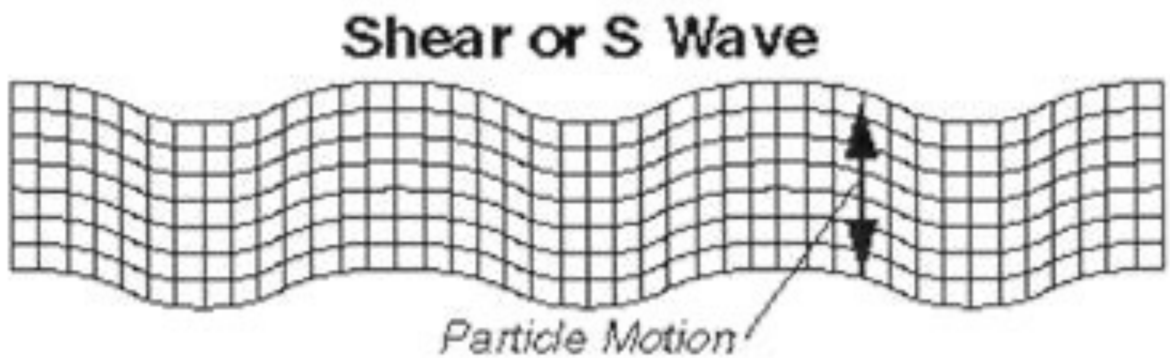



Surface waves arrive after the body waves. They have lower frequency and larger amplitude than body waves.

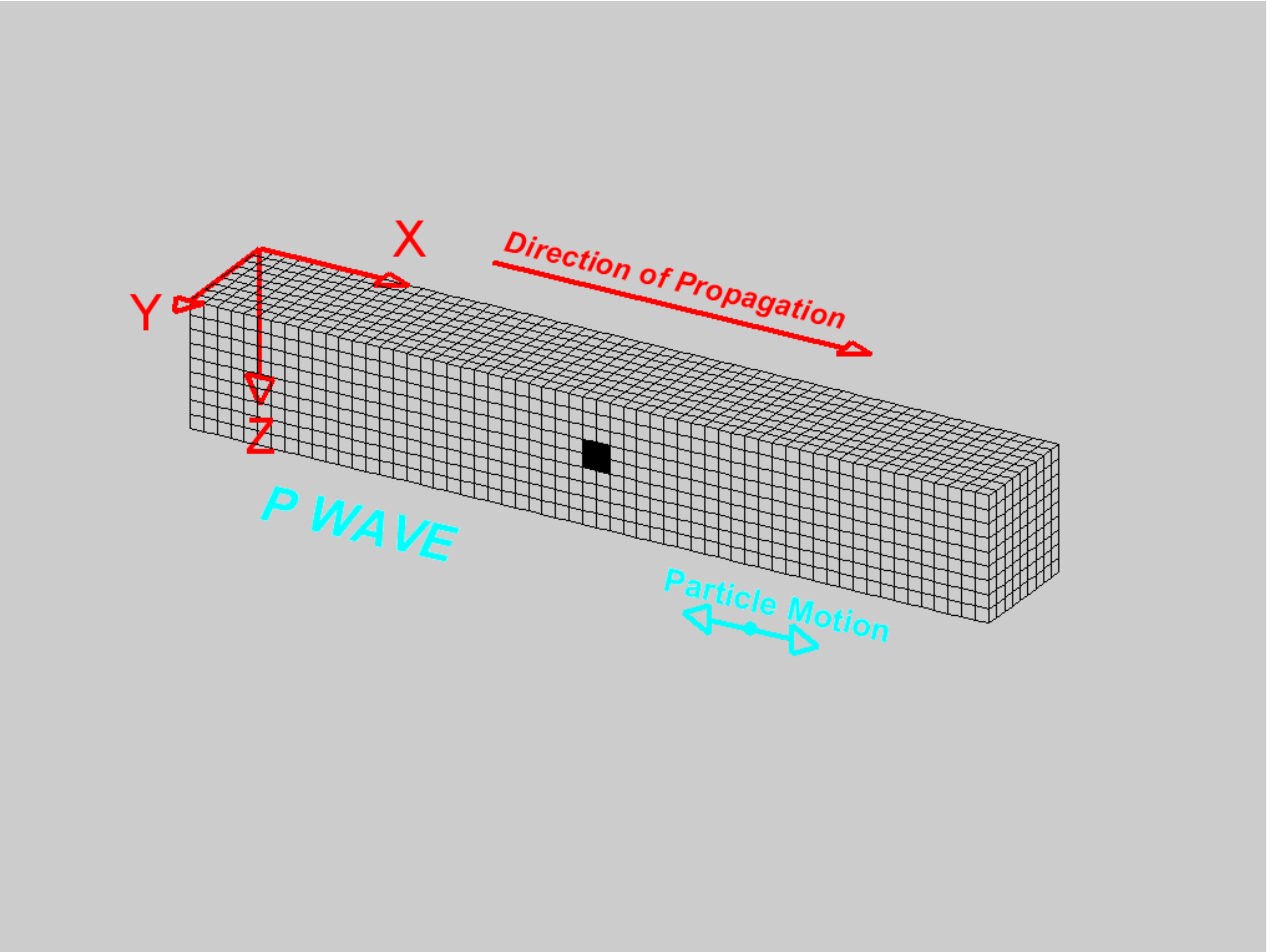
# Basic Types of Seismic Waves

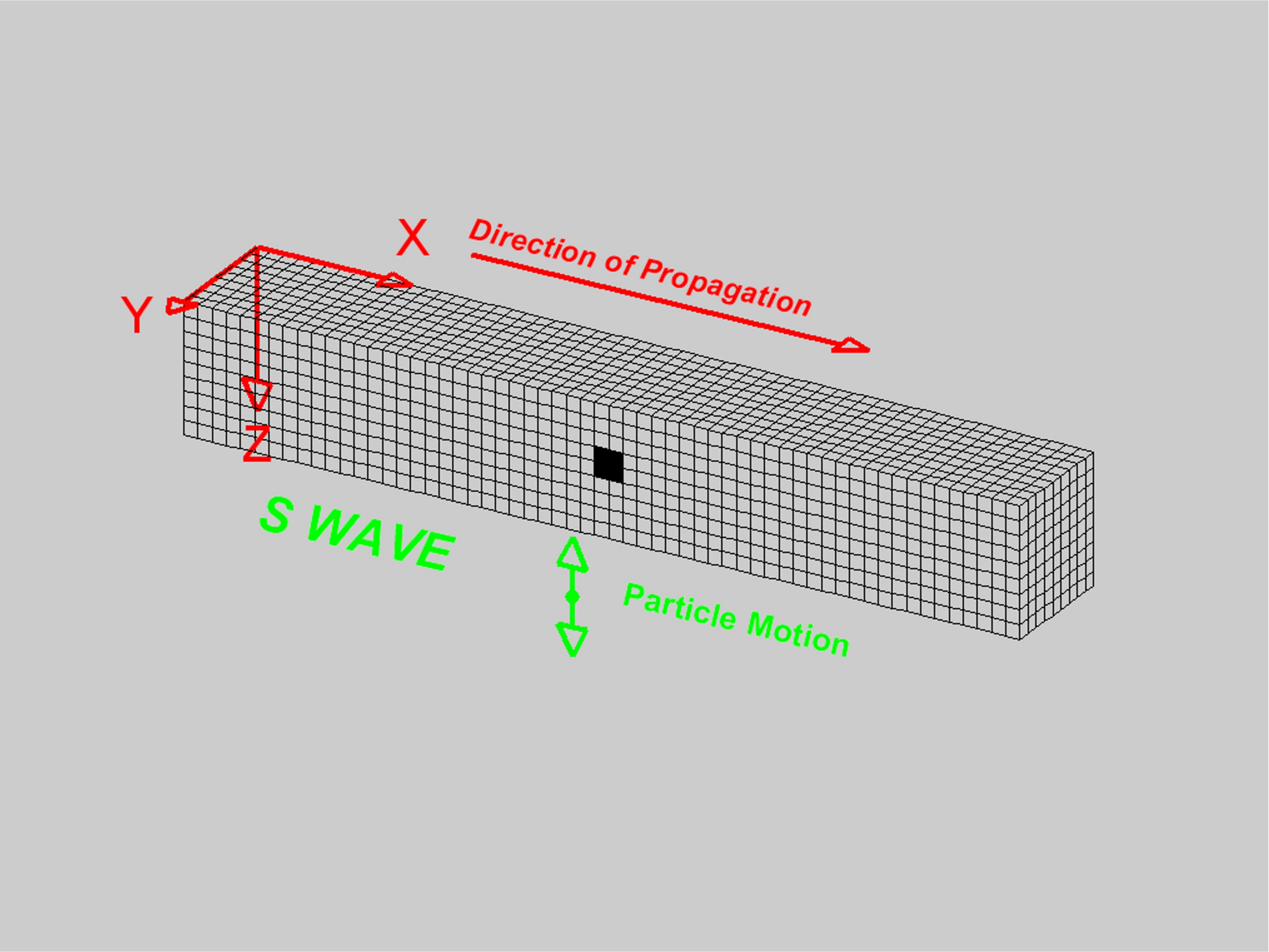
## P and S Waves (also called body waves)



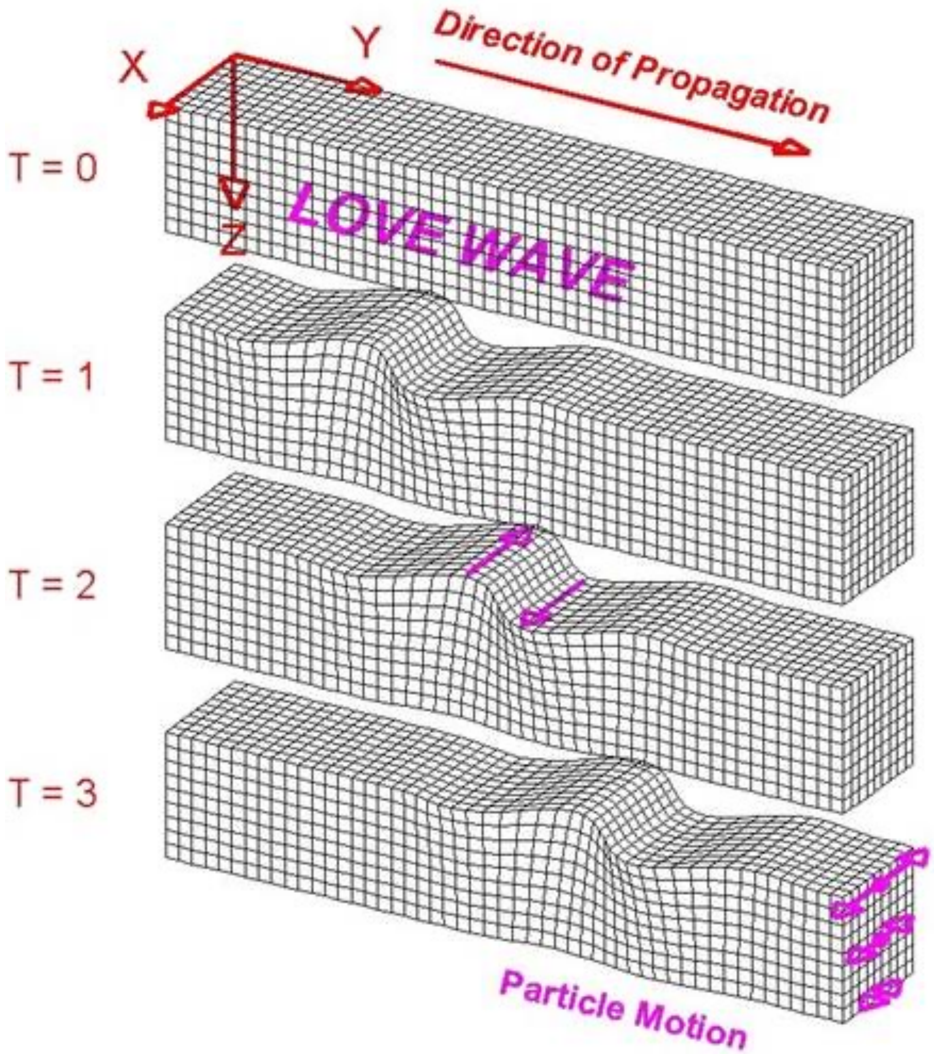

P waves are faster and travel at speeds of **6-14 km/s**


X
Y
Z
Direction of Propagation
P WAVE
Particle Motion

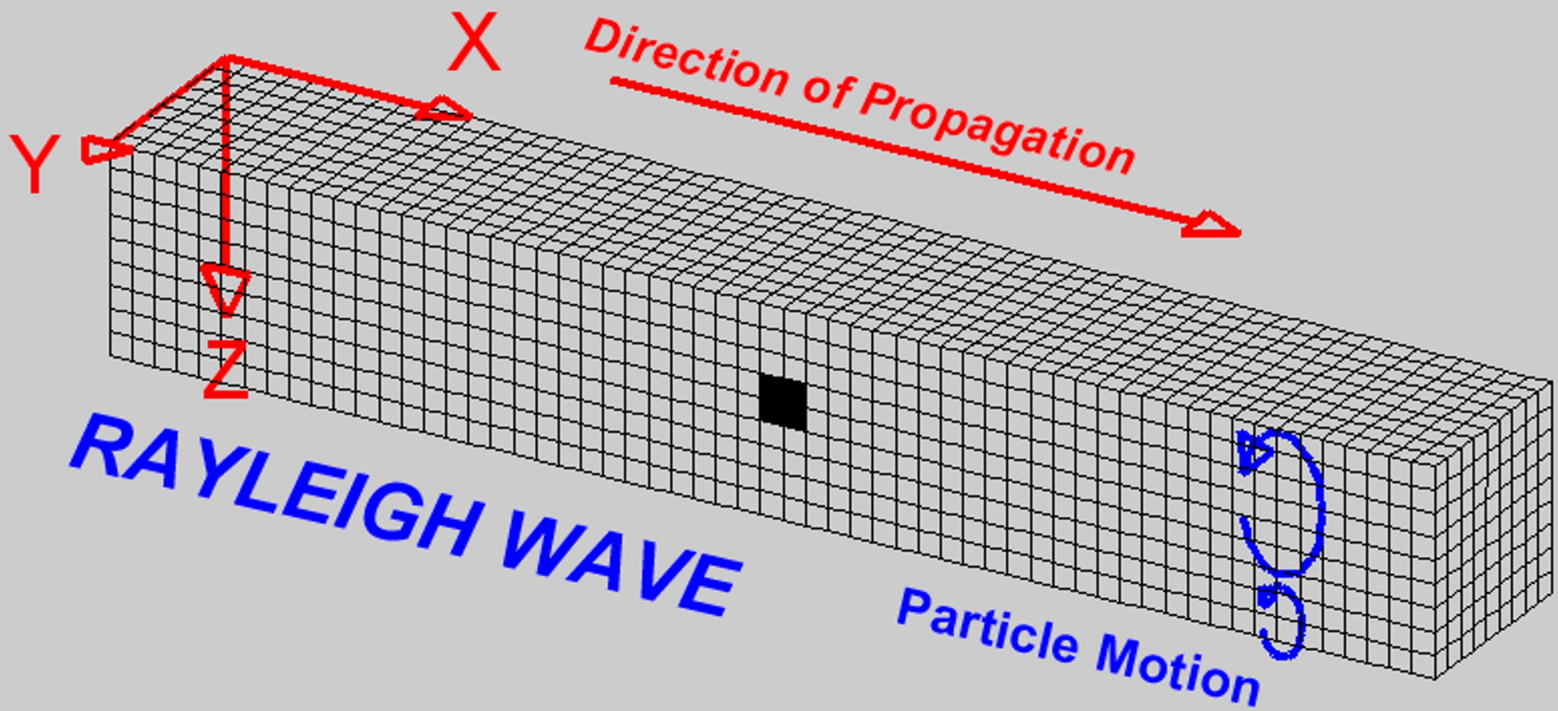

X
Y
Z
Direction of Propagation
S WAVE
Particle Motion

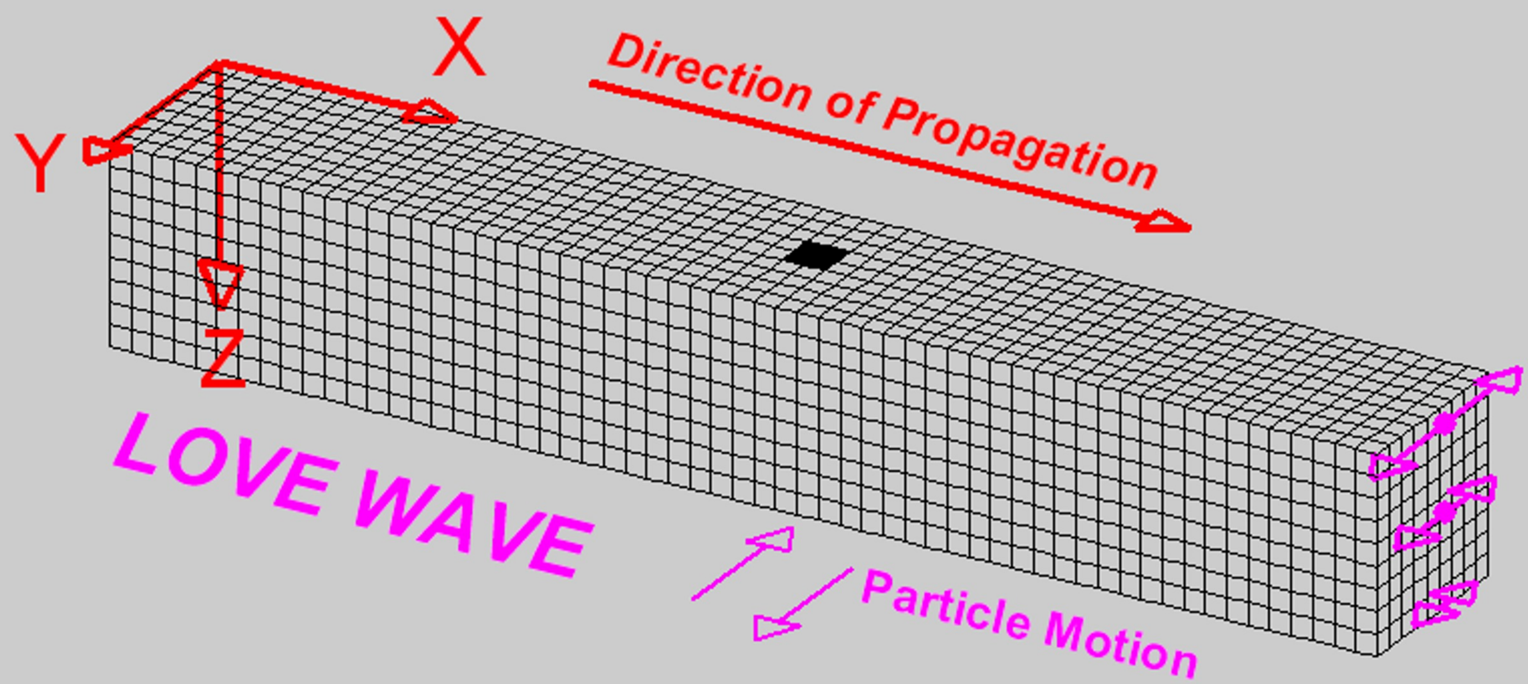
# Basic Types of Seismic Waves

## Surface Waves
## (do not travel through the earth)

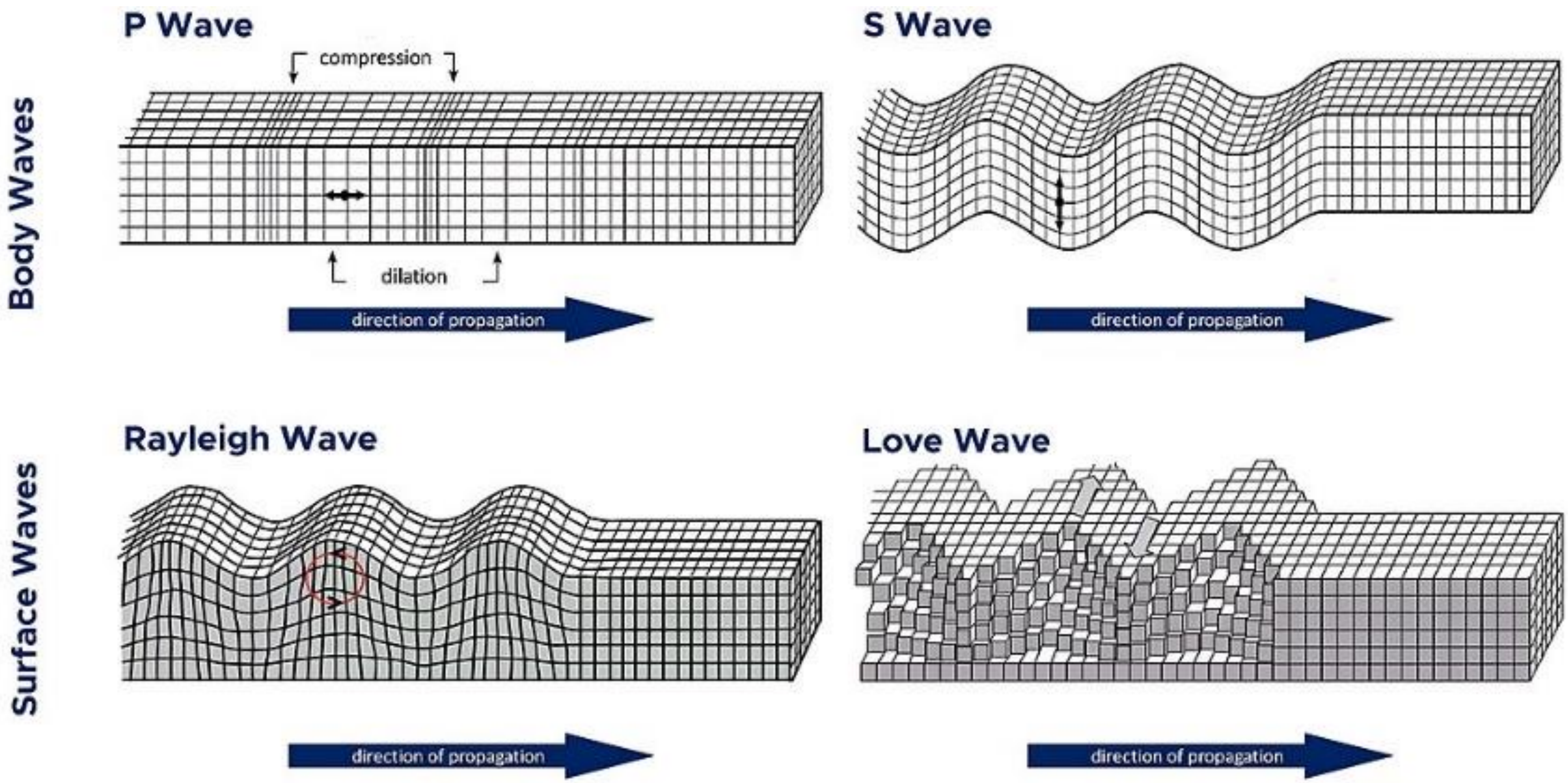



Surface waves travel along the Earth's surface at speeds of **~3/km/sec**, much slower than the body waves.

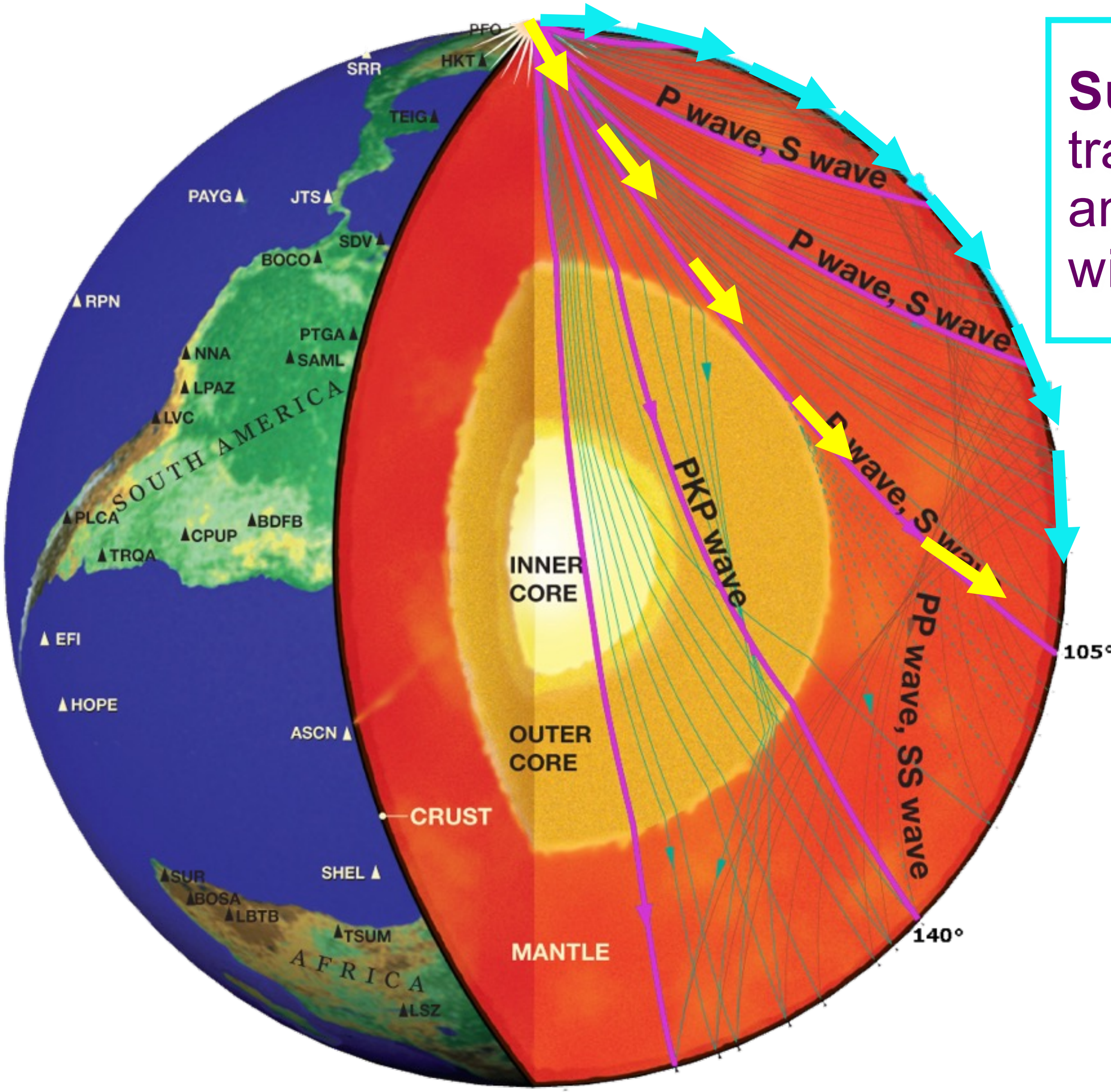

X
Y
Z
Direction of Propagation
RAYLEIGH WAVE
Particle Motion



X
Y
Z
Direction of Propagation
LOVE WAVE
Particle Motion


Body Waves
P Wave
compression
dilation
direction of propagation
S Wave
direction of propagation
Surface Waves
Rayleigh Wave
direction of propagation
Love Wave
direction of propagation

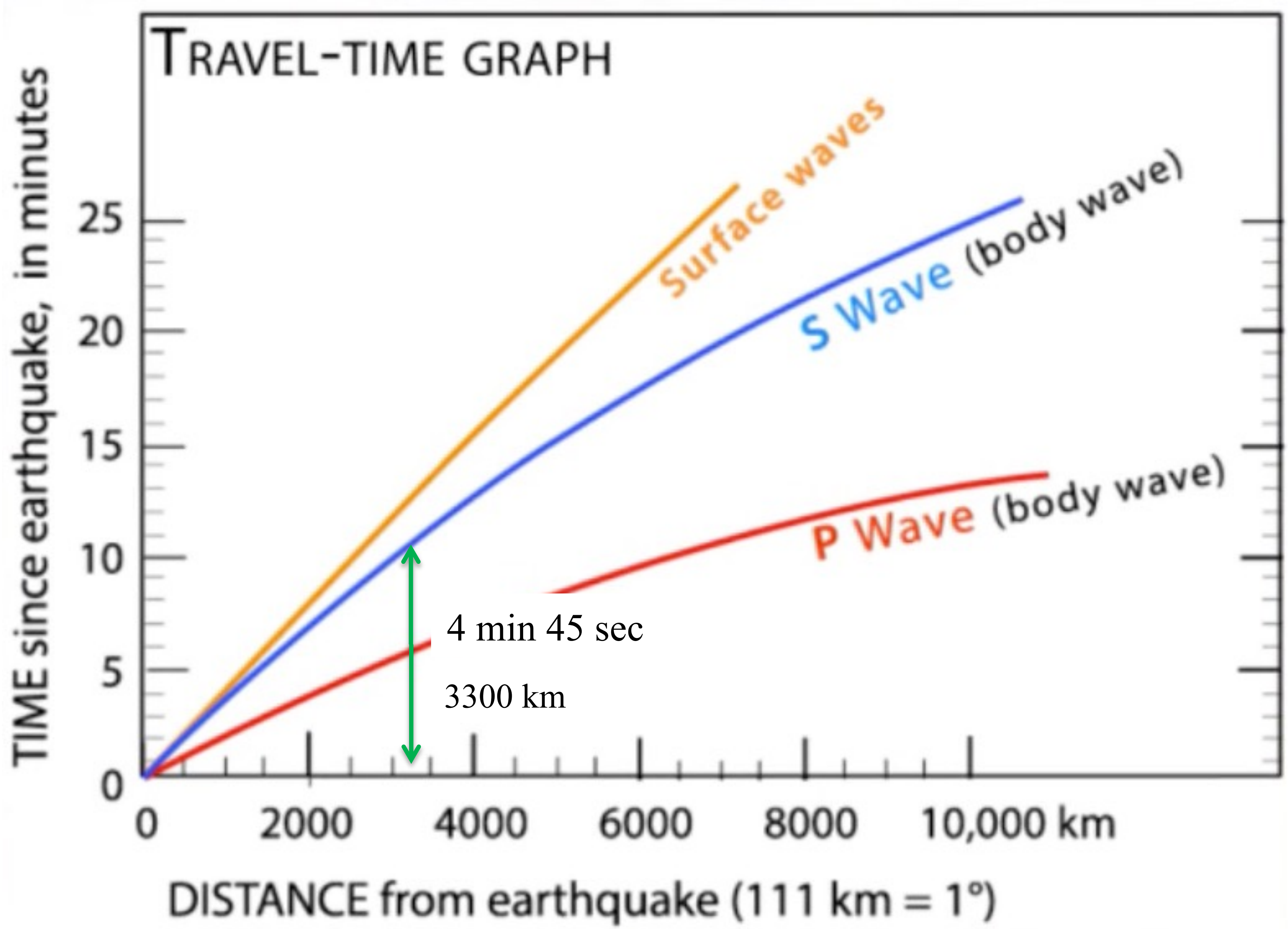
# Body Waves and Surface Waves




**Surface waves**
travel along Earths surface, and decrease in amplitude with depth

**Body waves**
(P and S) radiate in all directions and travel inside Earth

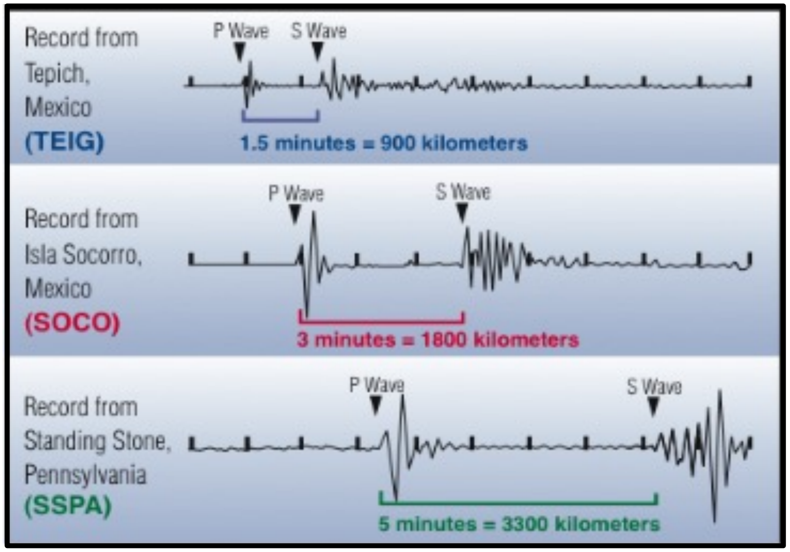
# Distance of earthquake from seismometer



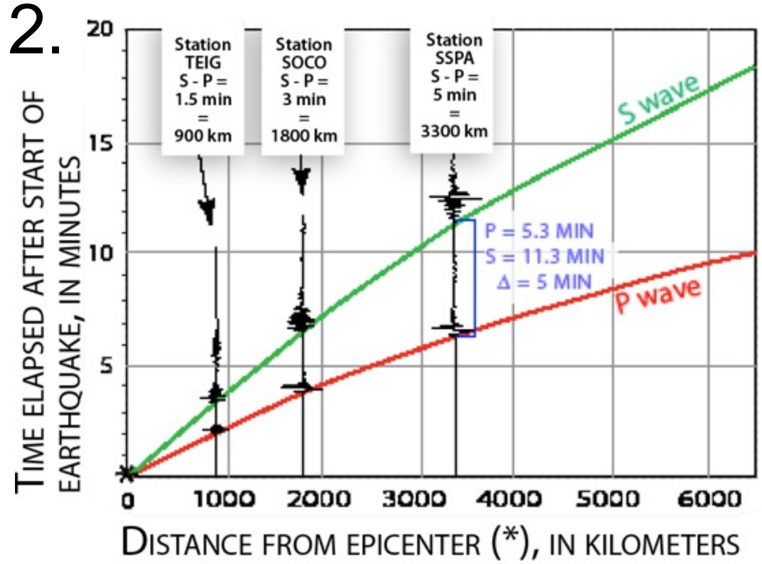

determined from S arrival time - P arrival time

# Locating an earthquake...the basics

1.




2.

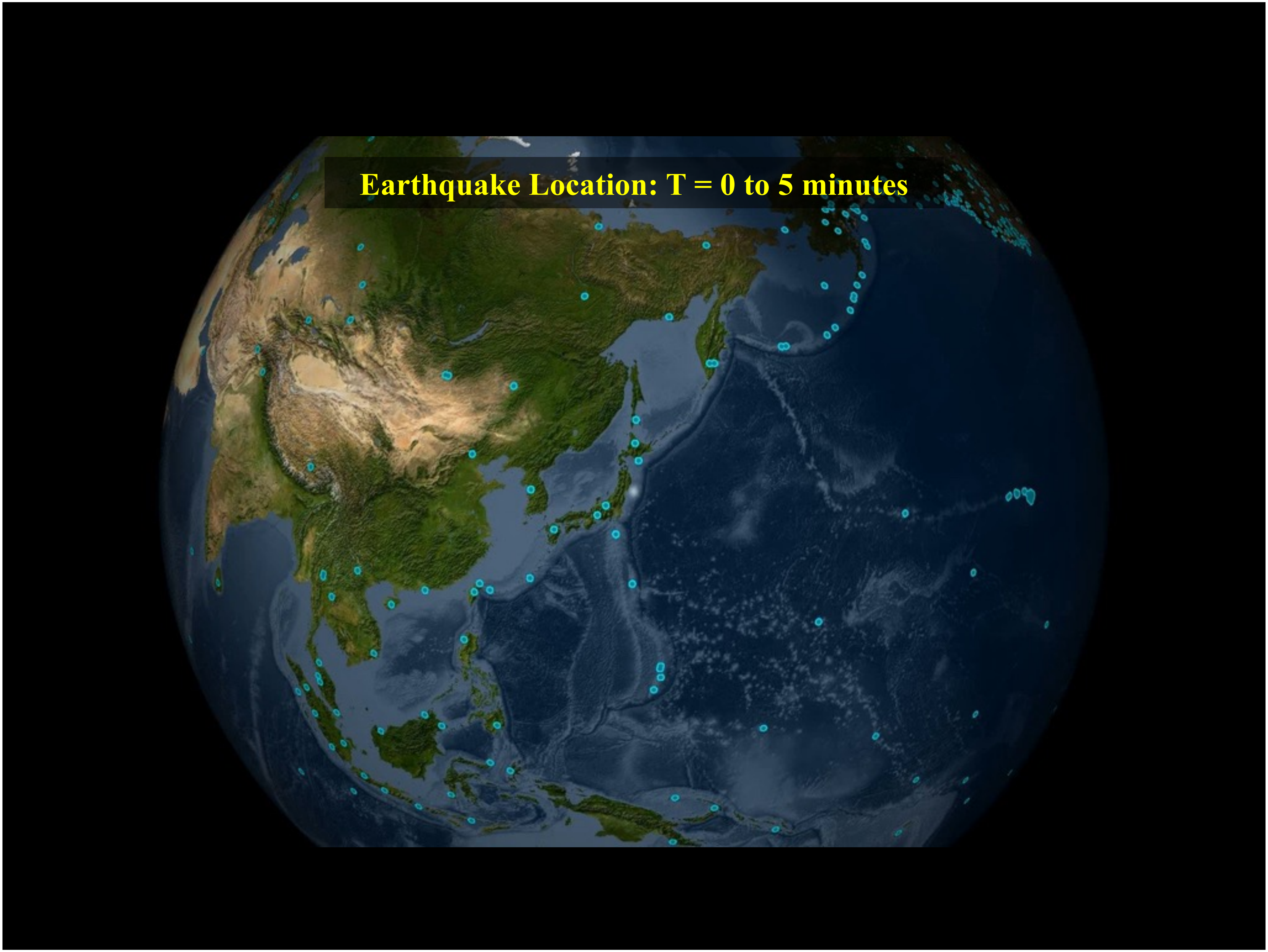



1. Determine distance of EQ from three seismic stations by calculating the S minus P arrival times.

2. Plot on the travel-time graph.

3. Intersection of the circles gives the location.

3.


Earthquake Location: T = 0 to 5 minutes

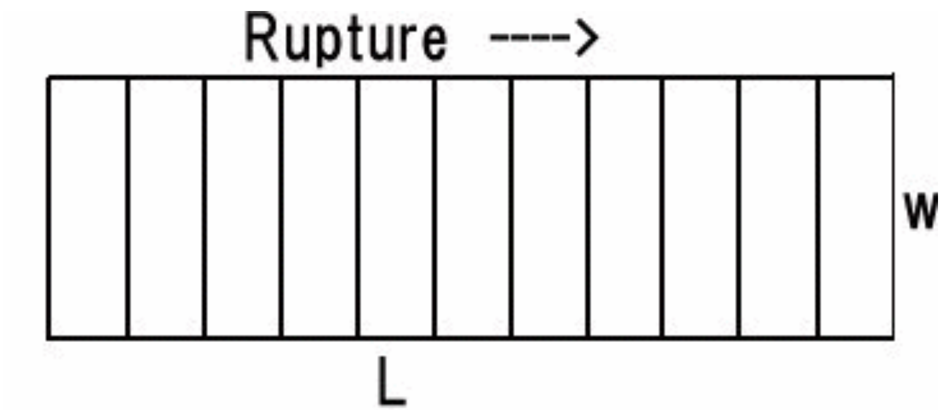
# Earthquake Rupture Complexity

Great Earthquakes ($M \geq 8$)

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

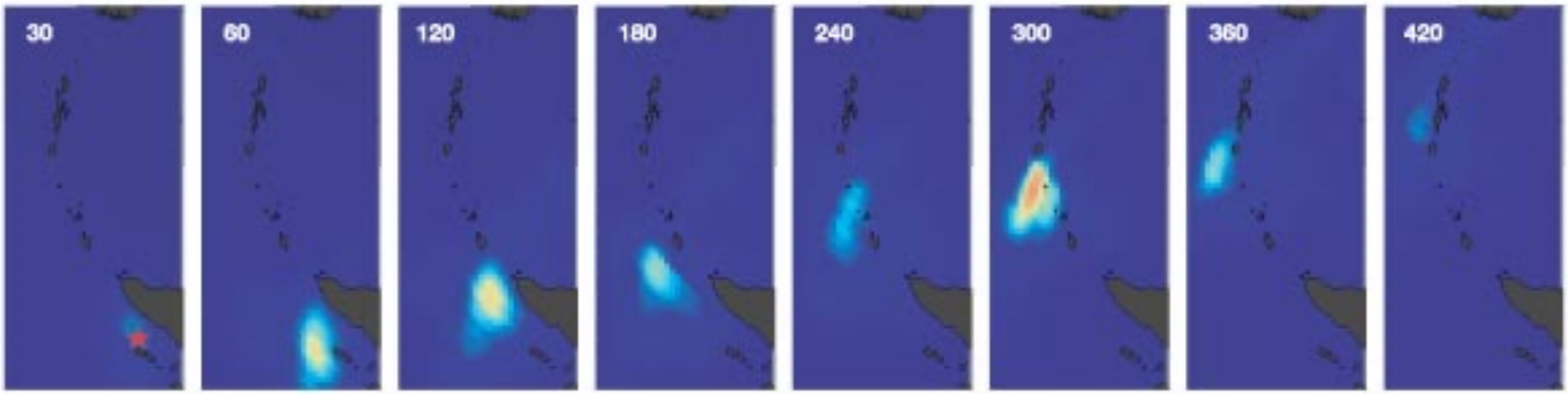
# 2004 Sumatra earthquake

Haskell Line Source
Dislocation Source

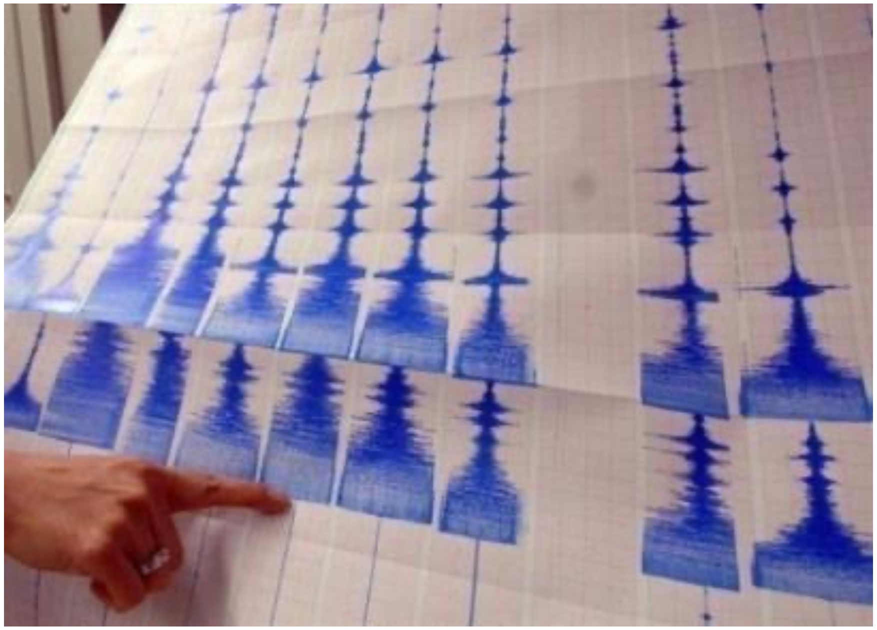




Energy Release imaged by Japan HINET Array



# Earthquake Magnitude & Energy



M7, Papua New Guinea earthquake

TAKE 2

Myth-conceptions

Dispelling myths, misconceptions, & misunderstandings about Earth science

# Earthquake Magnitude vs. Earthquake Intensity

Fixed value vs. variable

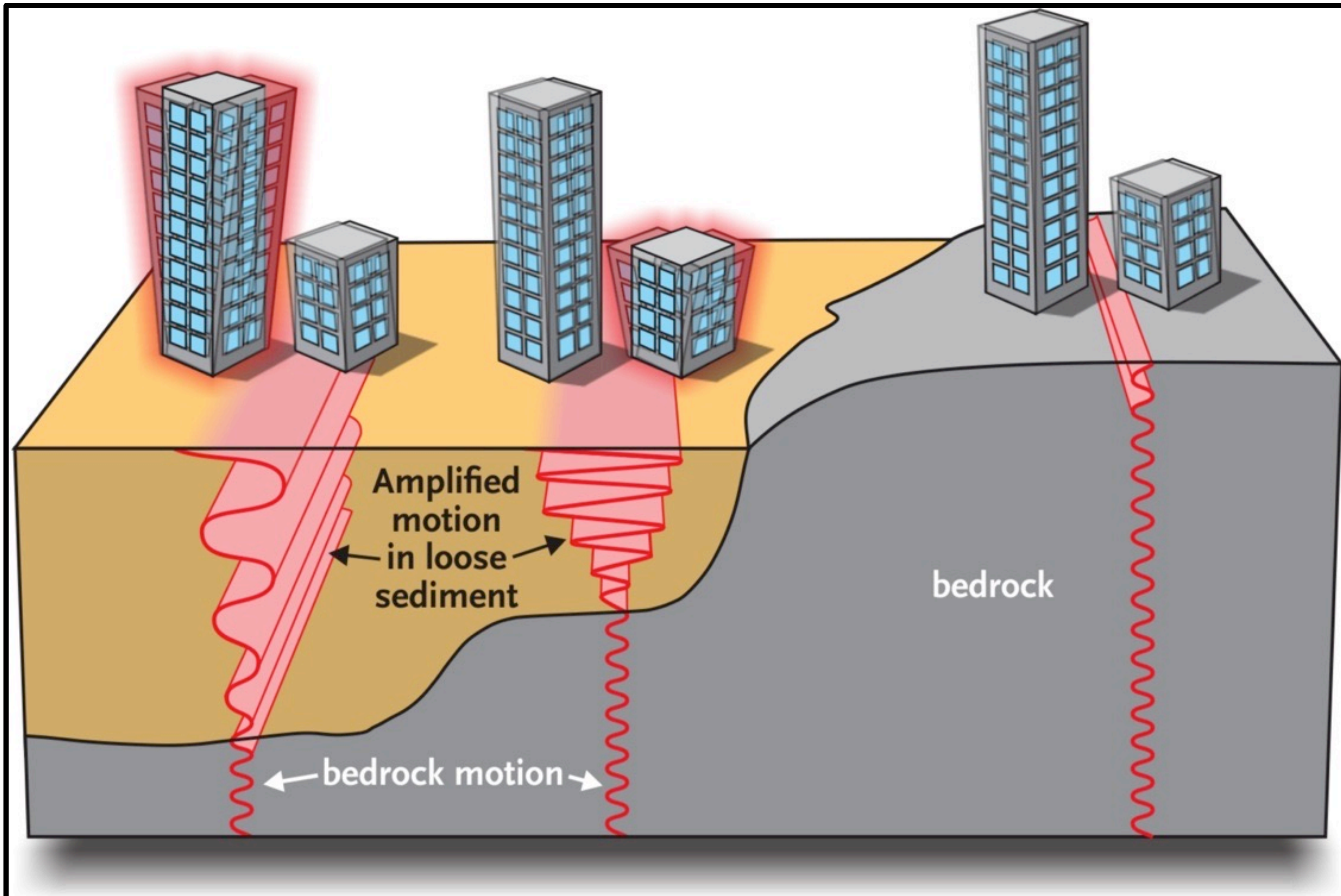
NSF

IRIS

www.iris.edu/earthquake

Incorporated Research Institutions for Seismology

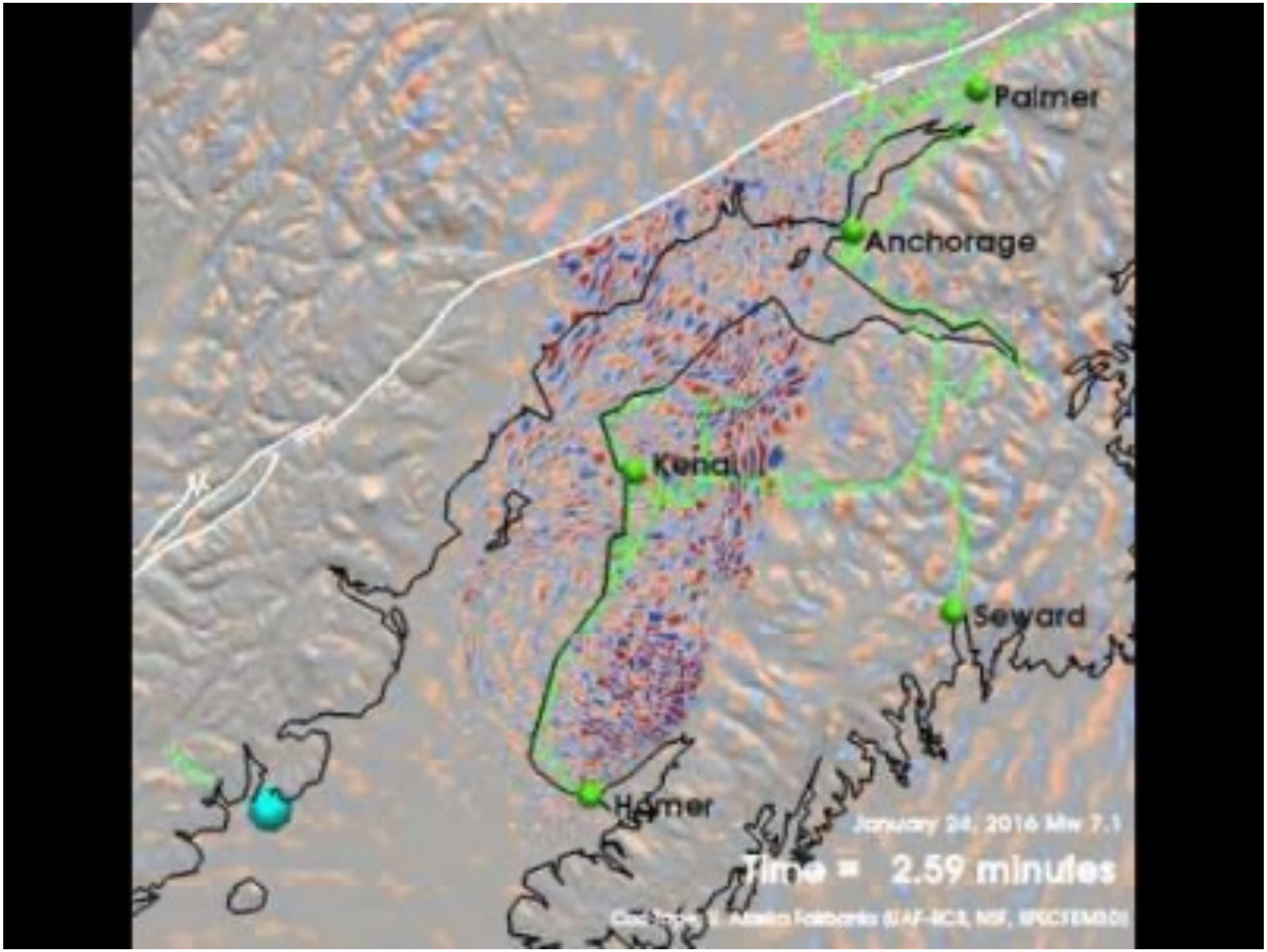
# Ground-Shaking Amplification




Seismic waves are amplified as they pass from bedrock into basins filled with sedimentary rock.

# Site Effects Related to soils and topography

M7.1 Pedro Bay Earthquake (animation by Carl Tape)



# Measuring Earthquake size

- **Historical – Used macroseismic information**
  - Fatalities
  - Maximum shaking
  - Area of intense shaking
- **Did not correlate well from one quake to the next because damage depended on**
  - ”True” size (i.e., magnitude)
  - Distance from the epicenter
  - Building design
  - Surface material (rock or dirt) beneath buildings
  - Proximity to populated regions

# Modified Mercalli Intensity Scale

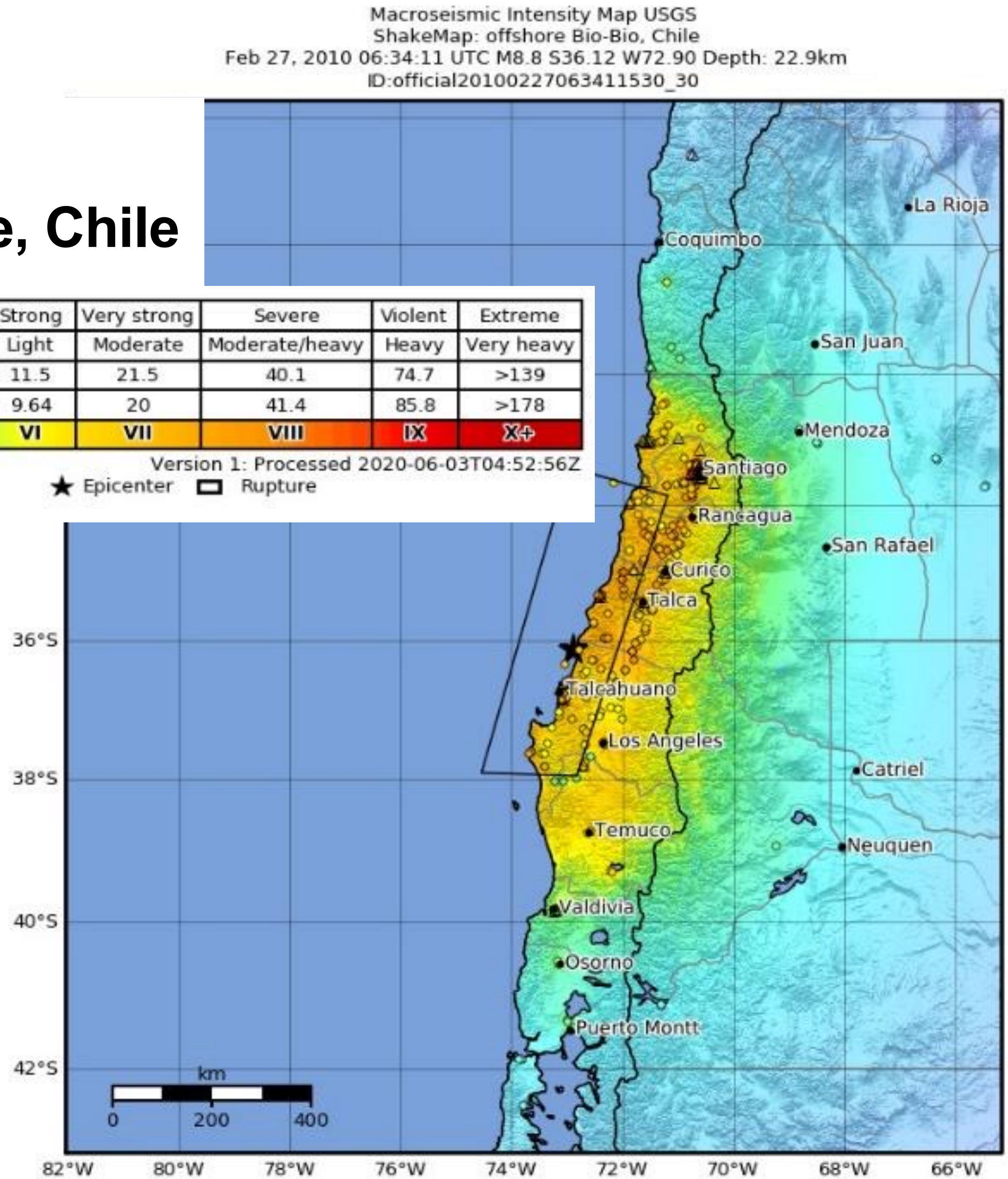
| CIIM Intensity | People's Reaction | Furnishings | Built Environment | Natural Environment |
|---|---|---|---|---|
| I | Not felt | | | Changes in level and clarity of well water are occasionally associated with great earthquakes at distances beyond which the earthquakes felt by people. |
| II | Felt by a few. | Delicately suspended objects may swing. | | |
| III | Felt by several; vibration like passing of truck. | Hanging objects may swing appreciably. | | |
| IV | Felt by many; sensation like heavy body striking building. | Dishes rattle. | Walls creak; window rattle. | |
| V | Felt by nearly all; frightens a few. | Pictures swing out of place; small objects move; a few objects fall from shelves within the community. | A few instances of cracked plaster and cracked windows with the community. | Trees and bushes shaken noticeably. |
| VI | Frightens many; people move unsteadily. | Many objects fall from shelves. | A few instances of fallen plaster, broken windows, and damaged chimneys within the community. | Some fall of tree limbs and tops, isolated rockfalls and landslides, and isolated liquefaction. |
| VII | Frightens most; some lose balance. | Heavy furniture overturned. | Damage negligible in buildings of good design and construction, but considerable in some poorly built or badly designed structures; weak chimneys broken at roof line, fall of unbraced parapets. | Tree damage, rockfalls, landslides, and liquefaction are more severe and widespread wiht increasing intensity. |
| VIII | Many find it difficult to stand. | Very heavy furniture moves conspicuously. | Damage slight in buildings designed to be earthquake resistant, but severe in some poorly built structures. Widespread fall of chimneys and monuments. | |
| IX | Some forcibly thrown to the ground. | | Damage considerable in some buildings designed to be earthquake resistant; buildings shift off foundations if not bolted to them. | |
| X | | | Most ordinary masonry structures collapse; damage moderate to severe in many buildings designed to be earthquake resistant. | |

# USGS ShakeMap
# 2010 $M_w$ 8.8 Maule, Chile

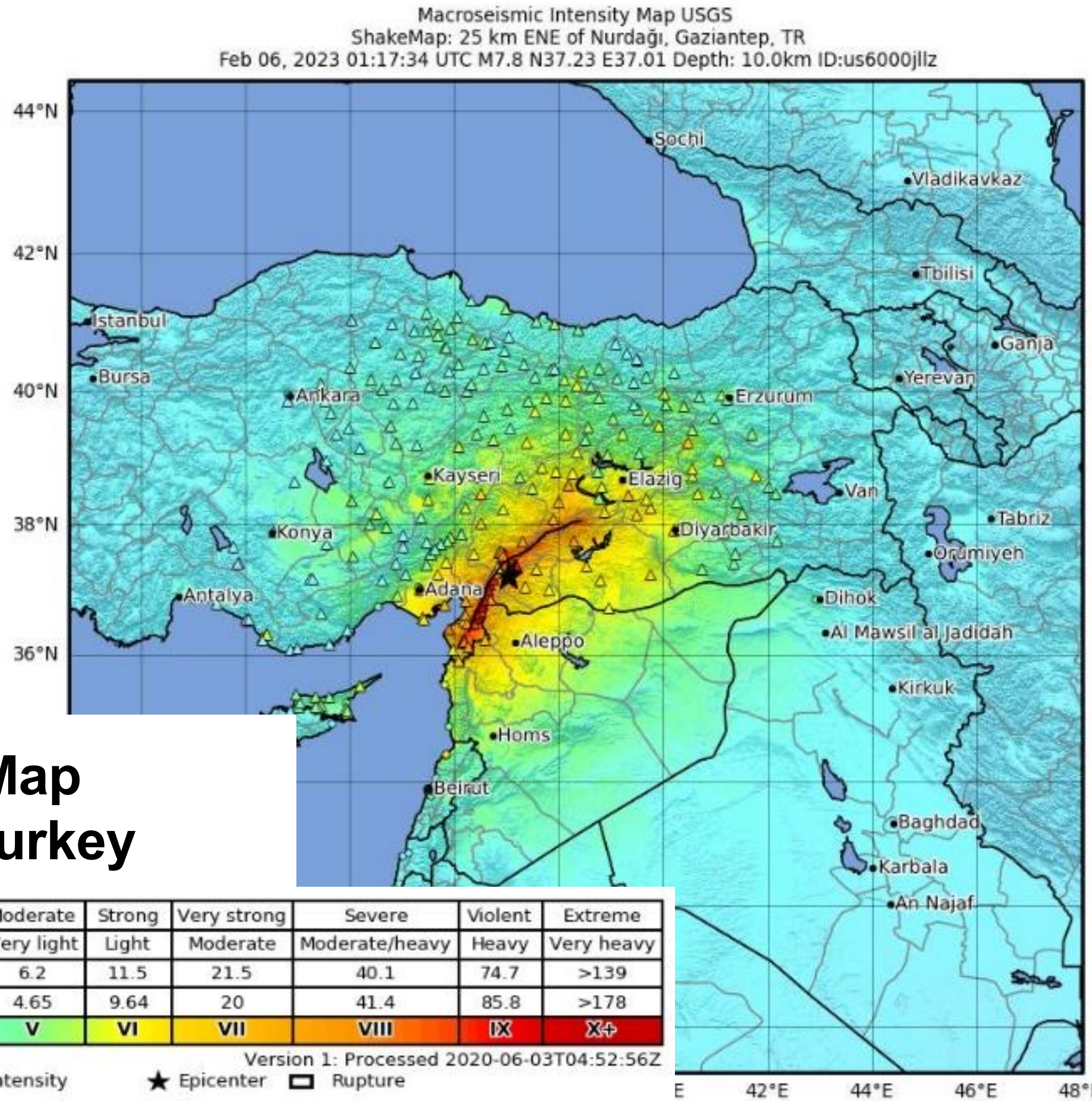
| SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| DAMAGE | None | None | None | Very light | Light | Moderate | Moderate/heavy | Heavy | Very heavy |
| PGA(%g) | <0.0464 | 0.297 | 2.76 | 6.2 | 11.5 | 21.5 | 40.1 | 74.7 | >139 |
| PGV(cm/s) | <0.0215 | 0.135 | 1.41 | 4.65 | 9.64 | 20 | 41.4 | 85.8 | >178 |
| INTENSITY | I | II-III | IV | V | VI | VII | VIII | IX | X+ |

Scale based on Worden et al. (2012) Version 1: Processed 2020-06-03T04:52:56Z

△ Seismic Instrument ○ Reported Intensity ★ Epicenter ▭ Rupture



# USGS ShakeMap 2023 $M_w$ 7.8 Turkey

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|---|---|---|---|---|---|---|---|---|---|
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△ Seismic Instrument ○ Reported Intensity ★ Epicenter ▭ Rupture

# Earthquake Magnitude

**General form:**

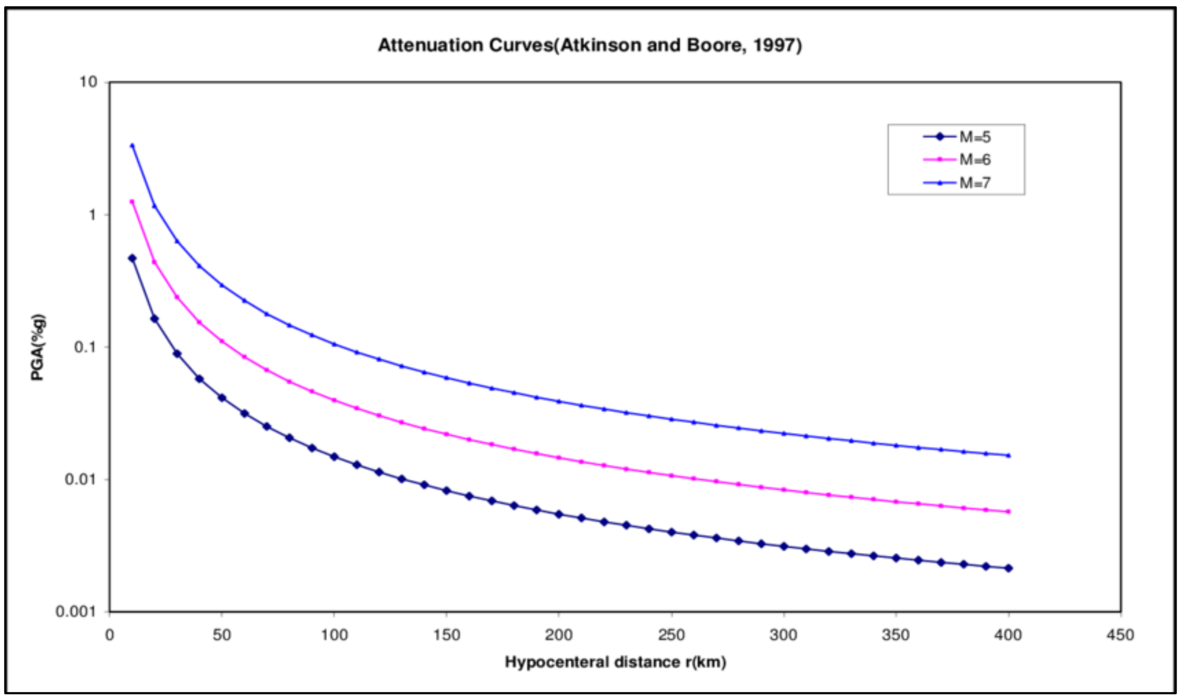
$$M = \log(A/T) + F(h,\Delta) + C$$

Regional scaling factor

Amplitude

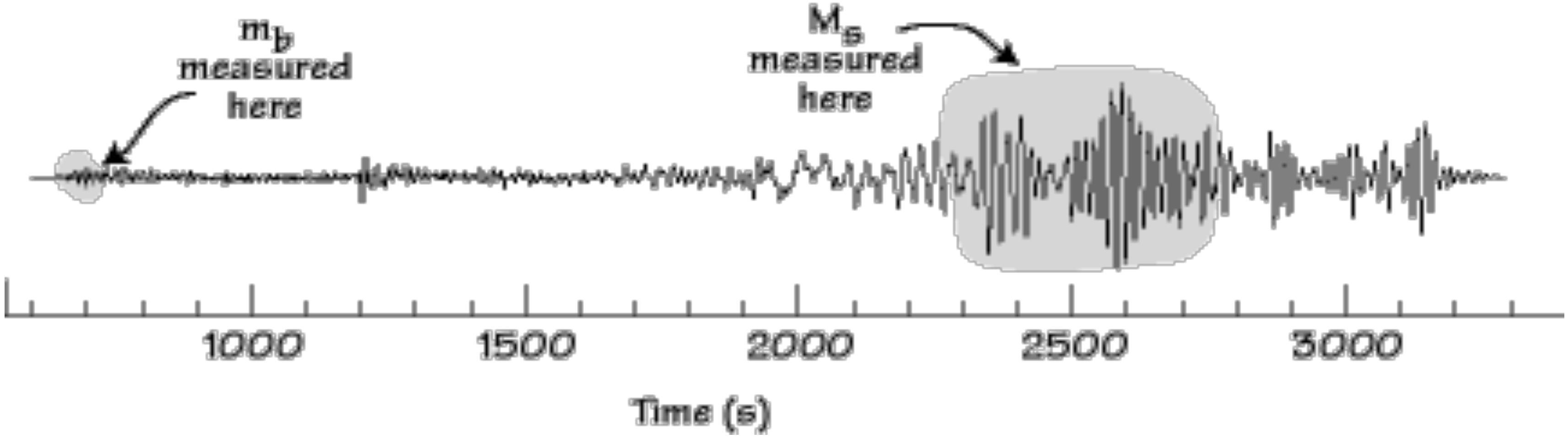
Period

Correction for depth and distance



# Richter and Gutenberg's Teleseismic (distant) magnitudes

## Body wave Magnitude mb and Surface wave and $M_S$




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

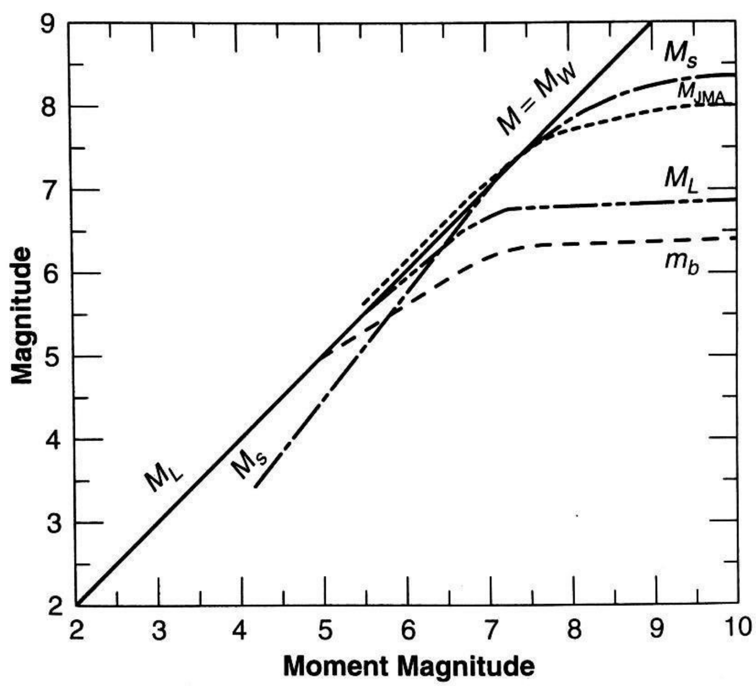
**T:** period (secs), 0.1 ≤ T ≤ 3.0
**A:** P wave amplitude (microns) (not necessarily the maximum)
**Q**: scale factor (D ≥ 5°)

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

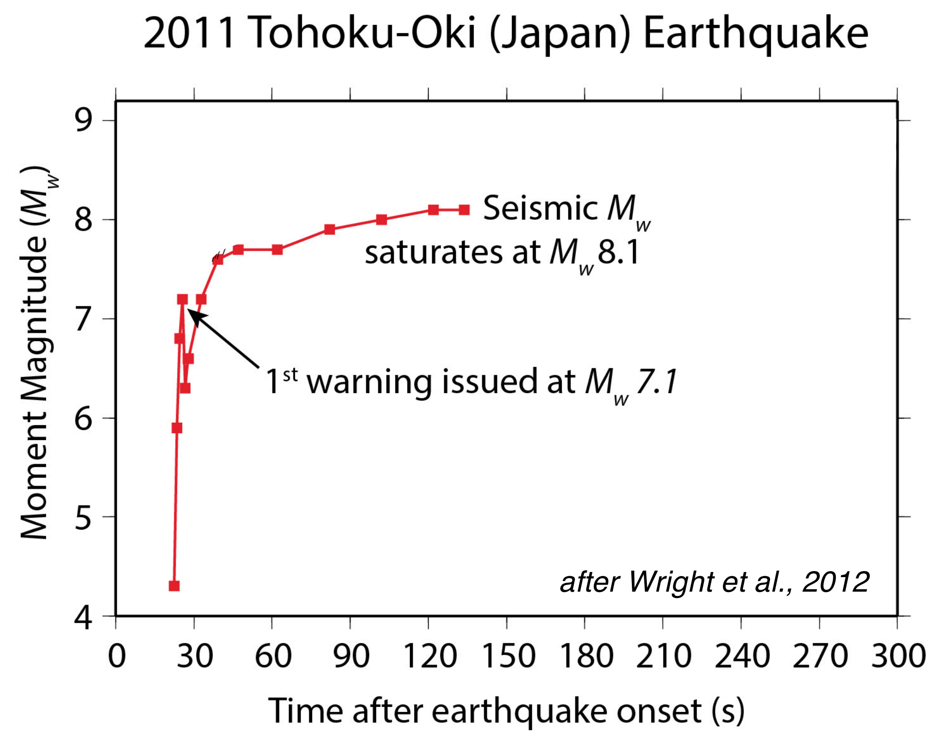
**A**: maximum amplitude (microns) vertical component of the surface wave within the period range 18 <= **T** <= 22.
**D**: 20° ≤ D ≤ 160°.

No depth corrections!

# Saturation!




*Idriss, 1985*

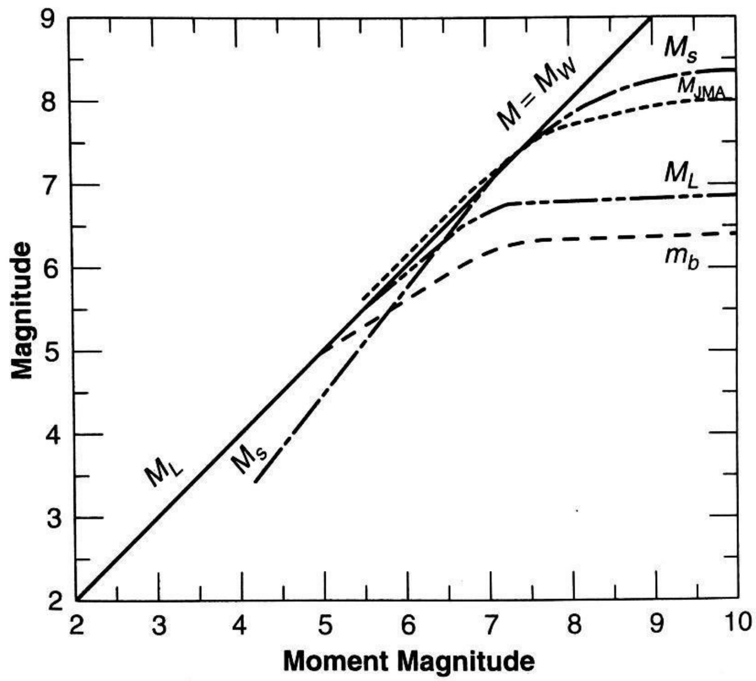



## When does this happen?

1) **Time window saturation – when time window is less than duration of rupture (particularly affects mb)**

2) **Spectral saturation – when wavelength too short to see entire rupture (affects mb, $M_L$, and $M_s$)**

# Saturation!

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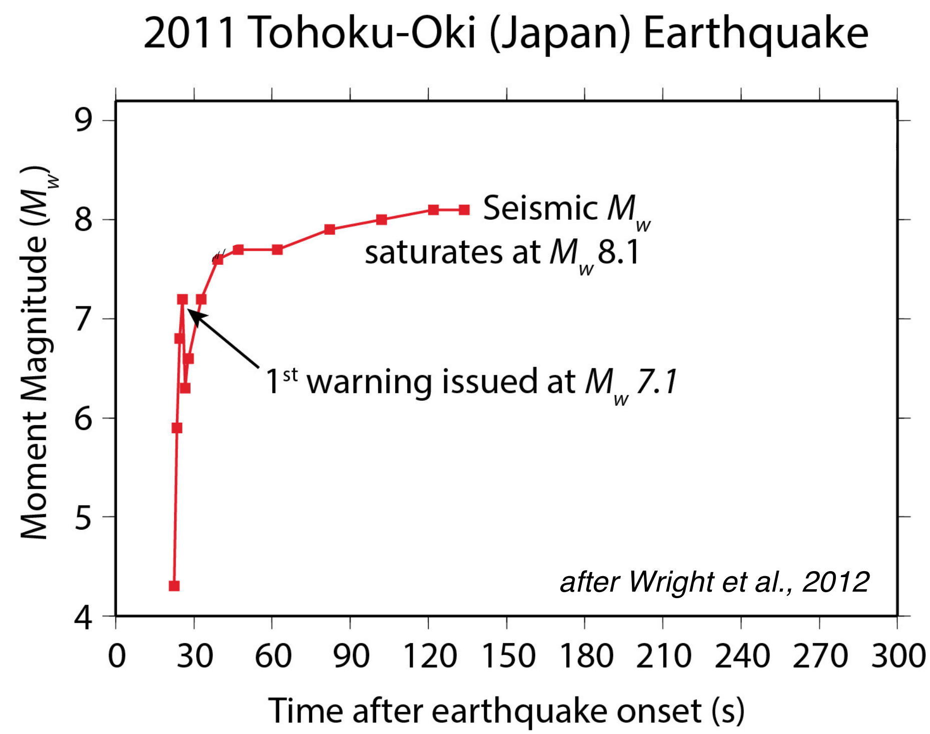



## How do we overcome this problem?

→ **Examine longer period waves**

→ **$M_w$, Mwp, Mantle magnitude (Mm), Centroid Moment Tensor (CMT) – moment magnitude**

→ **GNSS/GPS data (next talk)**

# 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)*

# Moment magnitude (Mw)

$$Mw = (2/3) \log_{10}(Mo) - 16.1$$

- Introduced in 1979 by Hanks and Kanamori
- **Based on source parameter Mo and is not frequency dependent, does NOT saturate**
- **Based on earthquake energy release**
- **Related to fault slip and not ground shaking**
- **Used to estimate the magnitude of large earthquakes**
- **Very useful for tsunami modeling**

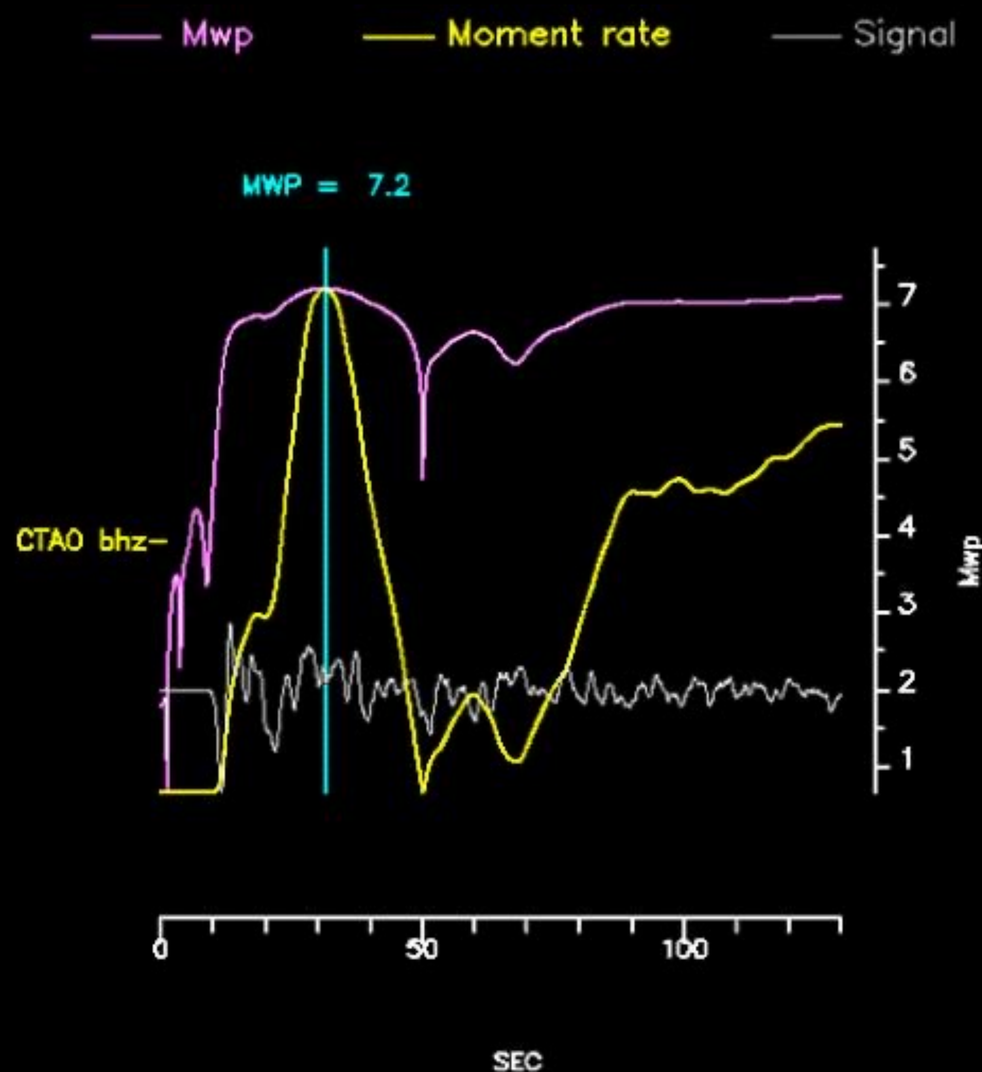
# Moment Magnitude

# Mwp Magnitude

- Moment magnitude based on initial long-period P-waves
- Developed by S. Tsuboi and others (1995)
- Empirical estimate of the moment magnitude
  - integrate the vertical velocity from a seismogram
- Accurate results within 3-4 minutes of OT (P, pP arrivals)
- Primary initial magnitude estimate at PTWC for M>6 (replaced Ms)
- Subject to site and path effects, source complexity, contamination from other large earthquakes

# $M_{wp}$ [Tsuboi et al.,1995;1999]

- Double integration of *v(t)*
  *v(t)* → *Mo(t)* → *Mw(t)*
- Peak *Mw(t)* → *Mwp*
- Fast; less prone to saturation



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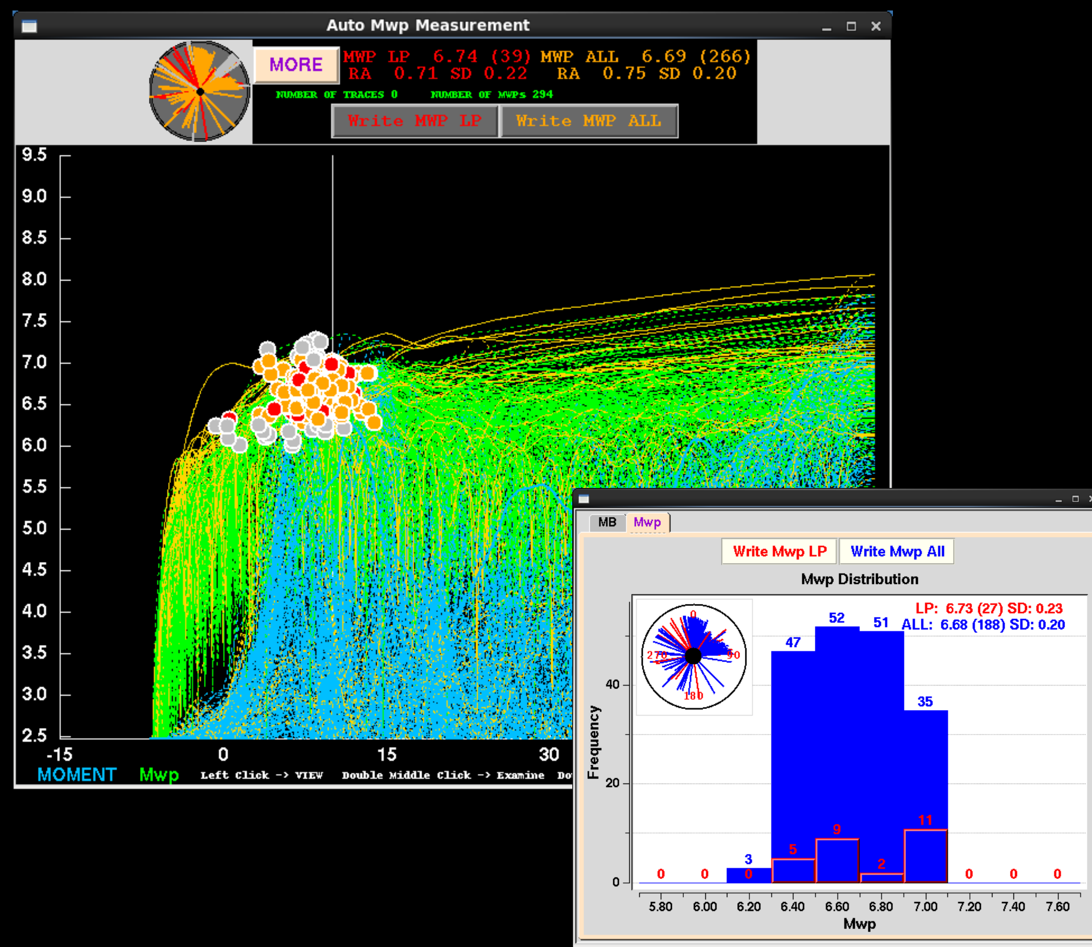

# TWC magnitude determination – PTWC (5 primary)

- ML - local magnitude, HI/PR/USVI (2<M<6)
- mb - body wave magnitude, largest P-waves (4<M<6.5)
- **Mm - mantle wave magnitude, 50-400s surface waves (M>6)**
- **Mwp – estimate of moment magnitude from integrated P-waves (5<M<8)**
- **W-phase - long-period phase, gives stable results, does not saturate, but takes ~20-25 minutes (M>5)**

# TWC magnitude determination – PTWC (5 primary)

- Measurements are not precise.
  Different magnitudes result from using different scales/methods and datasets.
- **Many methods saturate for large earthquakes**
- **Mo → EQ energy → ”true” EQ size but takes time**
- **TWC’s rely on Mwp for preliminary message products,  method can still underestimate great earthquake sizes.**
- **WCMT provides fault geometry and authoritative estimate of Mw but takes time (~15-25 minutes)**

# Thank You

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