# Lecture 15

## Earthquakes

Where do Earthquakes Occur?

Fault Movement

Seismology

Measuring Earthquakes

Hazards

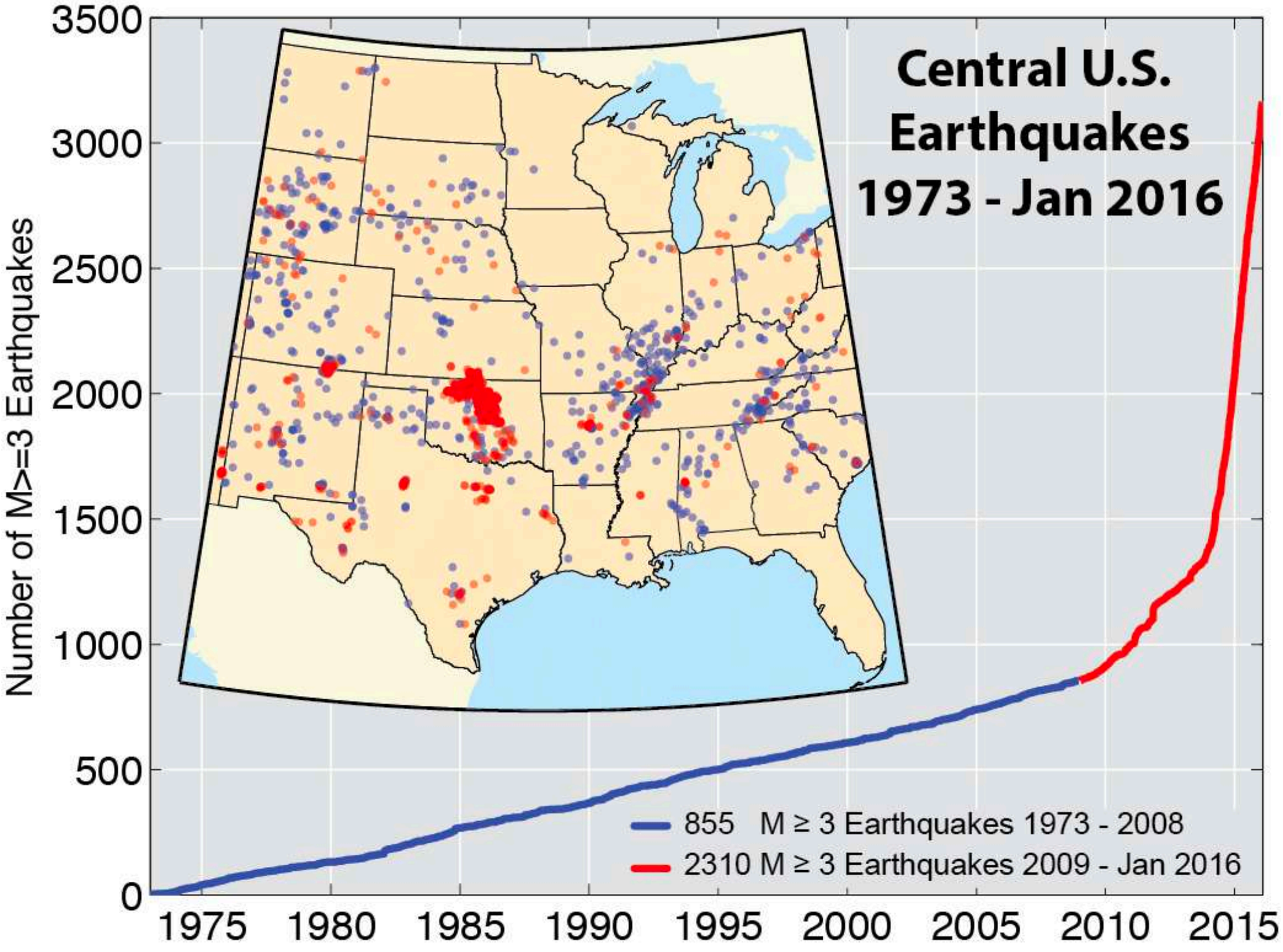
# Where do Earthquakes Occur?

- **Earthquakes** occur when pressure builds up along faults and is suddenly released
- They mainly occur along plate boundaries, but can occur anywhere

http://earthquake.usgs.gov/earthquakes/

# Where do Earthquakes Occur?

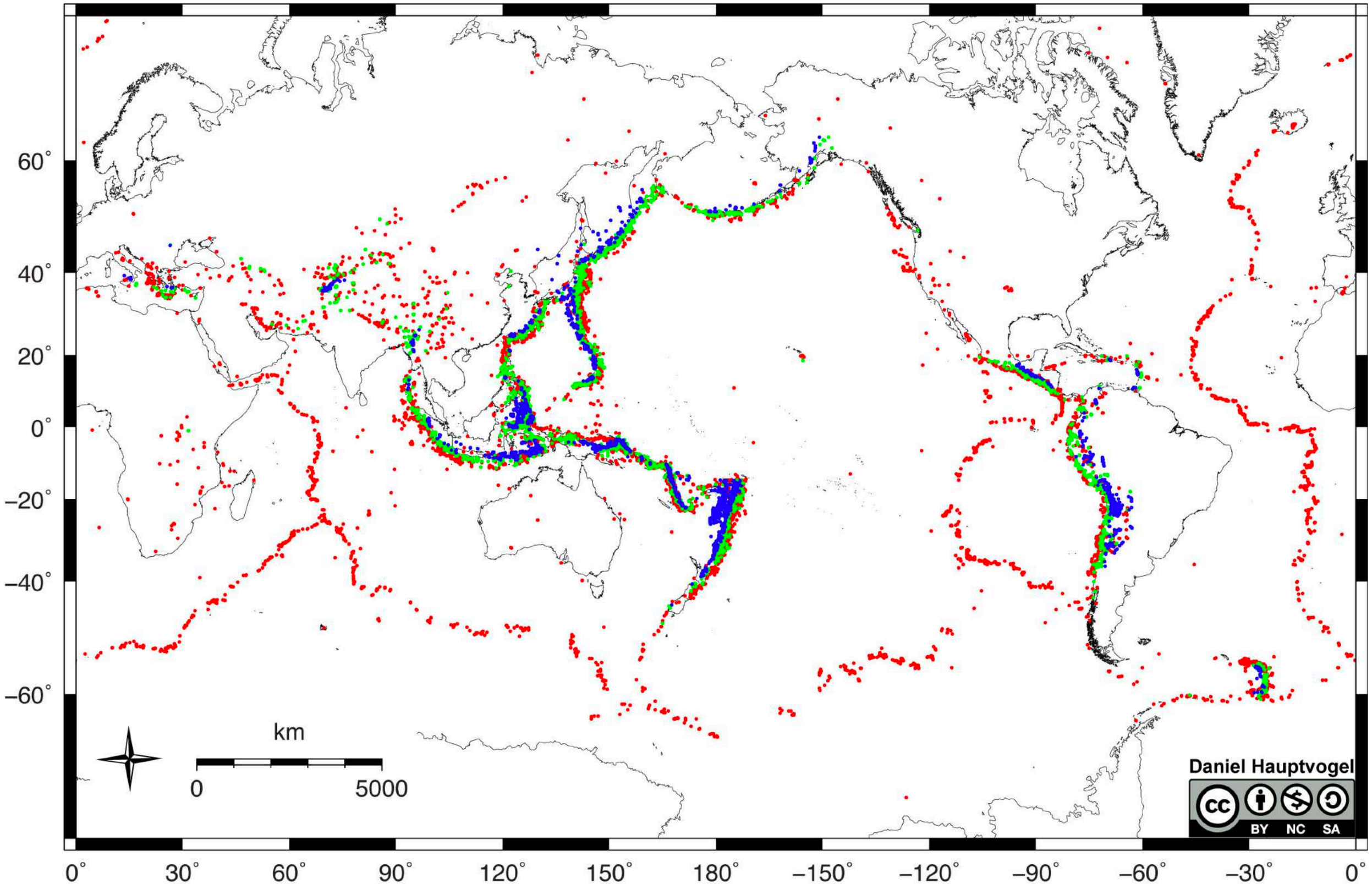
# Where do Earthquakes Occur?




- No earthquakes have been felt in Houston
- Closest was in 1910, M3.8 in Hempstead TX

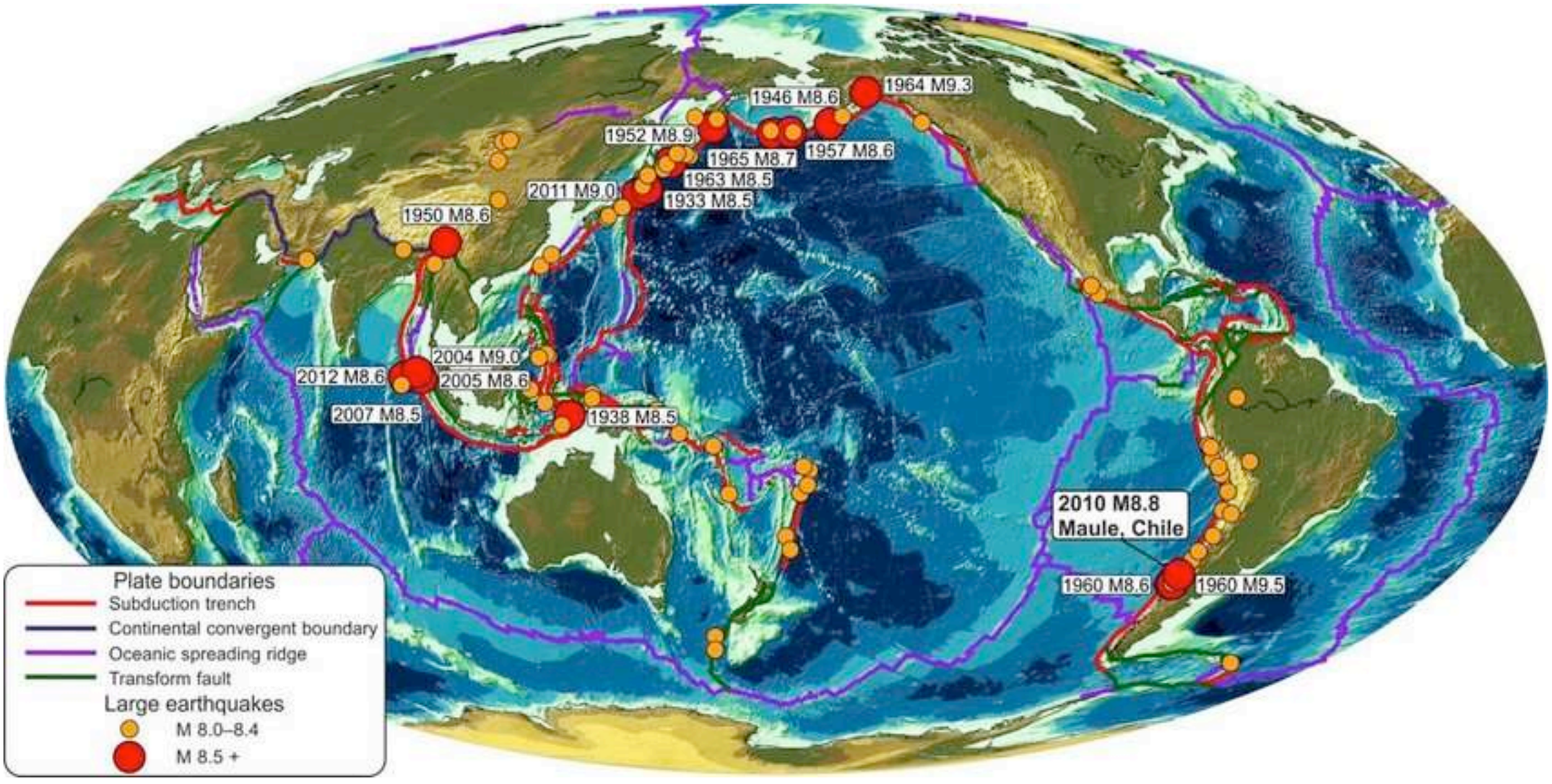
# Where do Earthquakes Occur?

## Earthquake locations 2015-2016, >M4.5



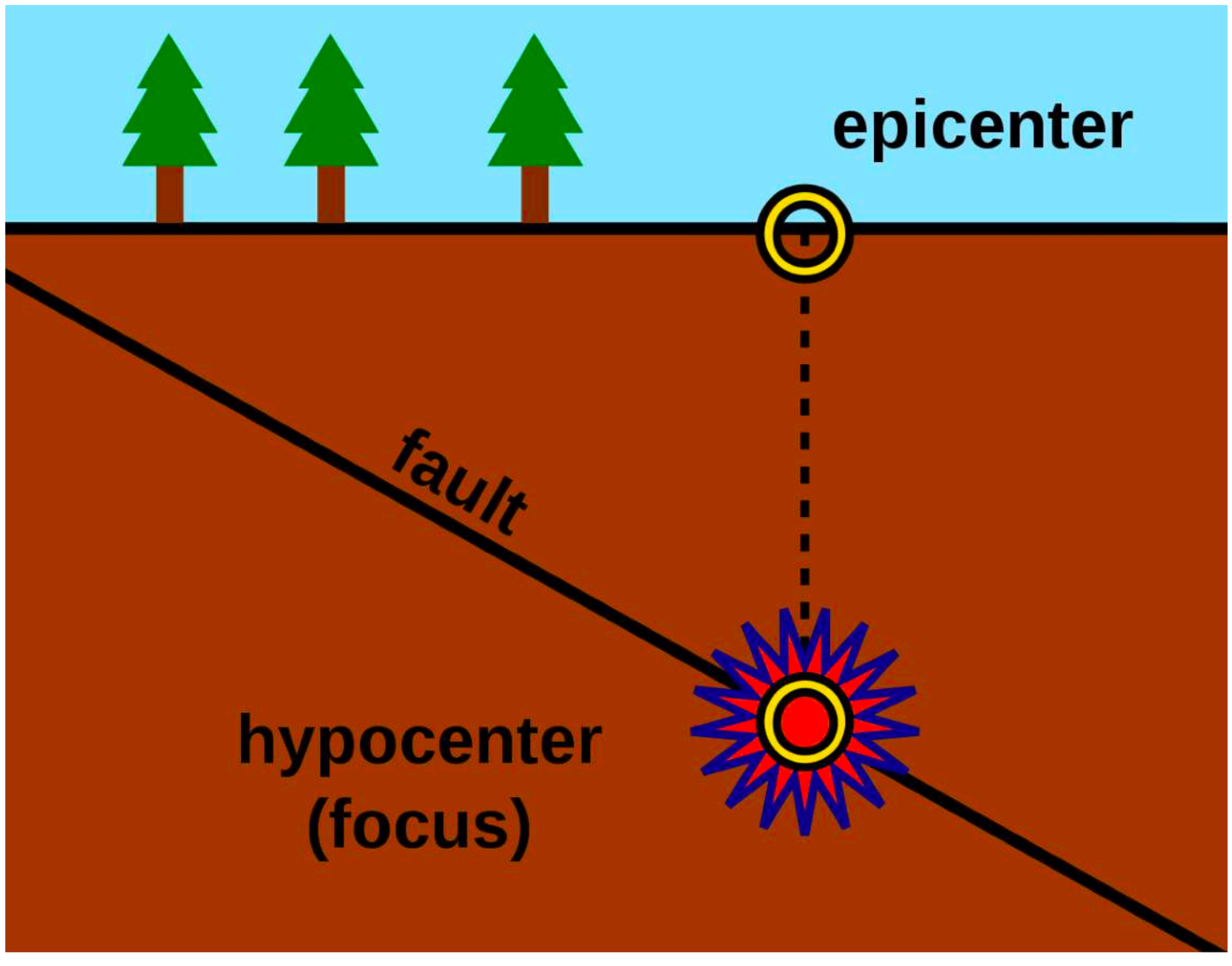
# Where do Earthquakes Occur?

## Historic Big Earthquakes since 1900



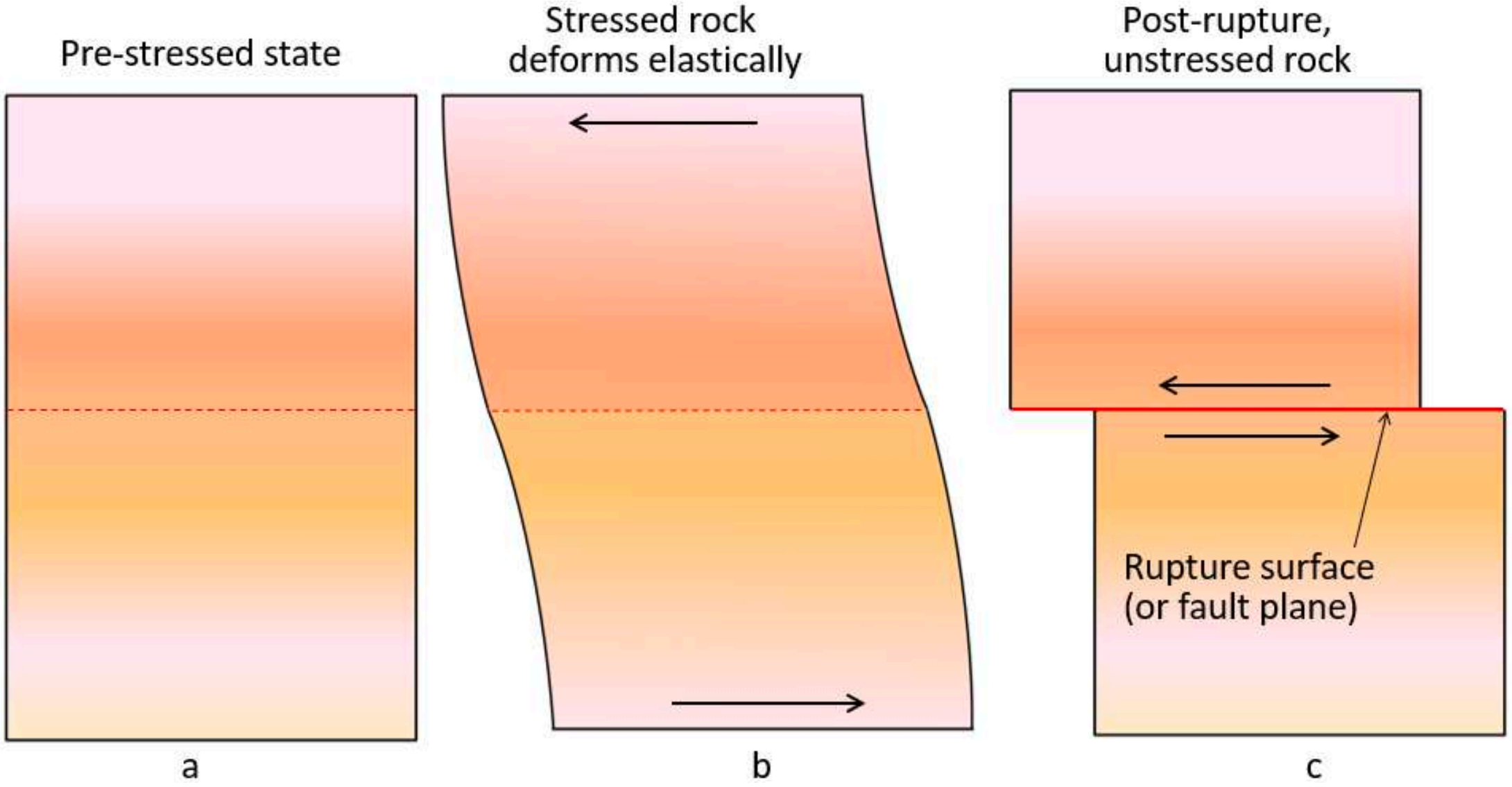
# Where do Earthquakes Occur?

- **Hypocenter (focus)** – Exact location of the earthquake within the Earth
- **Epicenter** – Location on the surface directly above the hypocenter



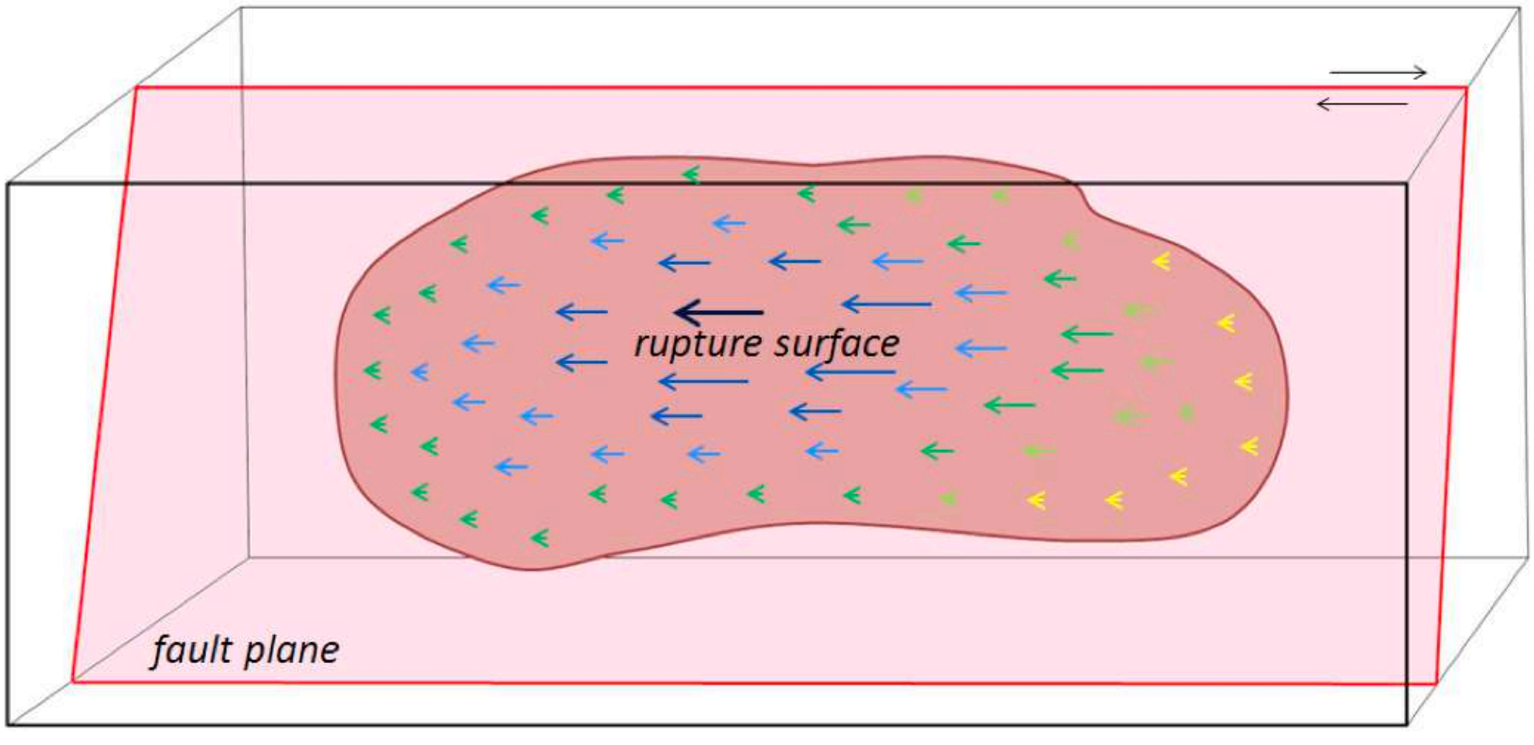
# Fault Movement

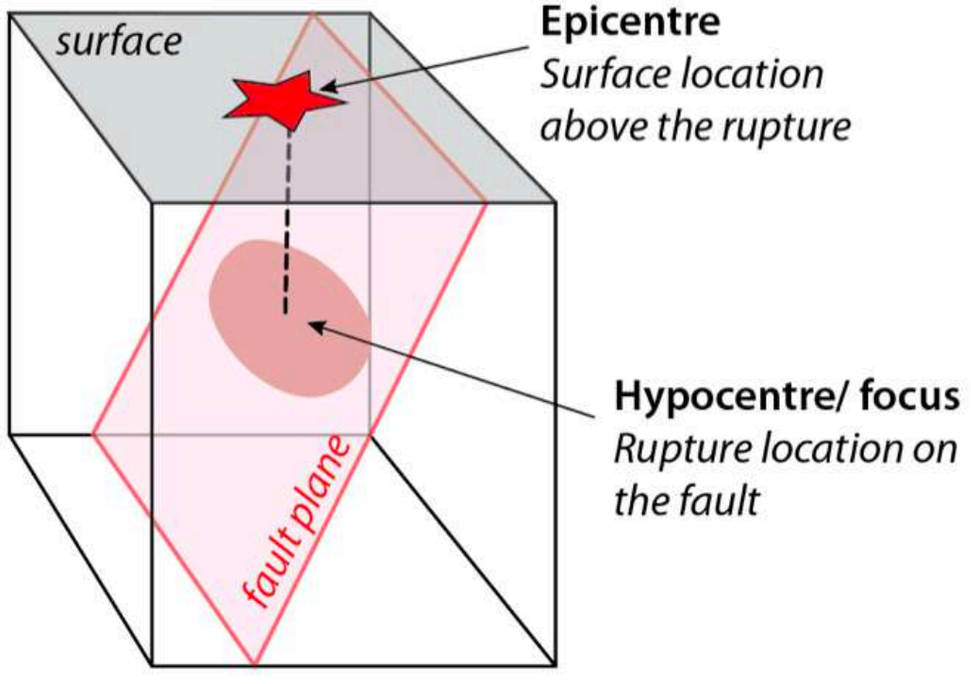
- Pressure builds up along a fault until it reaches a critical threshold
- Then the pressure (energy) is suddenly released > Earthquake



# Fault Movement

- Not everywhere along the fault will move (rupture), only where energy is released



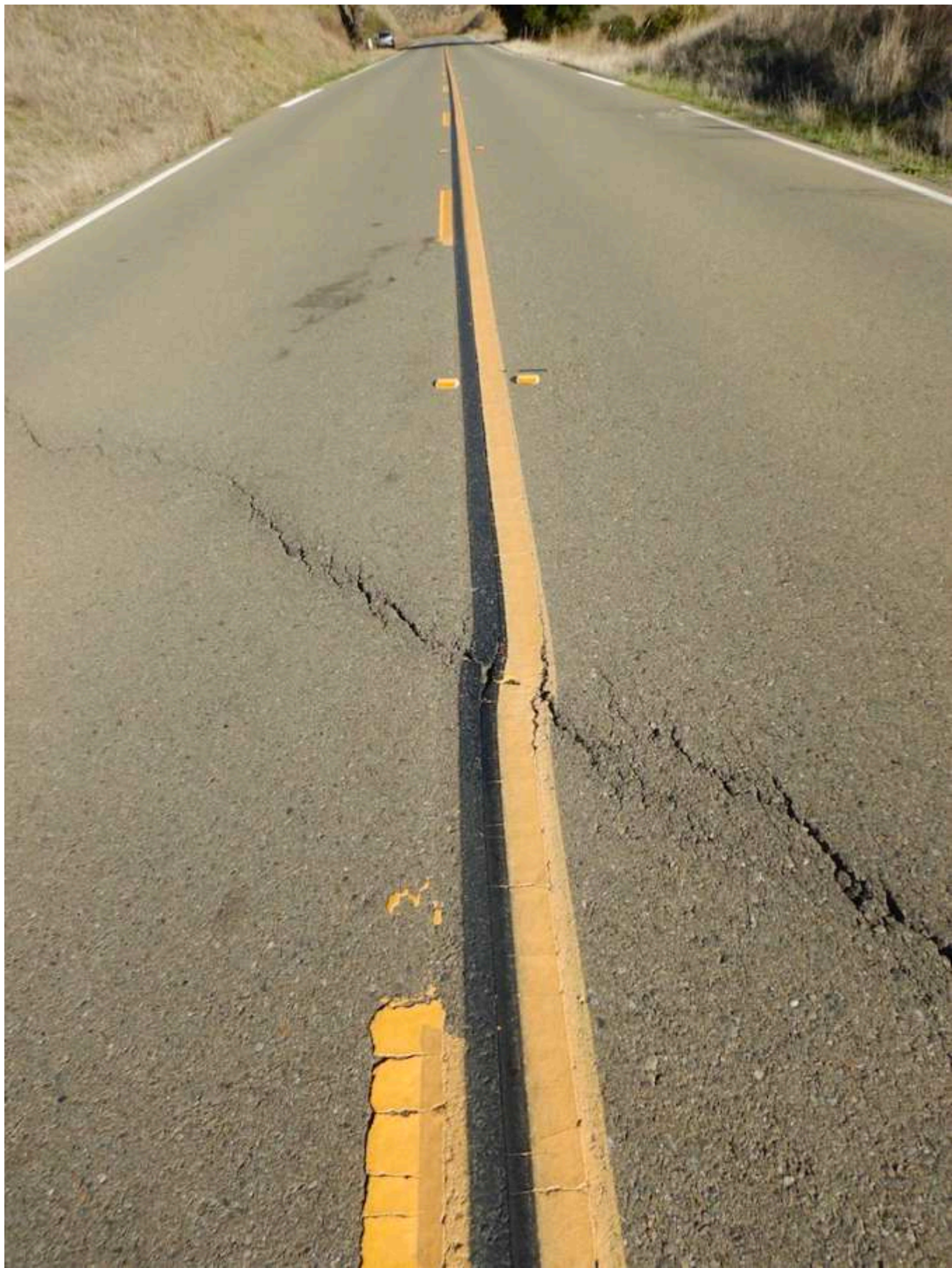
# Fault Movement

- Faults move in two different ways
- **Fault creep** – Slow, gradual displacement (motion)
  - Small earthquakes
- **Stick-slip** – Fault stays “locked”, storing energy, then suddenly slips, releasing the stored energy
  - Big earthquakes

# Fault Movement

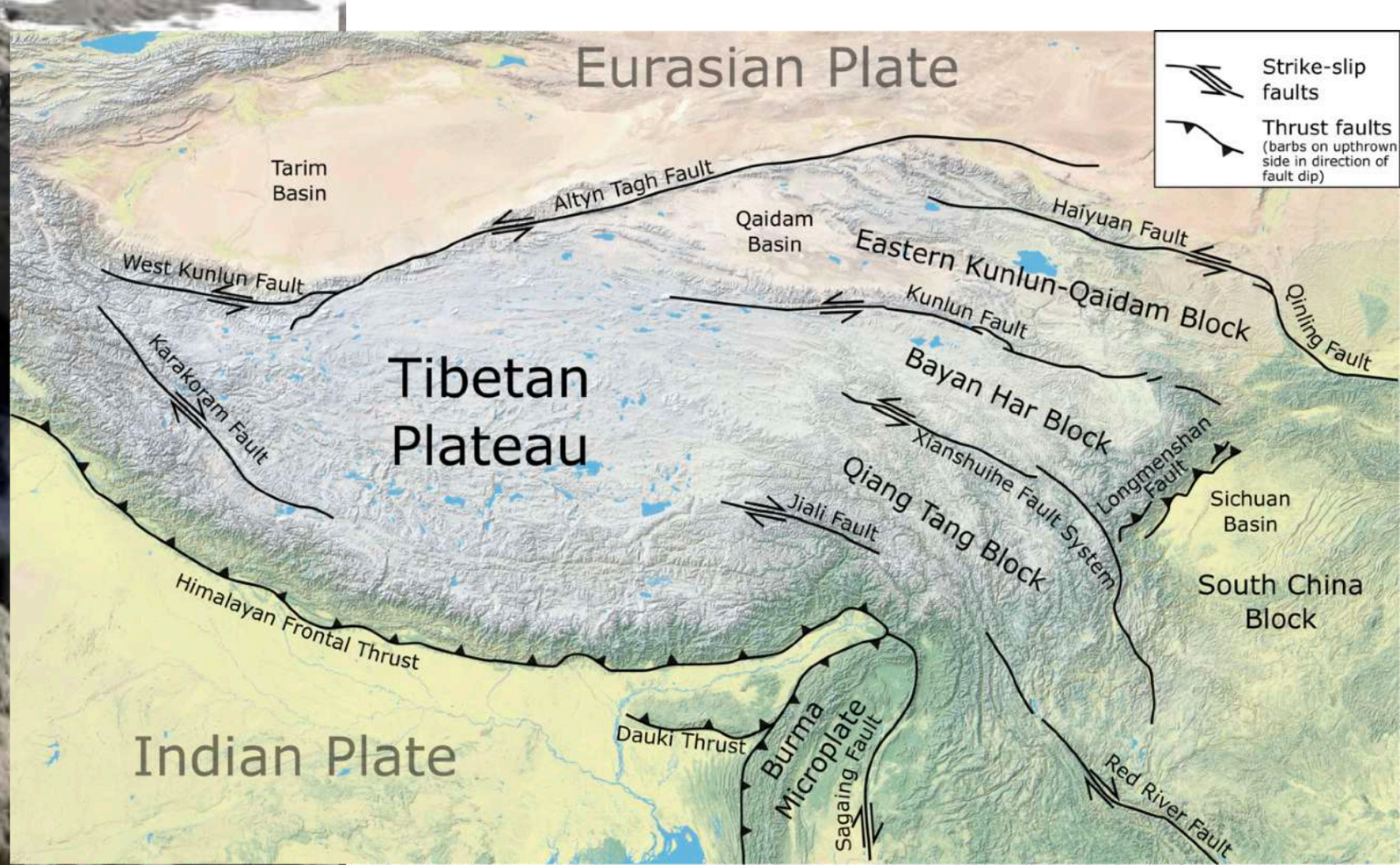
## Fault Creep behavior

San Andreas Fault



Fault Movement

# Results of stick-slip behavior Kunlun Fault, Northern Tibet



Fault Movement

# Results of stick-slip behavior

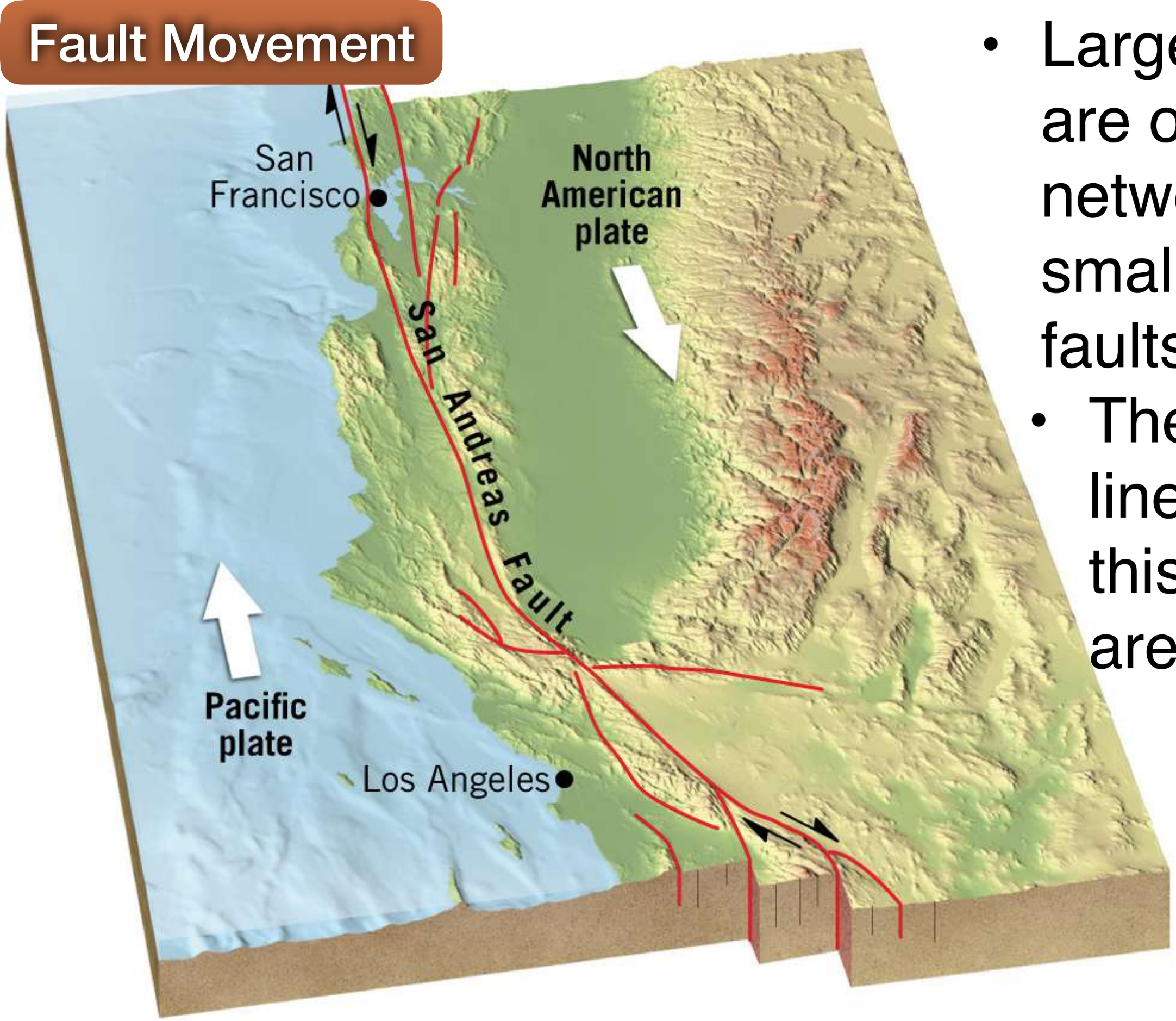

Fault Movement

# Results of stick-slip behavior

# Fault Movement


- Both types of movement can occur along the same fault

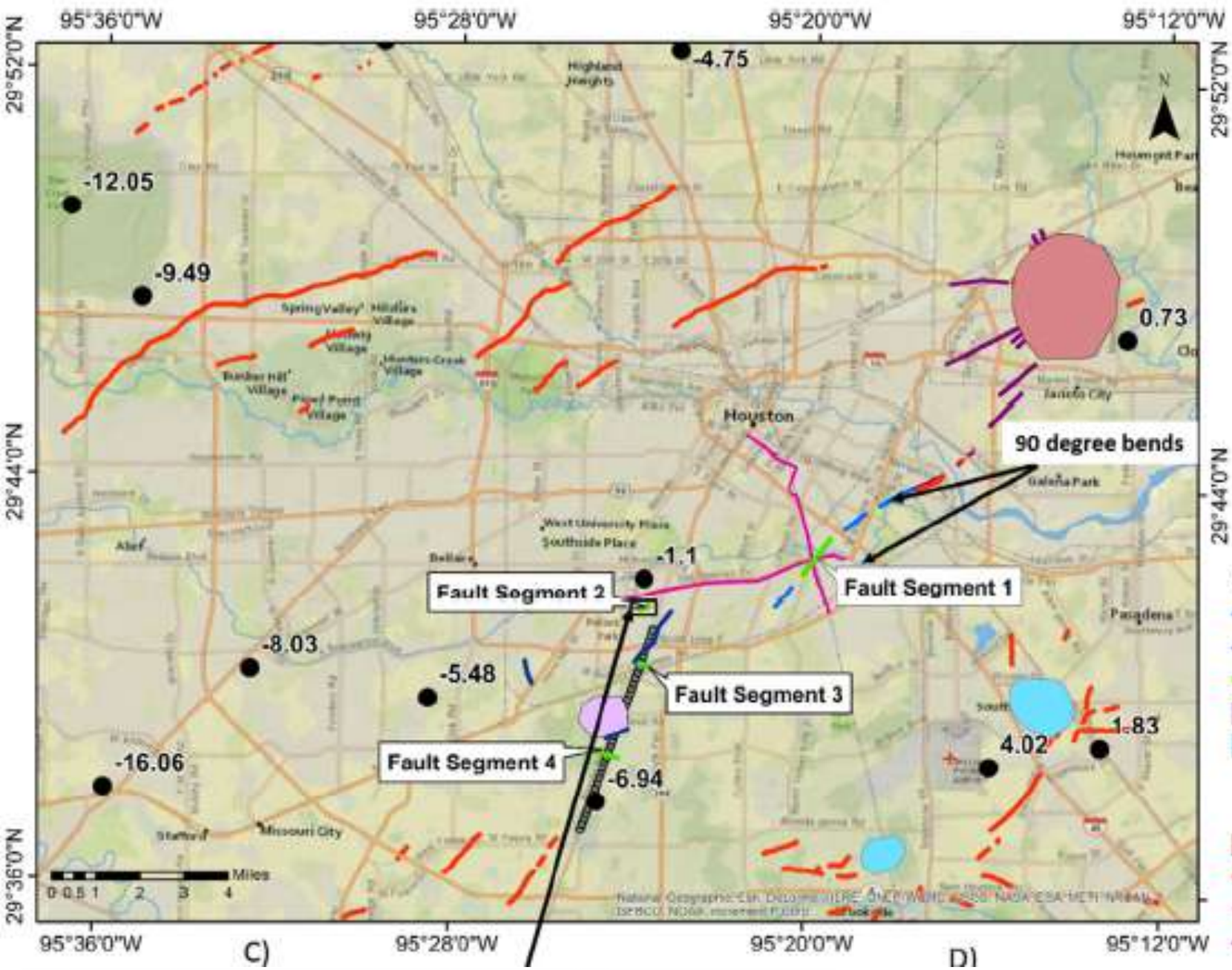
# Fault Movement




- Large faults are often networks of smaller faults
- The red lines on this image are faults

# Fault Movement

- Faults around Houston are from the opening of the Gulf of Mexico and uplift of salt domes





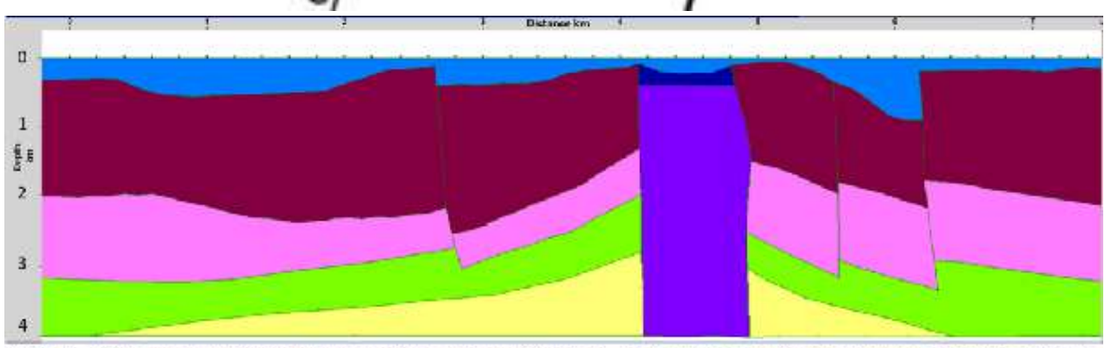


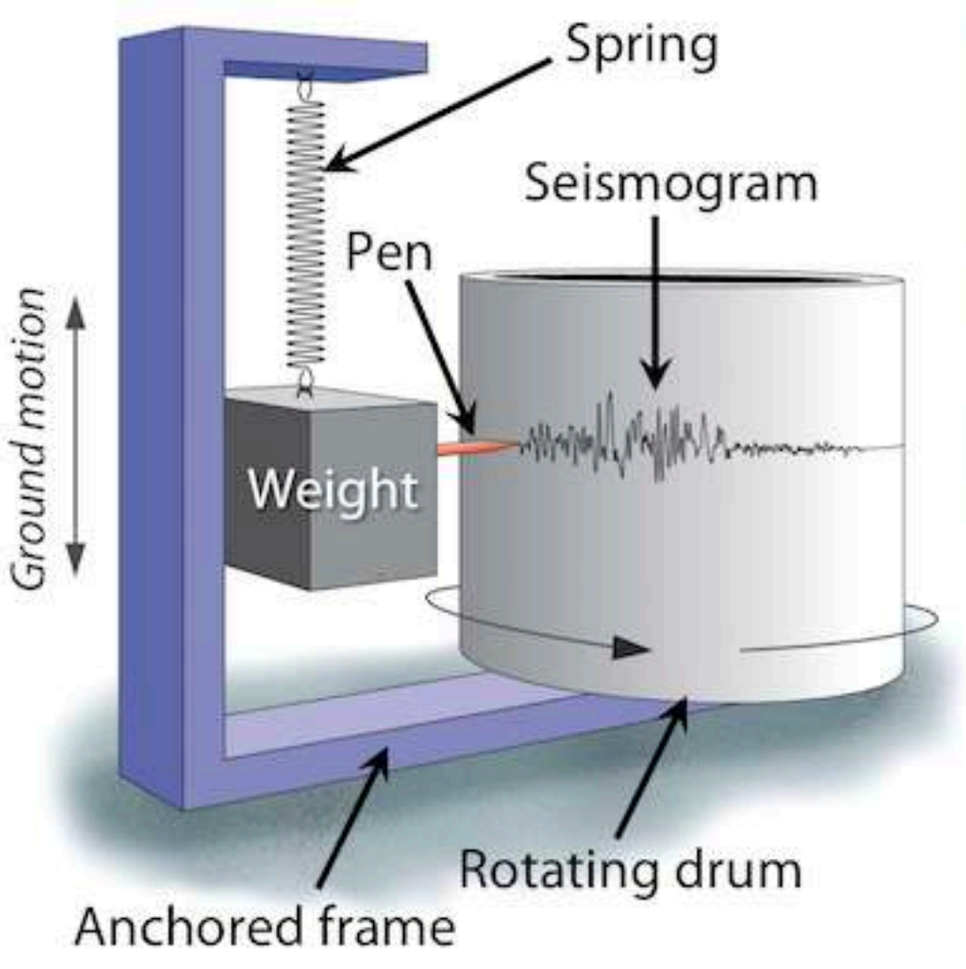
Figure 5. 7600 m long gravity profile cross Pierce Junction Salt Dome. Red dots and red line represent the observed and calculated gravity, respectively. Fault segments 3 and 4 were modeled based on the gravity data (Fossen, 2010).

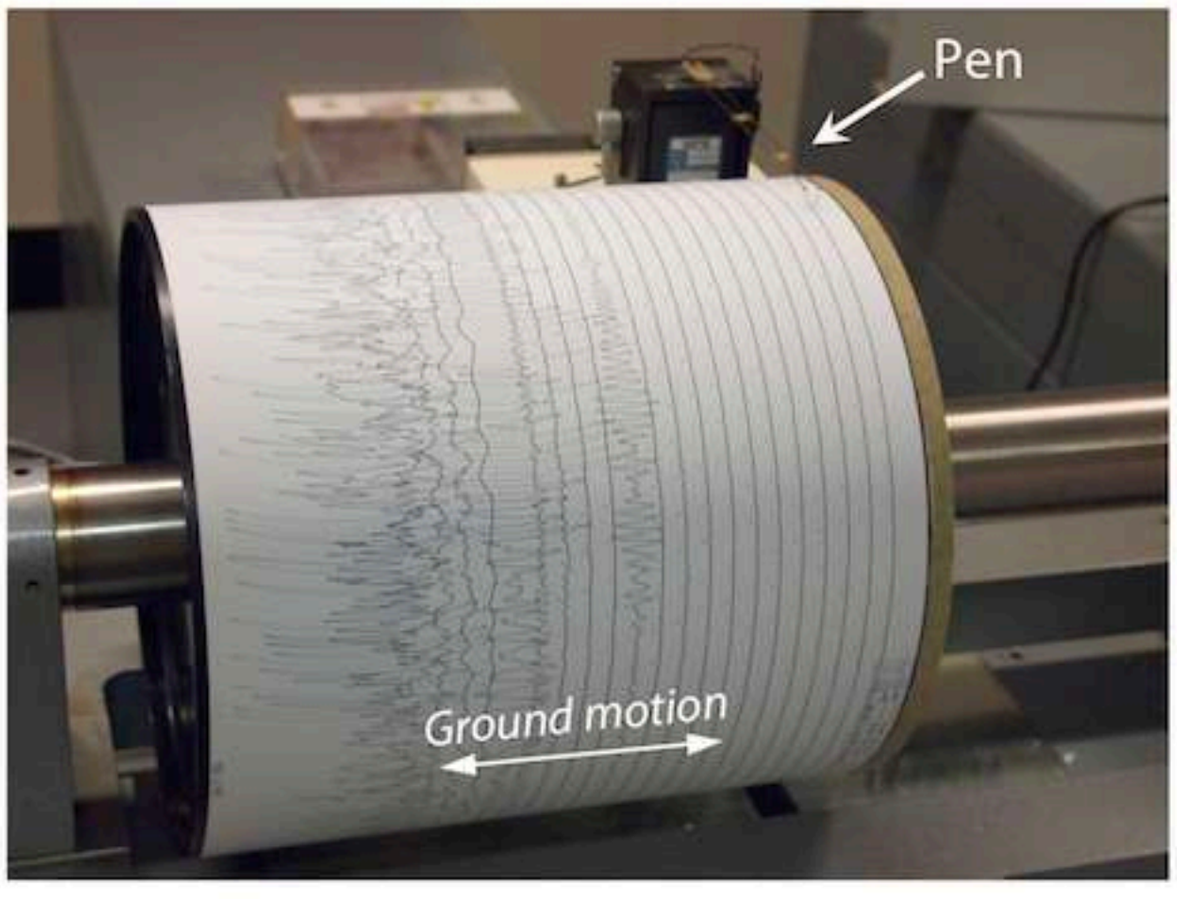
Data from Huang et al. (2015)

# Houston Faults

# Seismology

- **Seismology** is the study of earthquake waves
- These waves are recorded by seismographs

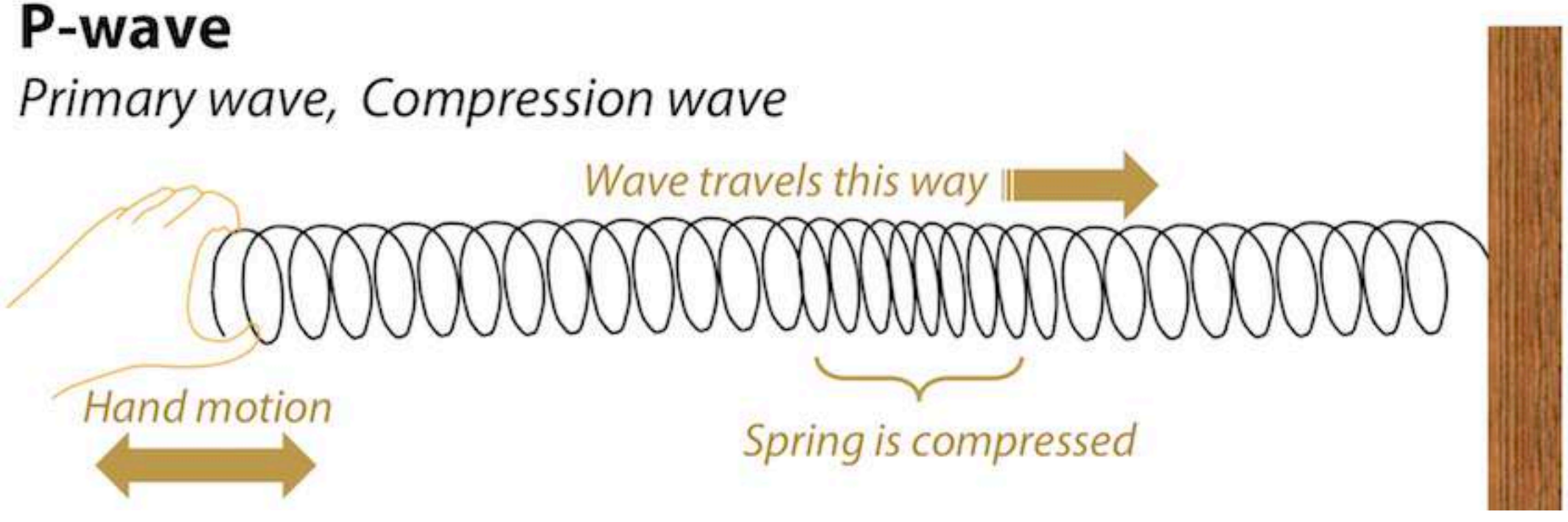


# Seismology

- Types of seismic waves
  - **P-waves (primary)**
    - Push-pull (compress and expand) motion
    - Travel through solids, liquids, and gases
  - **S-waves (secondary)**
    - Shaking motion at right angles to their direction of travel
    - Only travels through solids
  - **Surface waves**
    - Travel along the outer part of Earth
    - Cause the greatest destruction

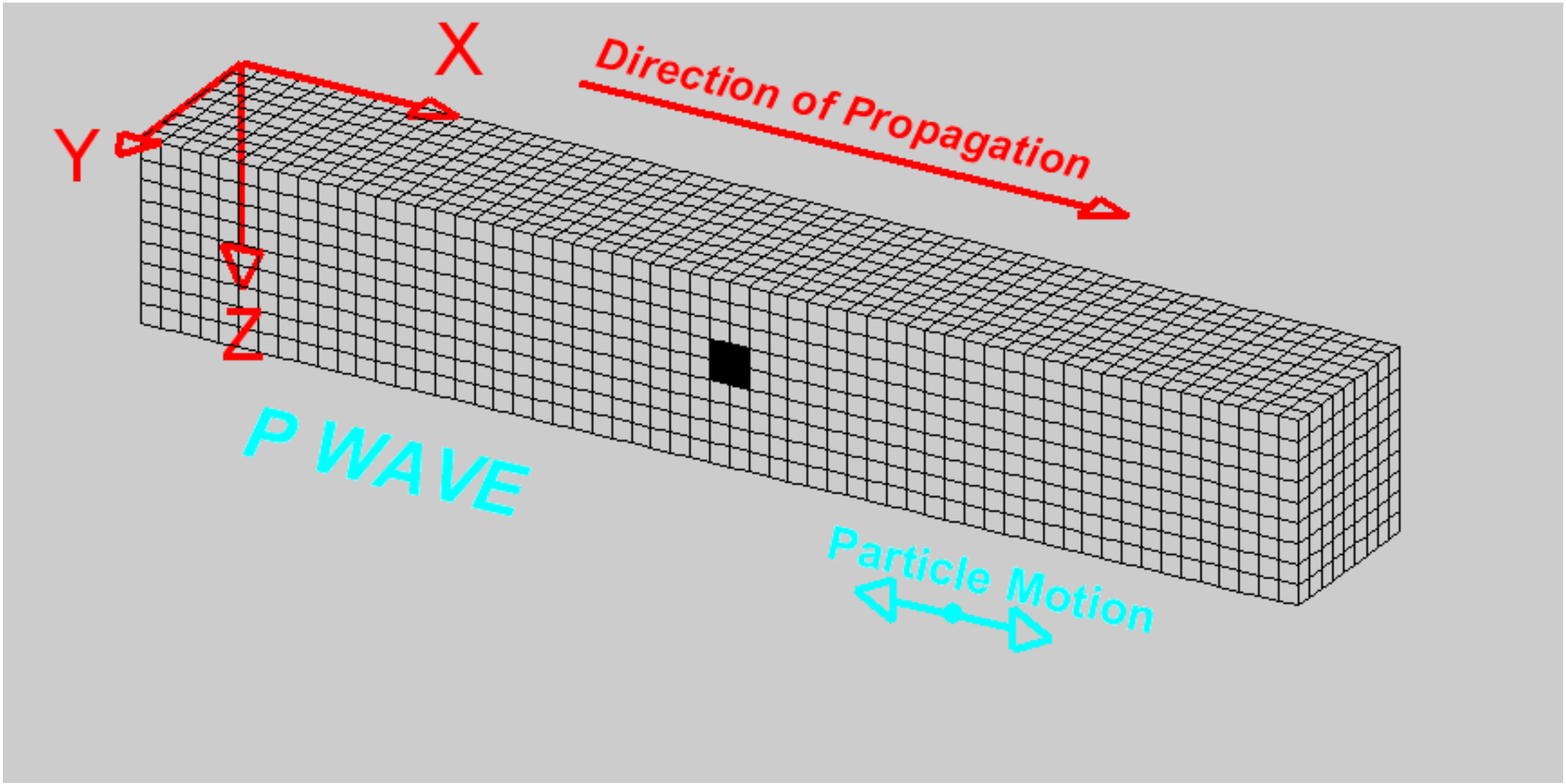
- **P-waves (primary)**
  - Push-pull (compress and expand) motion
  - Travel through solids, liquids, and gases
  - Fastest of the seismic waves



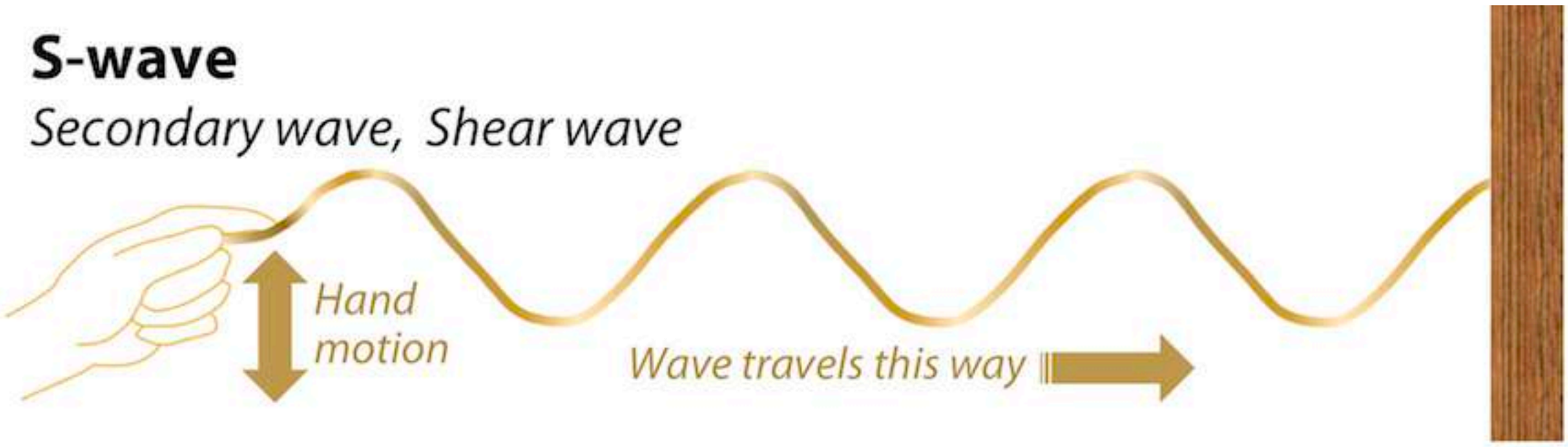
# Seismology

Animation link

- **P-waves (primary)**
  - Push-pull (compress and expand) motion
  - Travel through solids, liquids, and gases

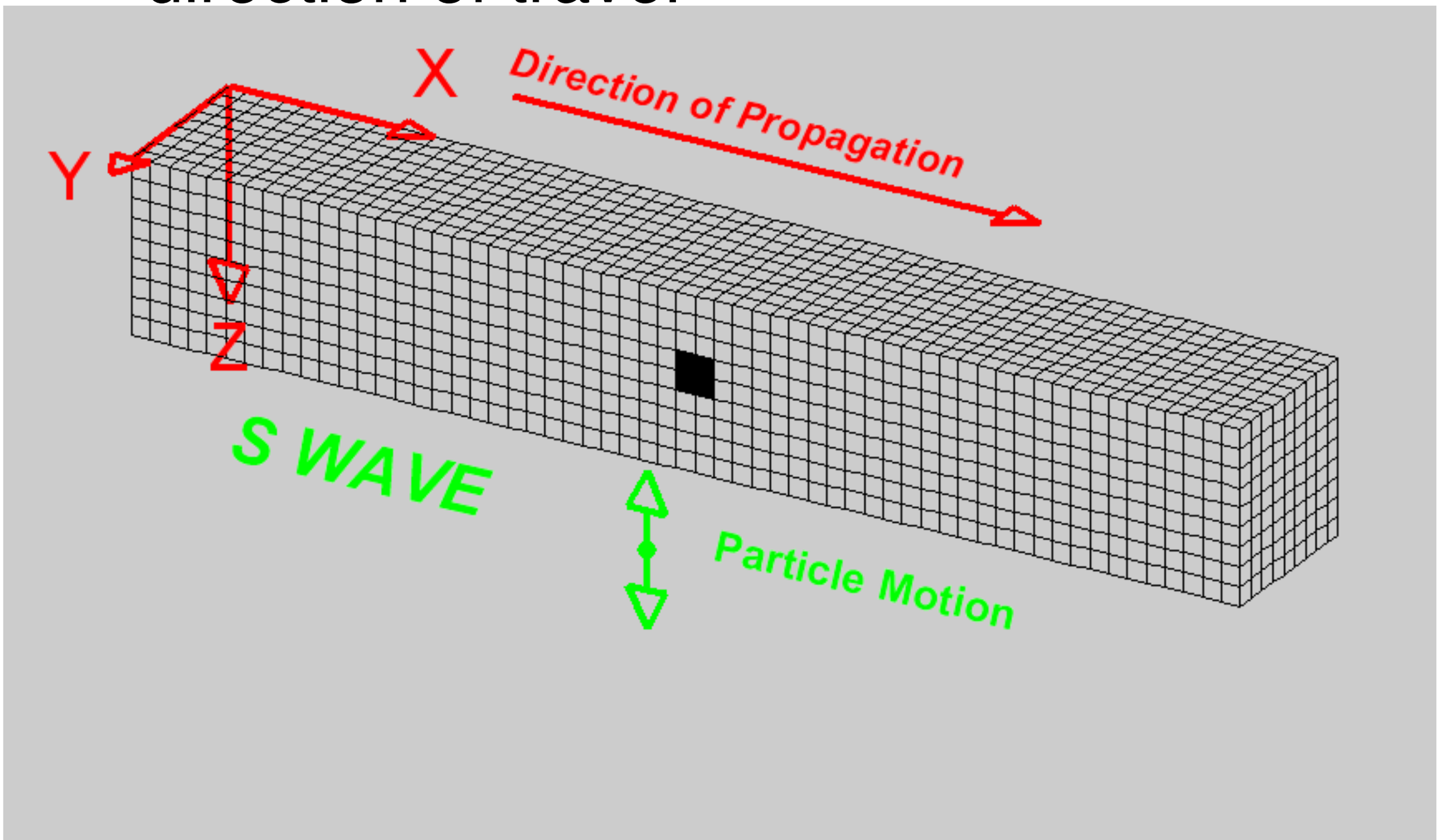


- **S-waves (secondary)**
  - Shaking motion at right angles to their direction of travel
  - Only travels through solids
  - 2nd fastest of the seismic waves



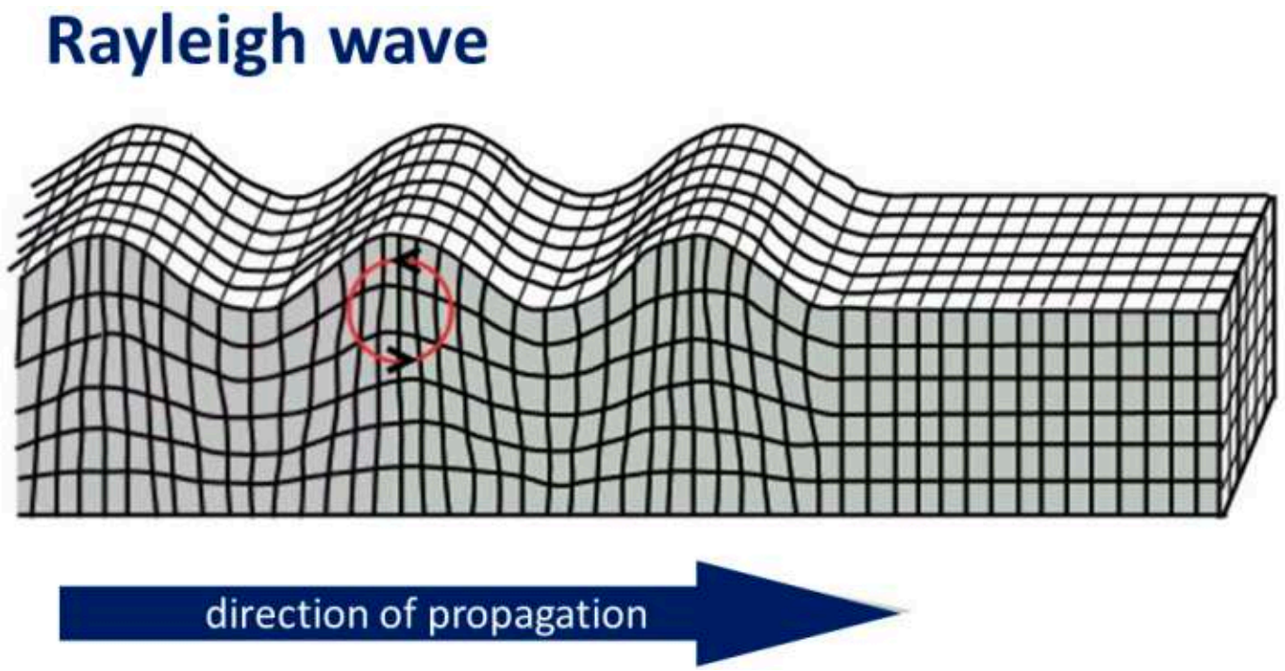
Animation link

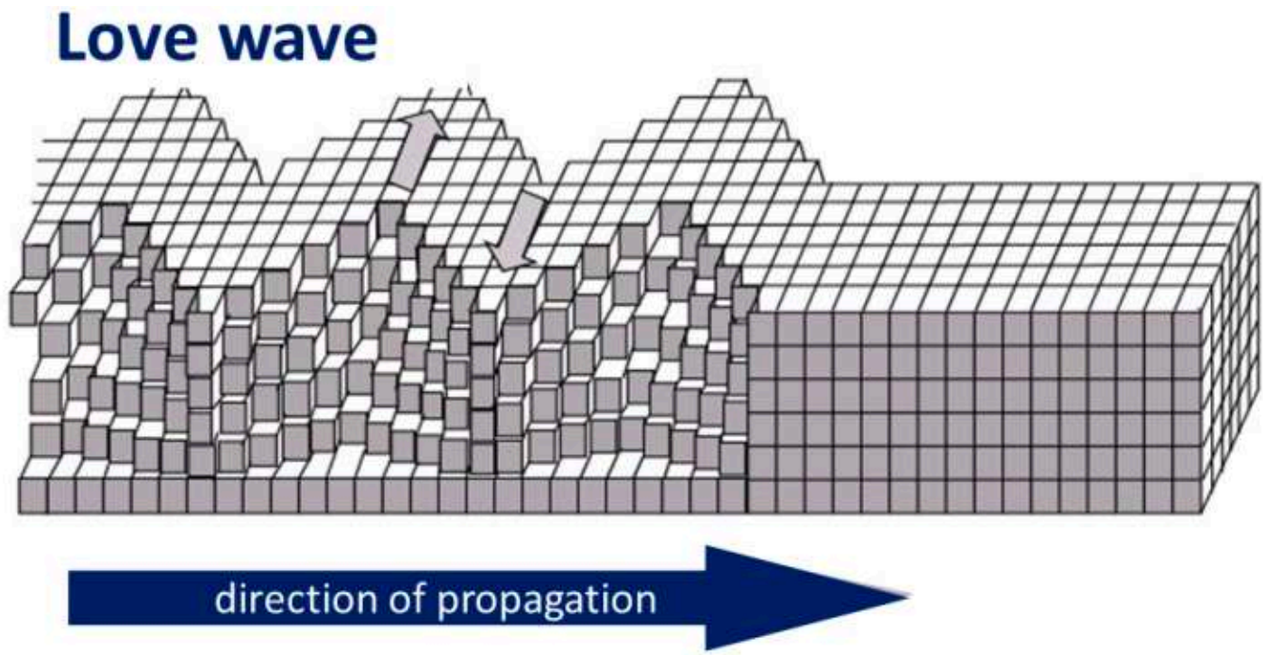
- **S-waves (secondary)**
  - Shaking motion at right angles to their direction of travel



# Seismology

- **Surface waves**
  - Travel along the outer part of Earth
  - Cause the greatest destruction
  - Slow moving waves with high amplitude

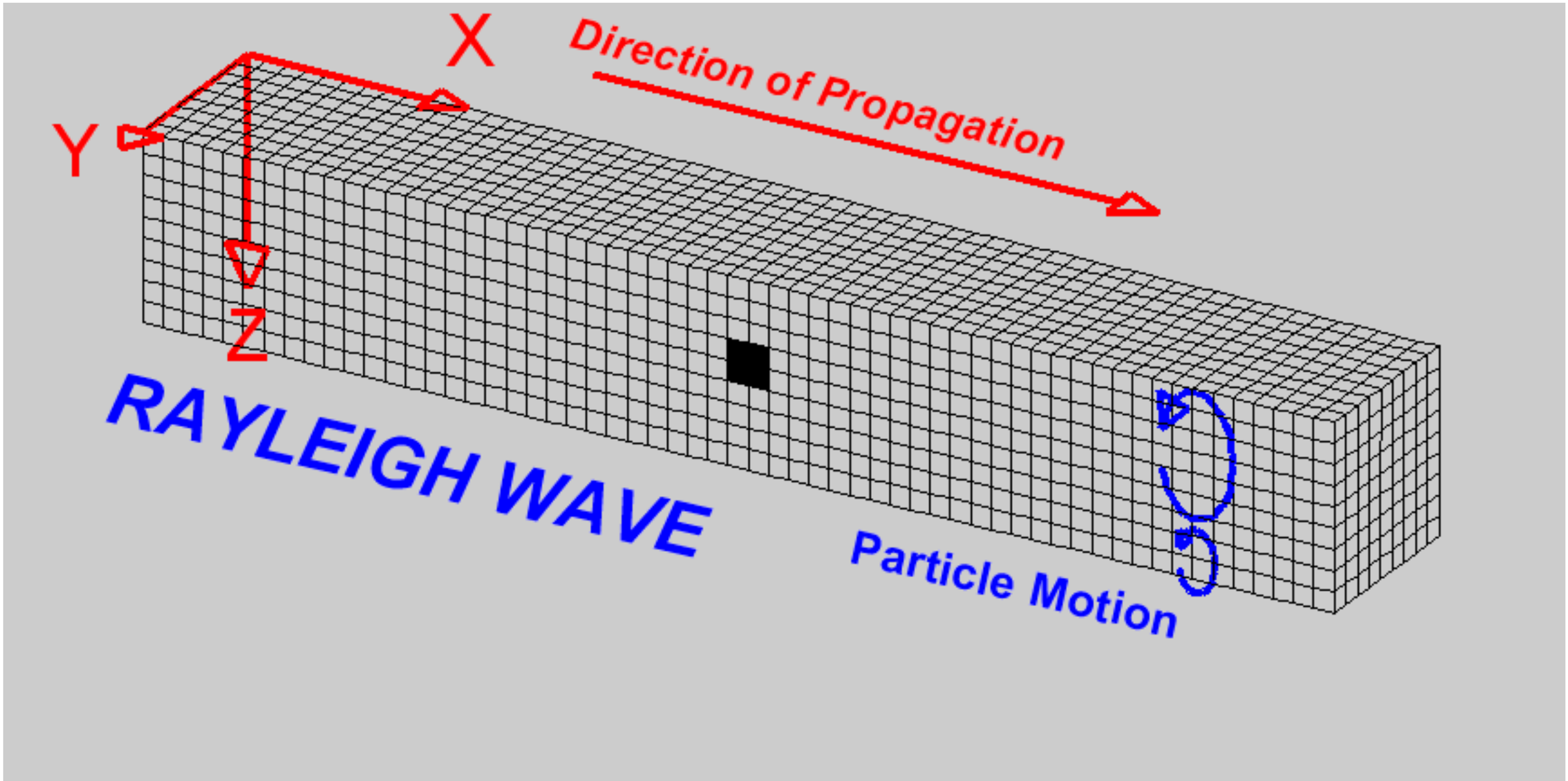


# Seismology

Animation link

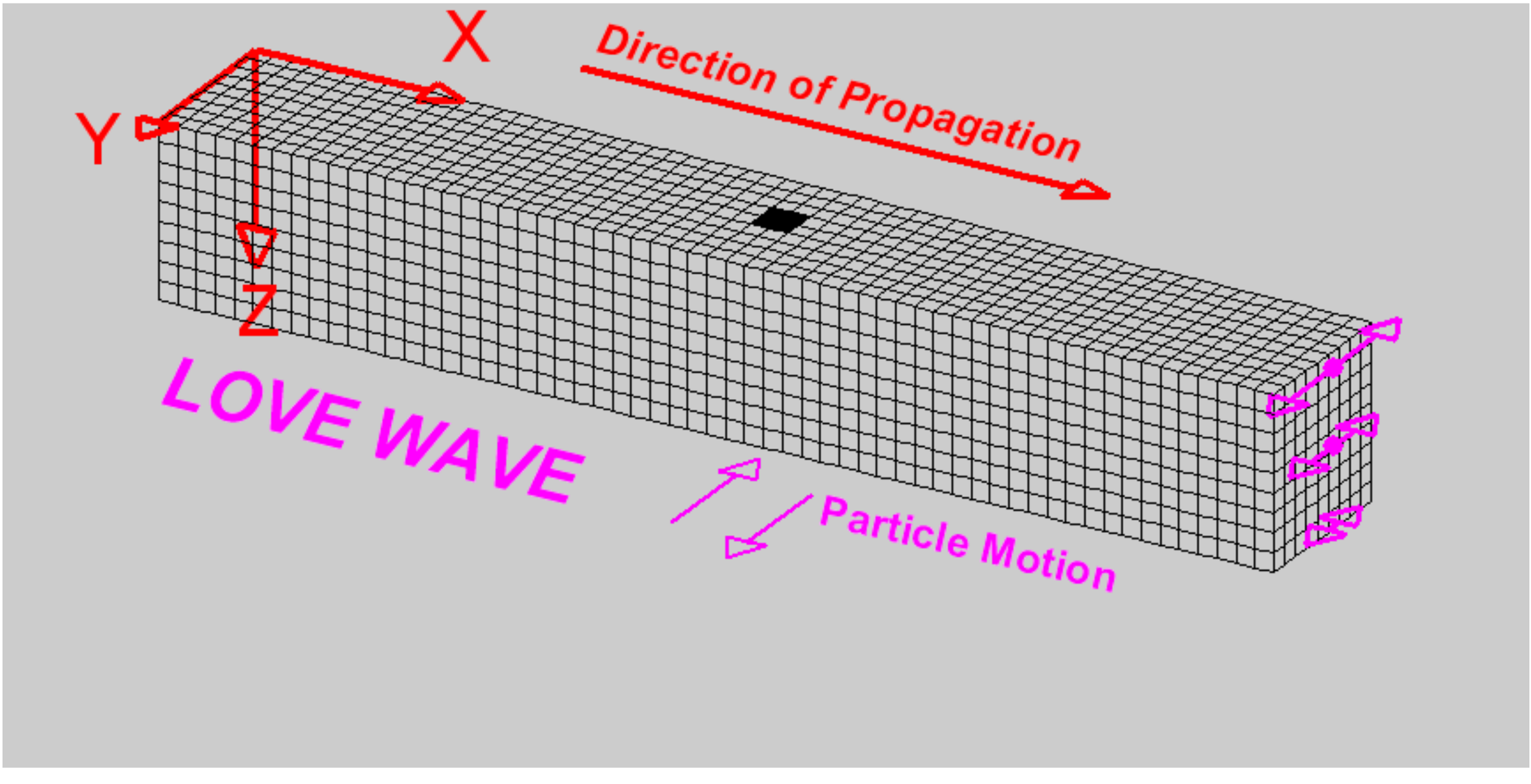
- **Surface waves**
  - Travel along the outer part of Earth
  - Cause the greatest destruction



# Seismology

Animation link

- **Surface waves**
  - Travel along the outer part of Earth
  - Cause the greatest destruction



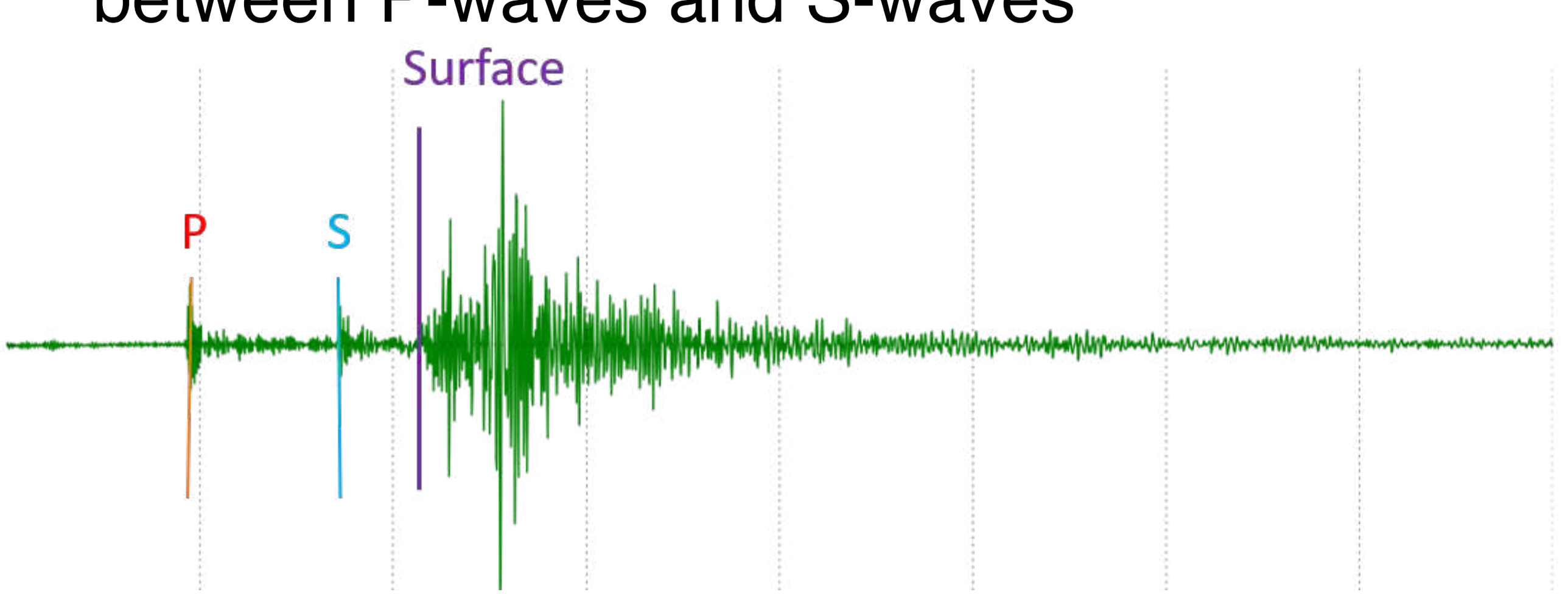
Seismology

# Properties of seismic waves

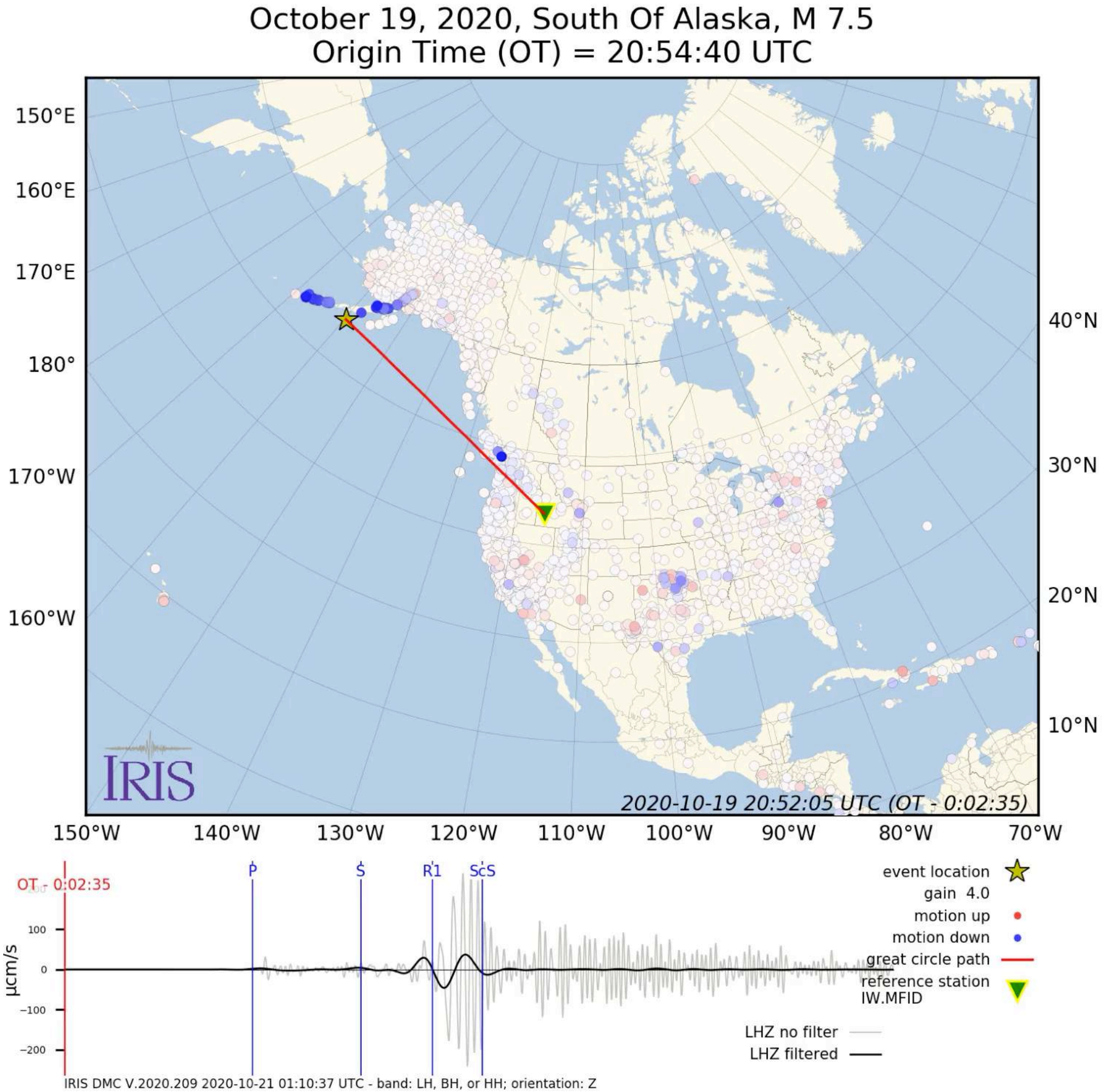
| | P-Waves | S-Waves | Surface Waves |
|---|---|---|---|
| **Velocity** | Fastest | Intermediate | Slowest |
| **Amplitude** | Lowest | Intermediate | Highest |
| **Period** | Shortest | Intermediate | Longest |
| **Medium** | Solid, Liquid, Gas | Solid | Earth's Surface |

# Seismology

- P-waves are first to arrive at seismic stations, followed by S-waves and then Surface Waves
- The further away a seismic station is from an earthquake, the longer the time gap between P-waves and S-waves

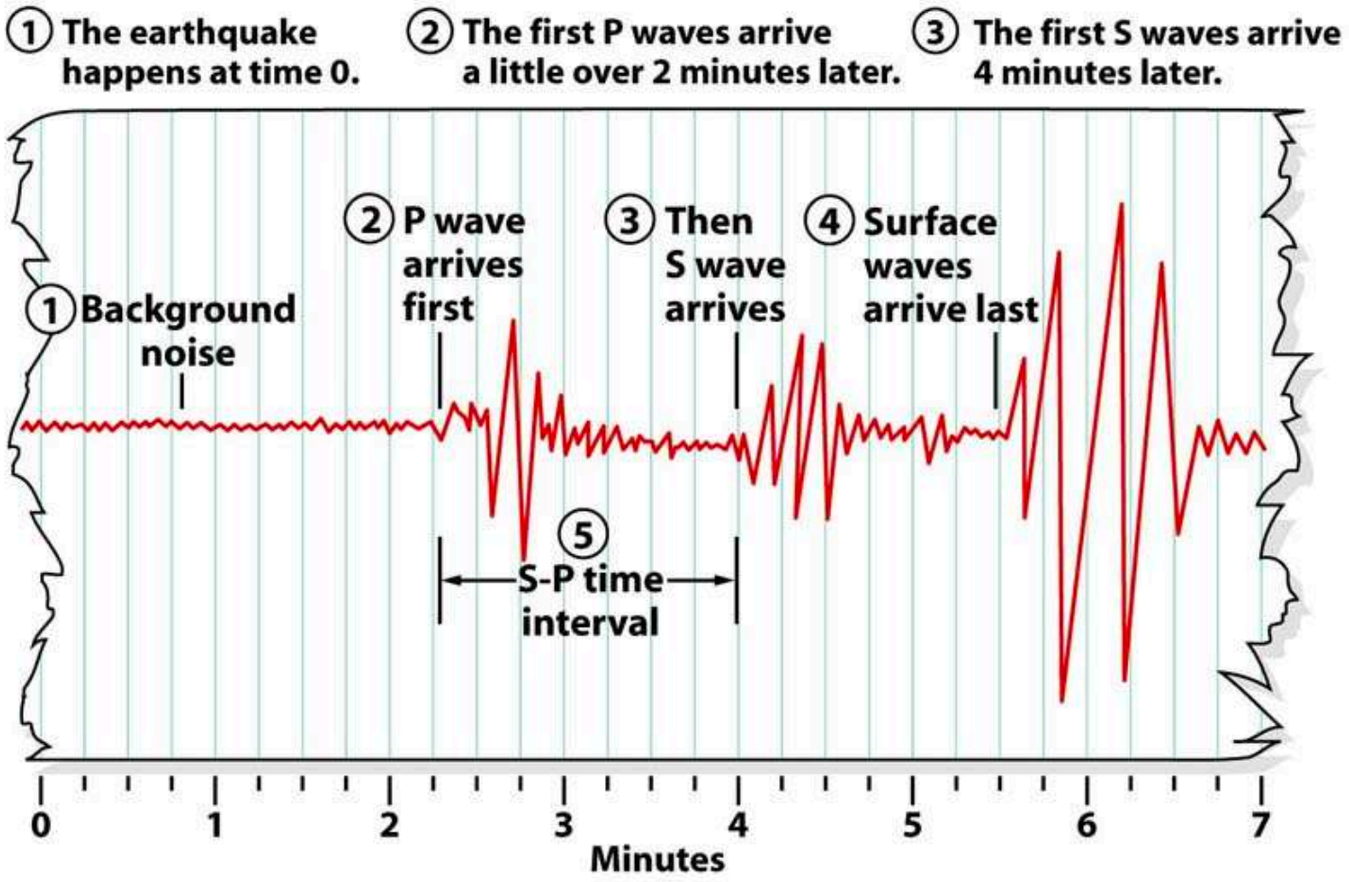


# Seismology


October 19, 2020, South Of Alaska, M 7.5
Origin Time (OT) = 20:54:40 UTC
150°E
160°E
170°E
180°
170°W
160°W
40°N
30°N
20°N
10°N
IRIS
2020-10-19 20:52:05 UTC (OT - 0:02:35)
150°W
140°W
130°W
120°W
110°W
100°W
90°W
80°W
70°W
OT - 0:02:35
P
S
R1
ScS
100
0
−100
−200
µcm/s
event location
gain 4.0
motion up
motion down
great circle path
reference station
IW.MFID
LHZ no filter
LHZ filtered
IRIS DMC V.2020.209 2020-10-21 01:10:37 UTC - band: LH, BH, or HH; orientation: Z

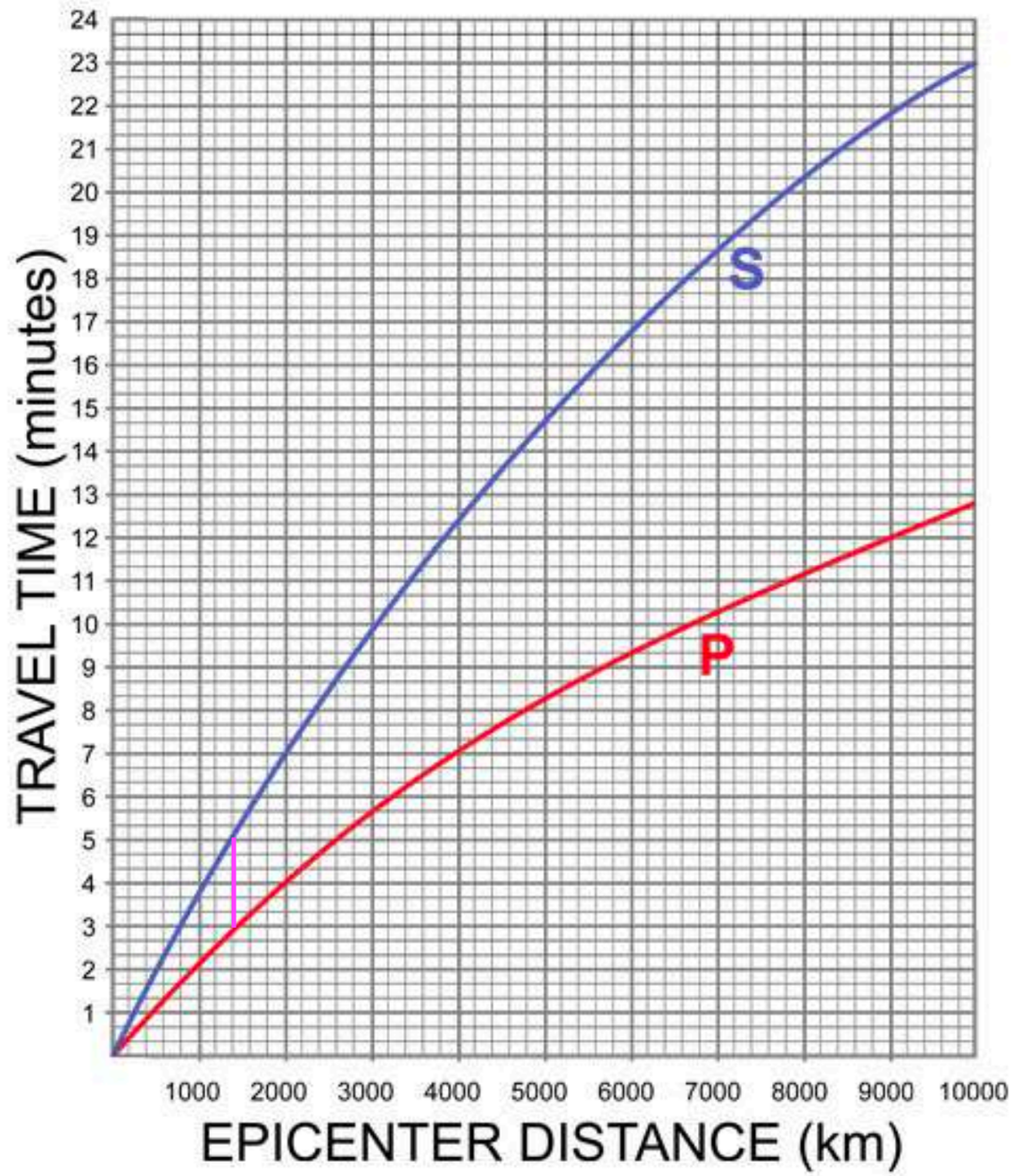
# Seismology

- By measuring the time difference between P-wave and S-wave arrival, we can tell how far away an earthquake was from a seismic station



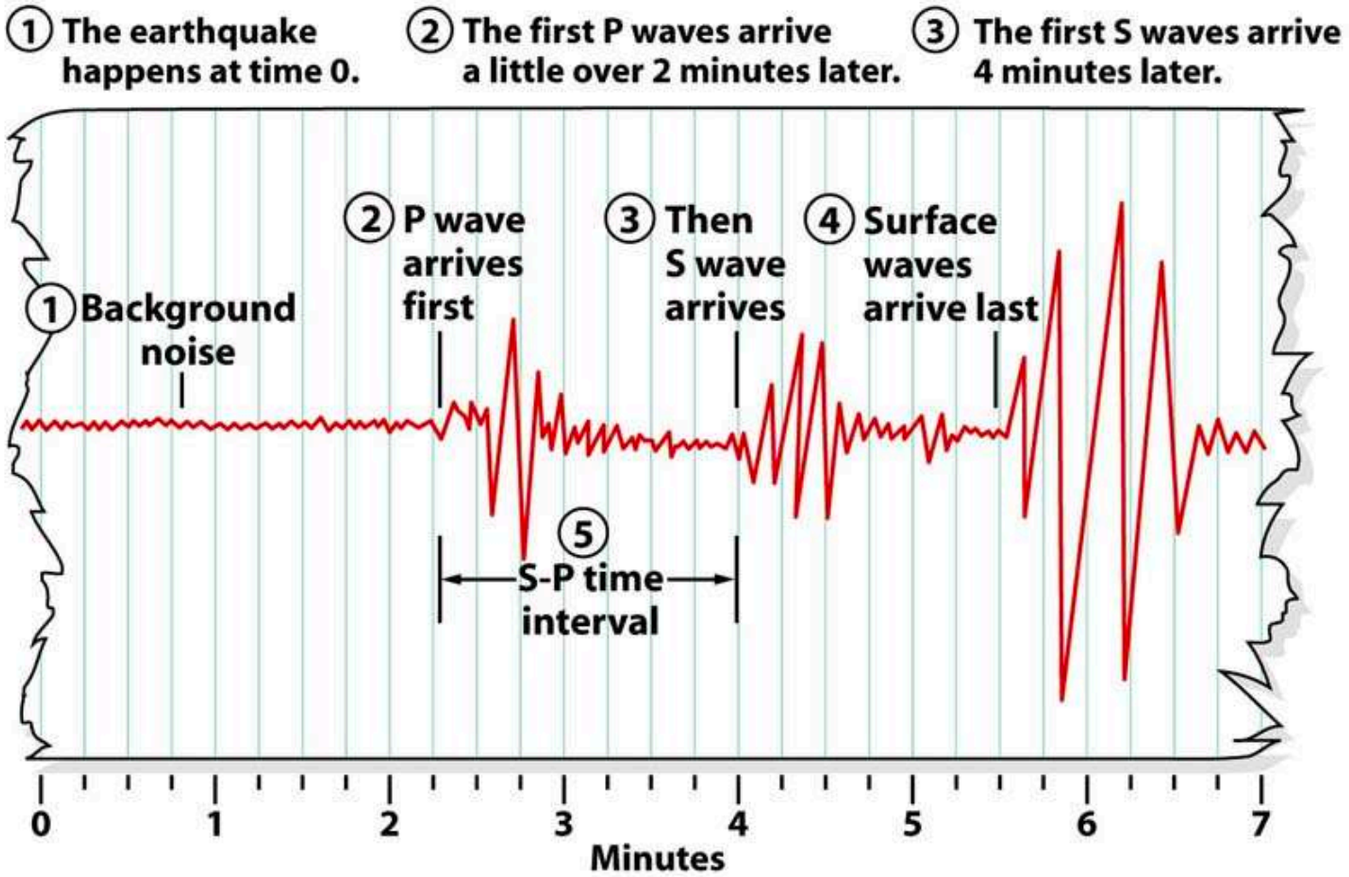

④ The surface waves, which travel the long way around Earth's surface, arrive last.

⑤ The S-P interval, here slightly less than 2 minutes, tells the seismologist how far away the earthquake was.



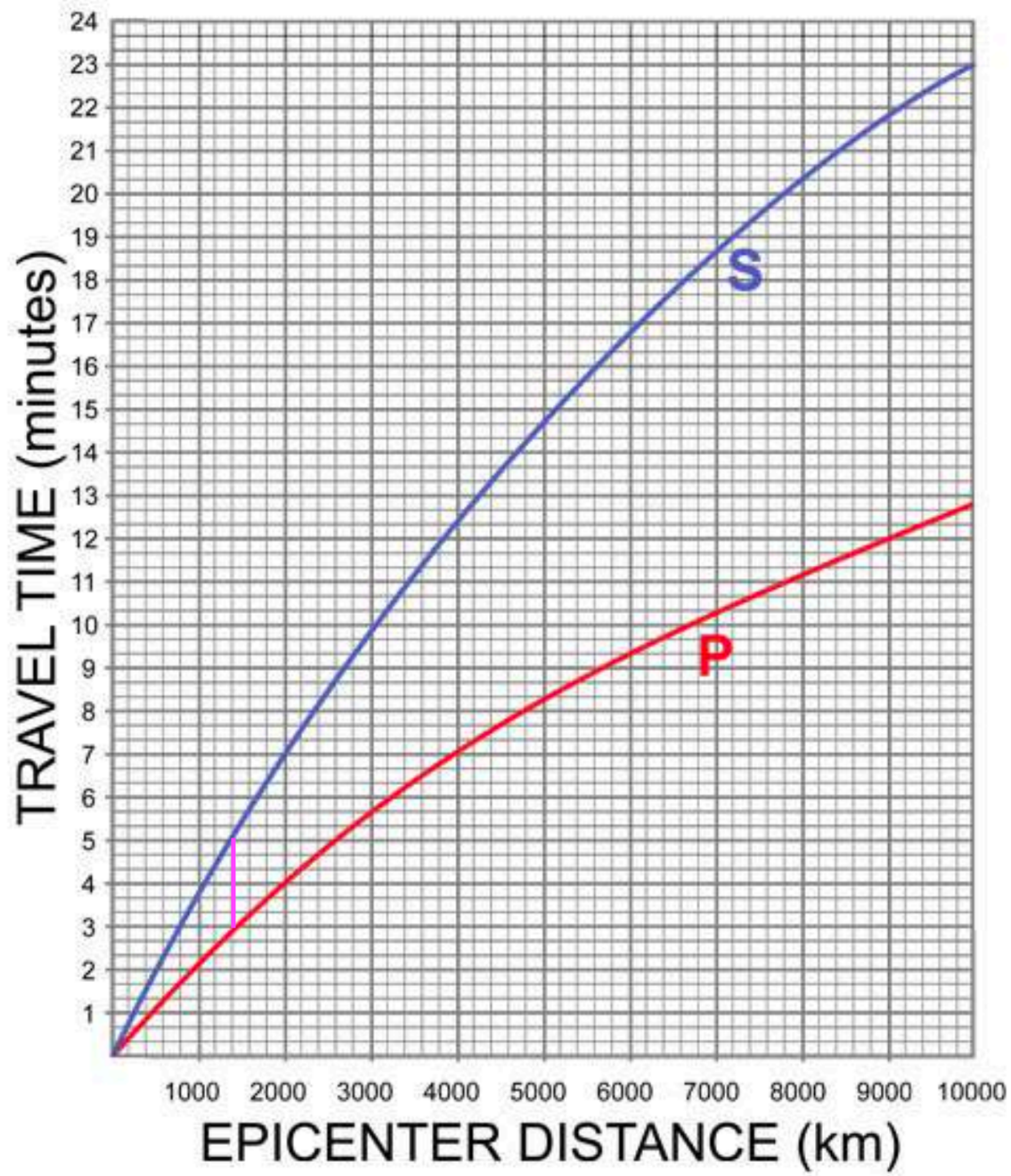
# Seismology

- This only tells you how far it is in a radius around the station, you don't know the direction



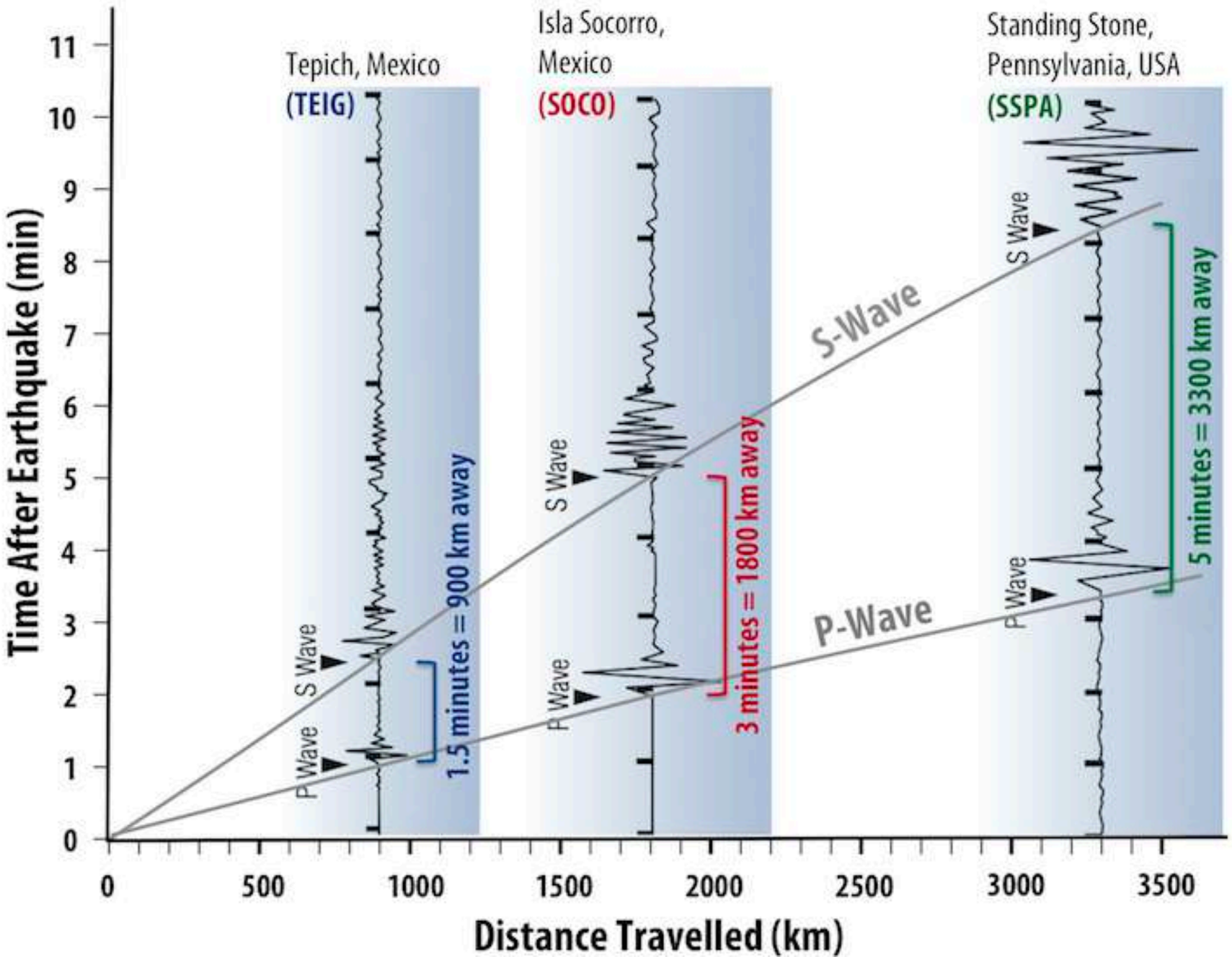

④ The surface waves, which travel the long way around Earth's surface, arrive last.

⑤ The S-P interval, here slightly less than 2 minutes, tells the seismologist how far away the earthquake was.



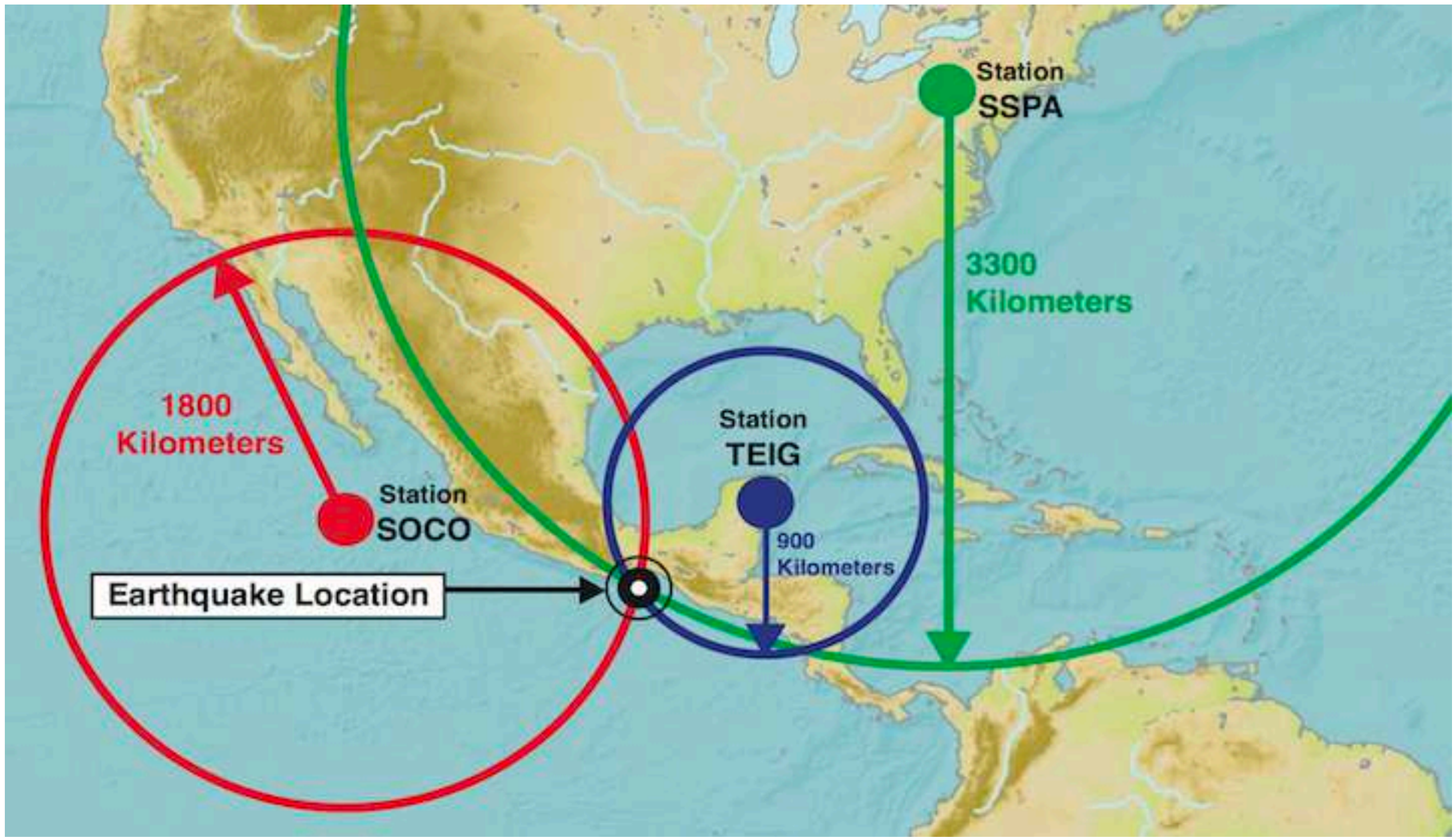
# Seismology

- Need 3 stations that measure the same earthquake to triangulate the location of the epicenter



# Seismology

- Circles of the measured radii around the stations will meet in exactly 1 place
  - The earthquake epicenter



# Measuring Earthquakes

- 2 ways to describe the size of an earthquake:

- **Intensity scale** - measures amount of ground shaking
  - Based on observed property damage

- **Magnitude scale** - Amount of energy released by the earthquake
  - Based on seismographs

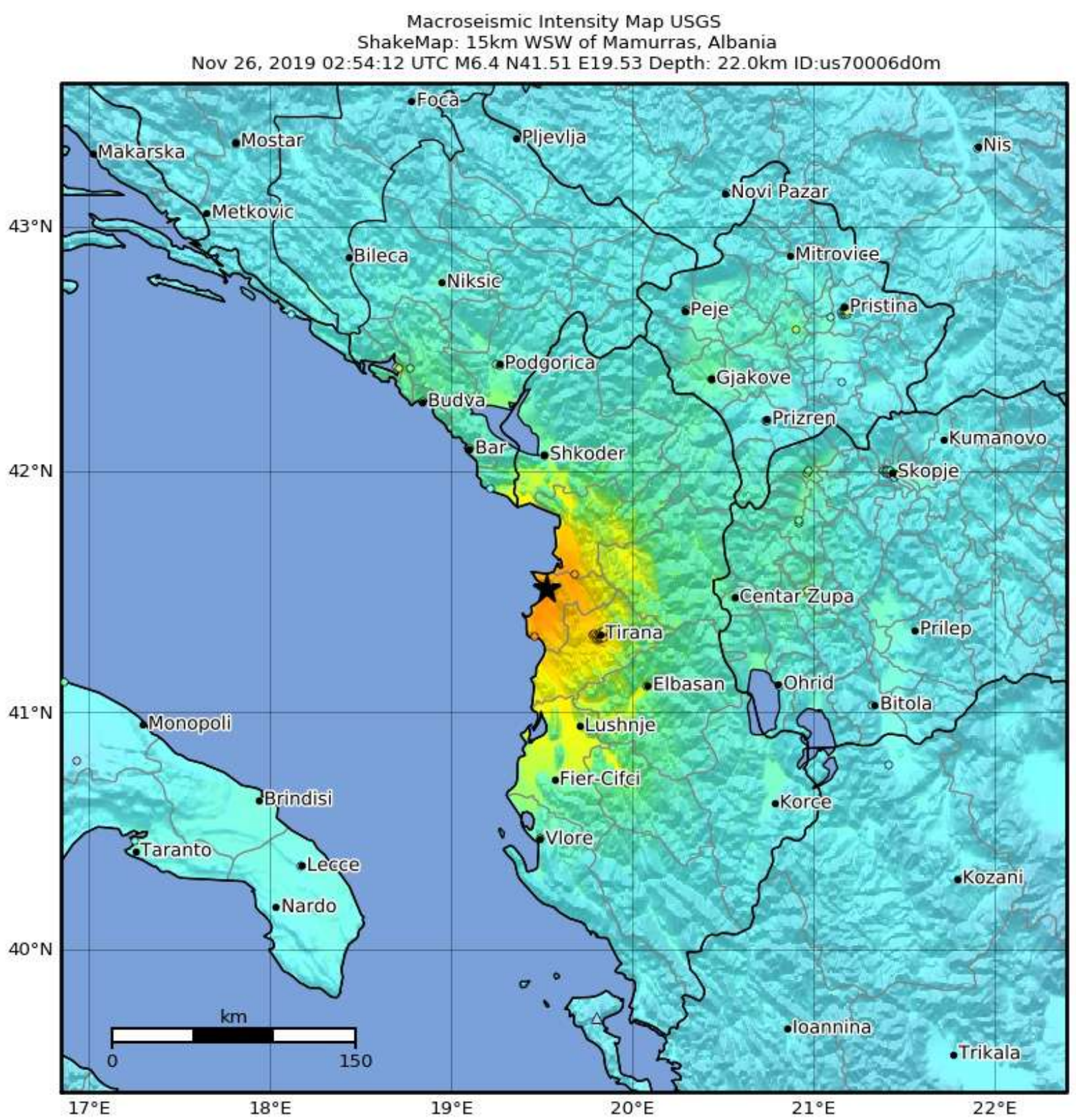
# Measuring Earthquakes

- **Intensity scale** - measures amount of ground shaking based on observed property damage

| Intensity | Shaking | Description/Damage |
|---|---|---|
| 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. |

# Measuring Earthquake

- Shake map for a M6.4 earthquake in Albania, 11/26/19

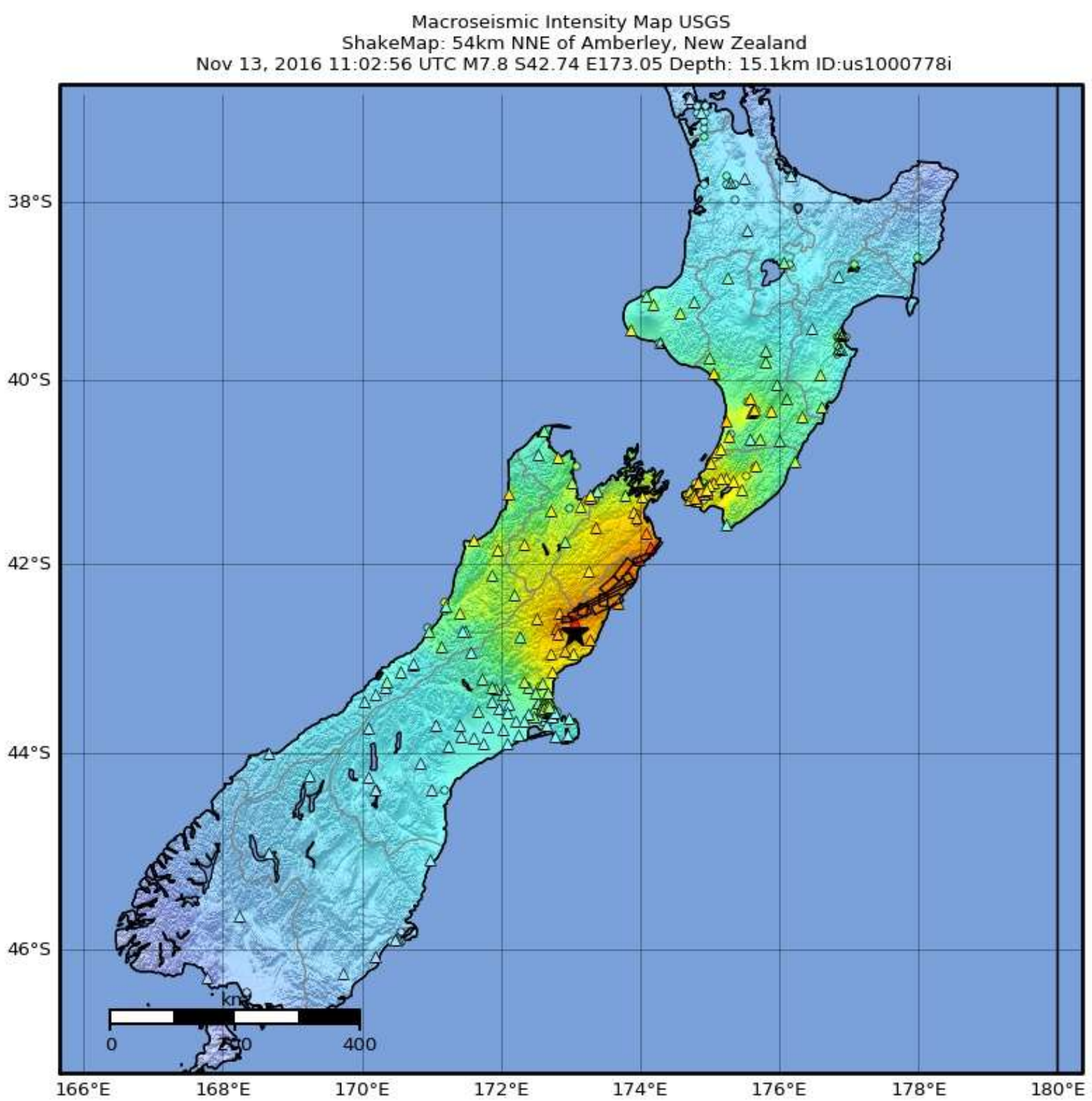



| SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| DAMAGE | None | None | None | Very light | Light | Moderate | Moderate/heavy | Heavy | Very heavy |
| PGA(%g) | <0.0464 | 0.297 | 2.76 | 6.2 | 11.5 | 21.5 | 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 2020-06-06T03:04:52Z
△ Seismic Instrument ○ Reported Intensity ★ Epicenter

# Measuring Earthquak

- Shake map for a M7.8 earthquake in New Zealand, 11/13/16
- [More USGS ShakeMaps]

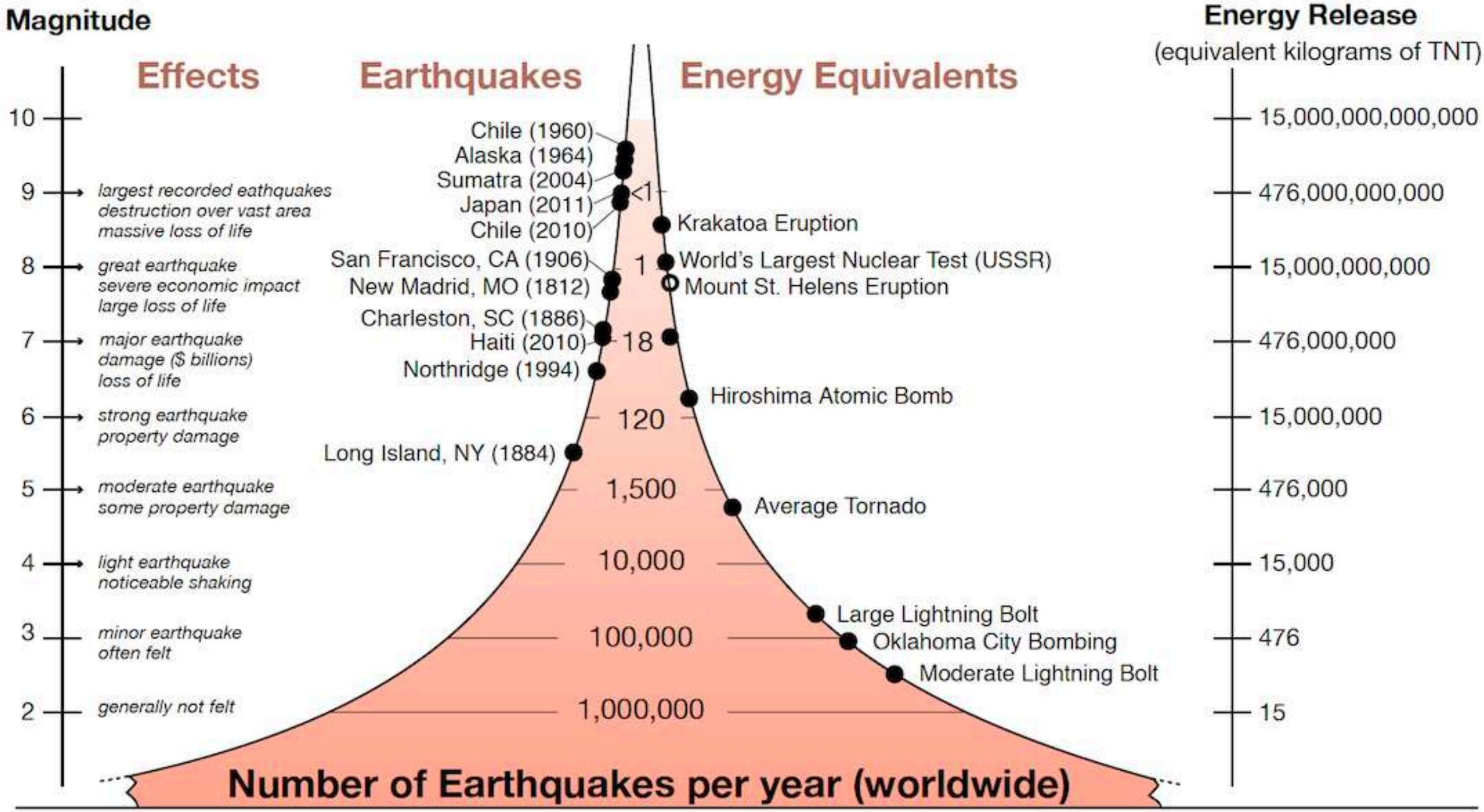



| SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| DAMAGE | None | None | None | Very light | Light | Moderate | Moderate/heavy | Heavy | Very heavy |
| PGA(%g) | <0.0464 | 0.297 | 2.76 | 6.2 | 11.5 | 21.5 | 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 2020-06-03T05:31:01Z
△ Seismic Instrument ○ Reported Intensity ★ Epicenter ▭ Rupture

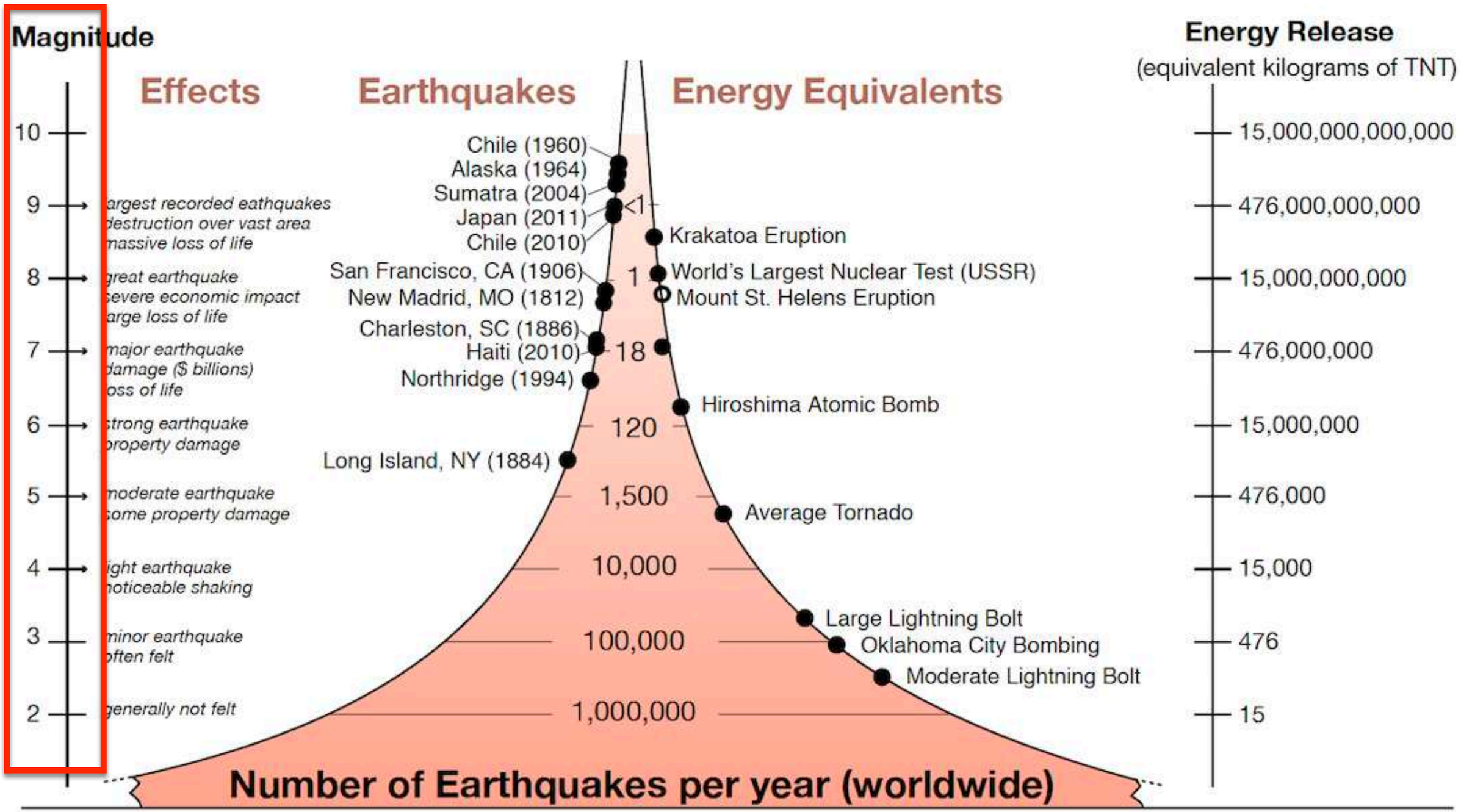
# Measuring Earthquakes

- **Magnitude scale** - Amount of energy released by the earthquake
- Scale 1 to 10



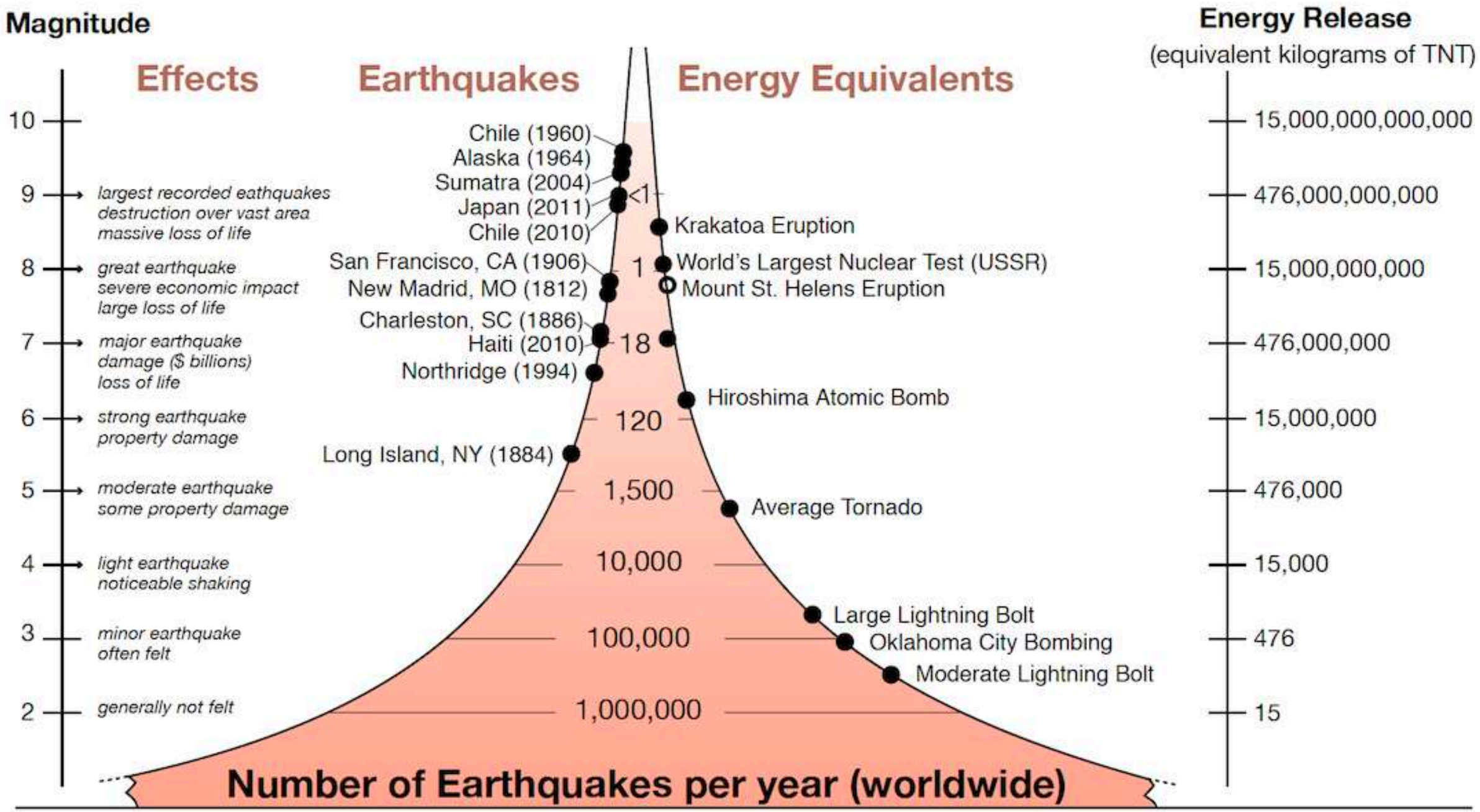
# Measuring Earthquakes

- Each level is 10 times stronger (amplitude) than the previous level



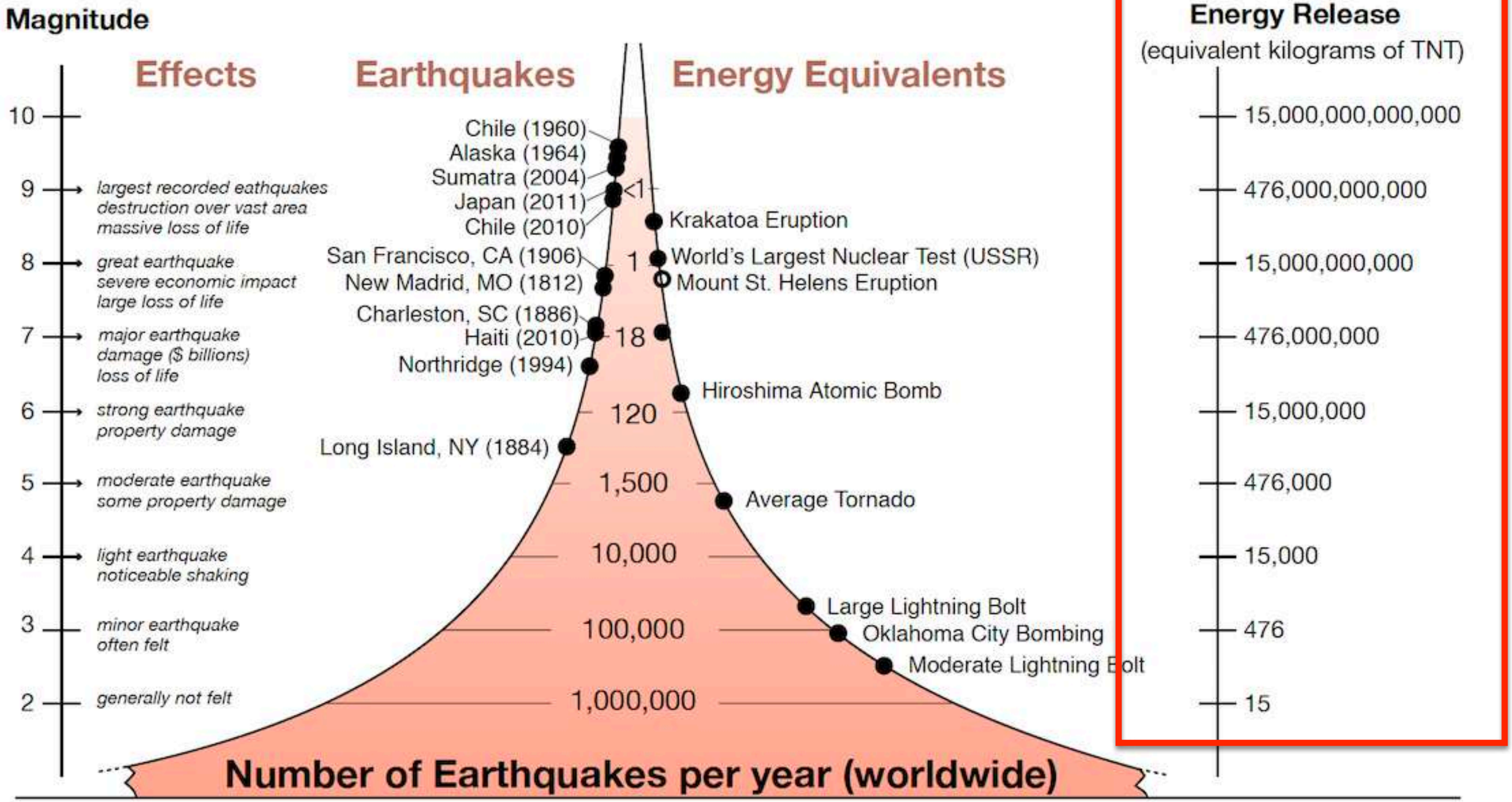
# Measuring Earthquakes

- A M4 has 10x the amplitude of a M3
- A M5 has 100x the amplitude of a M3
- A M8 has 100x the amplitude of a M6



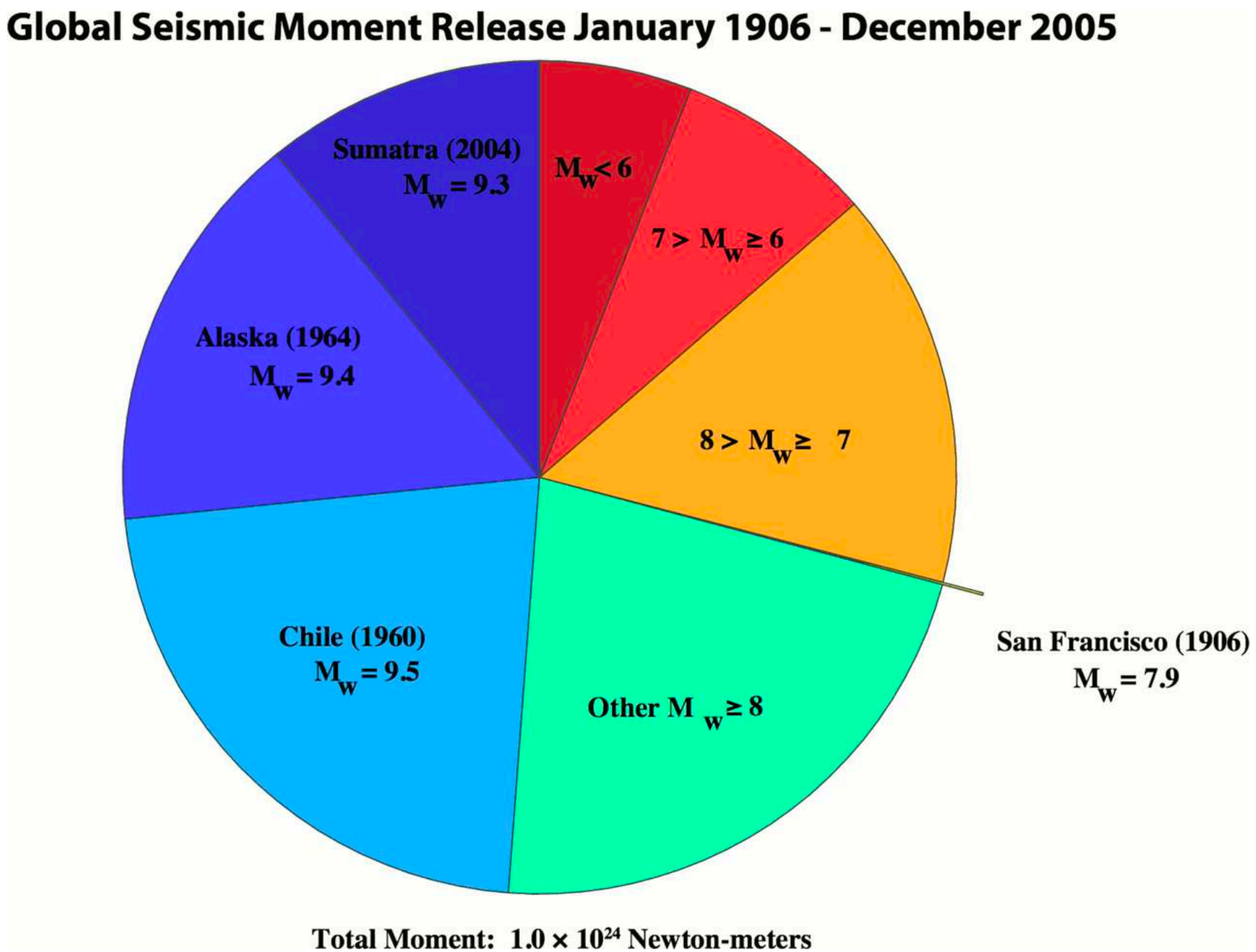
# Measuring Earthquakes

- Each level releases ~32x more energy
- A M9 earthquake releases 37,733,333x more energy than a M4



# Measuring Earthquakes

- Just 3 earthquakes are responsible for releasing 50 % of all seismic energy between 1906 and 2005



# Measuring Earthquakes

- General summary of damage from earthquakes

| Richter Magnitude | Earthquake effects |
|---|---|
| 0-2 | Not felt by people |
| 2-3 | Felt little by people |
| 3-4 | Ceiling lights swing |
| 4-5 | Walls crack |
| 5-6 | Furniture moves |
| 6-7 | Some buildings collapse |
| 7-8 | Many buildings destroyed |
| 8-Up | Total destruction of buildings, bridges and roads |

# Measuring Earthquakes

- Magnitude is based on seismograph readings
- Need to know how far away the earthquake was and the amplitude of the largest seismic waves

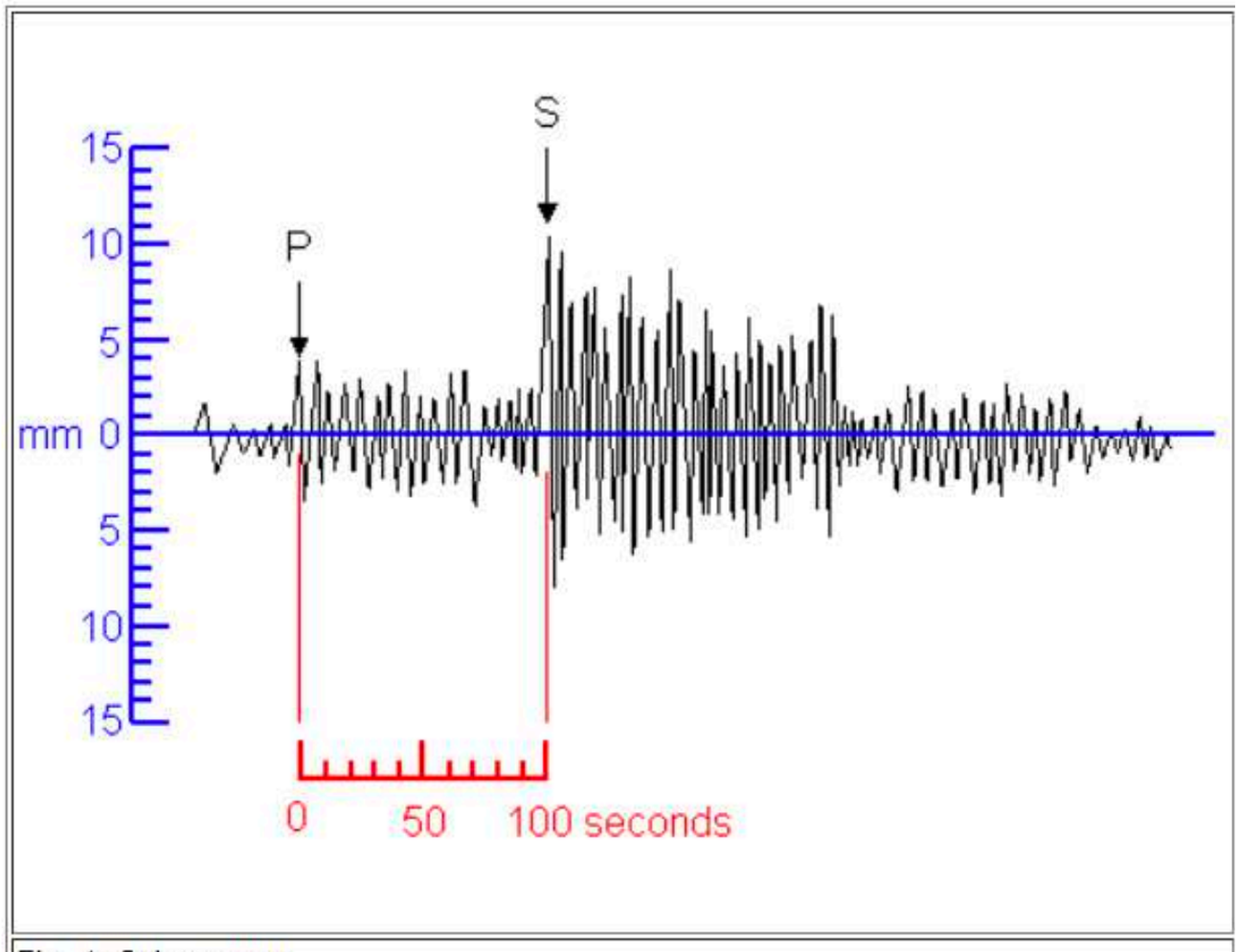



Fig. 1: Seismogram

# Measuring Earthquakes

- Figure out the distance for the S-P time interval of 100 s
- About 1,000 km

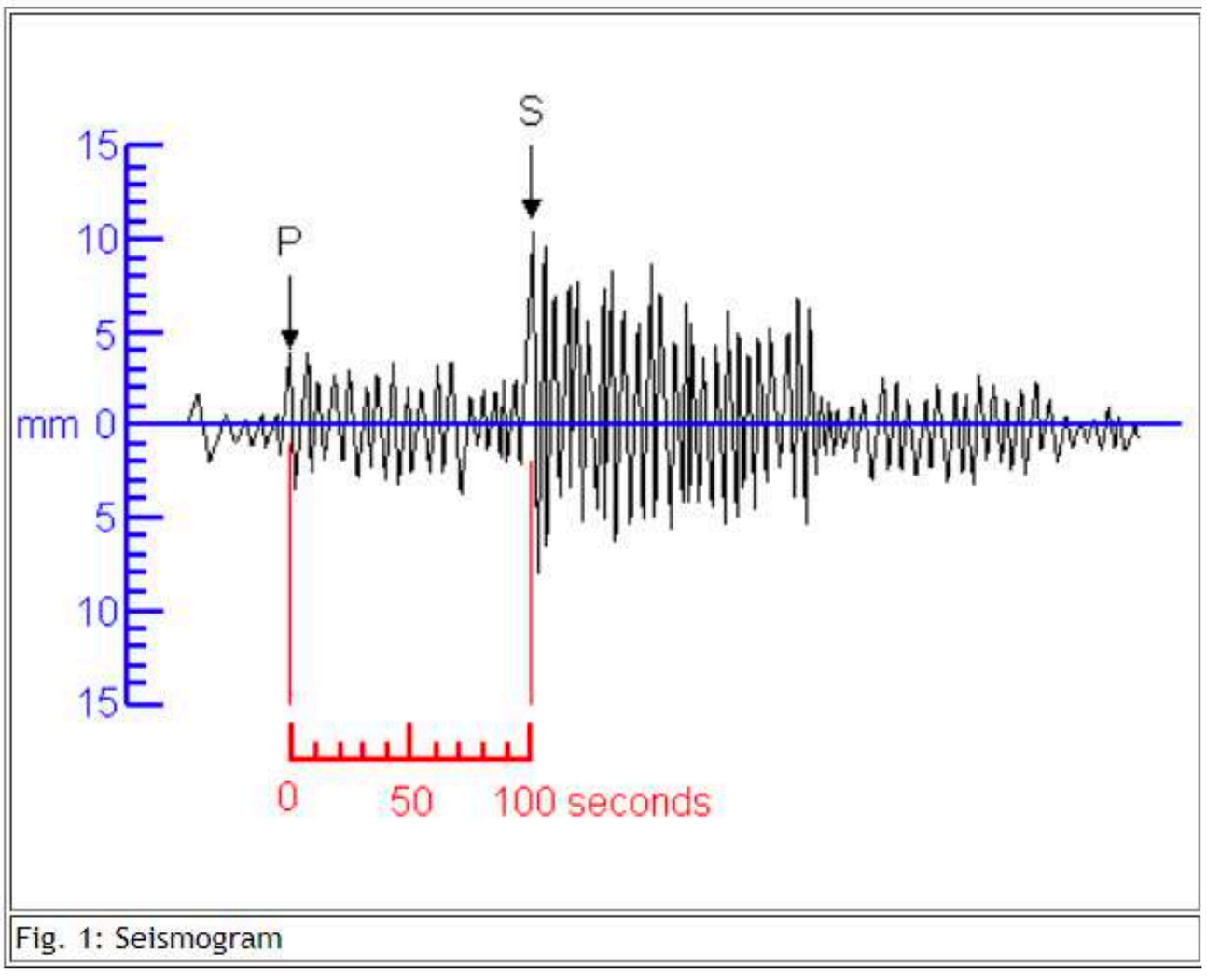
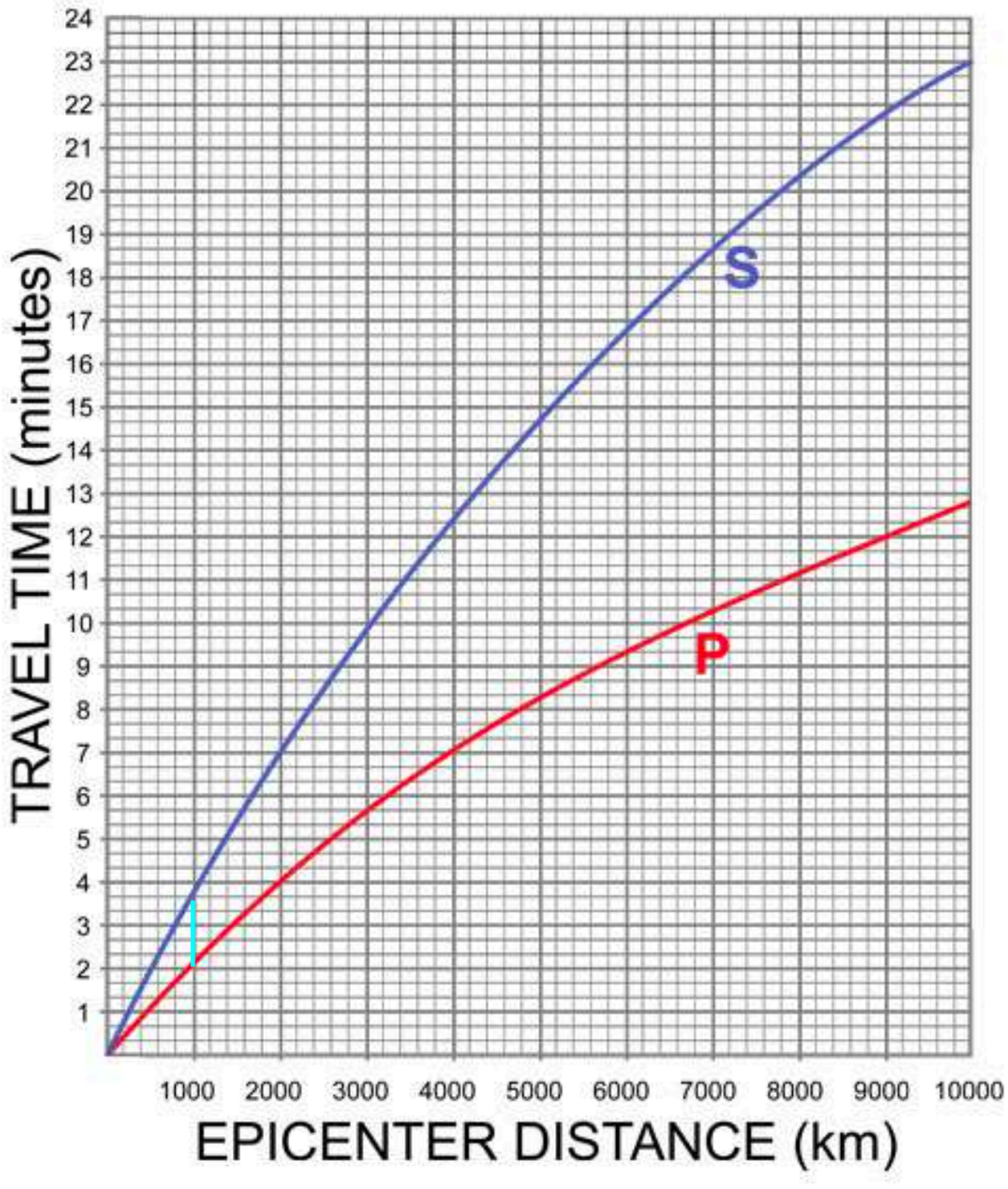



Fig. 1: Seismogram



# Measuring Earthquakes

- Use the distance and amplitude to determine the magnitude

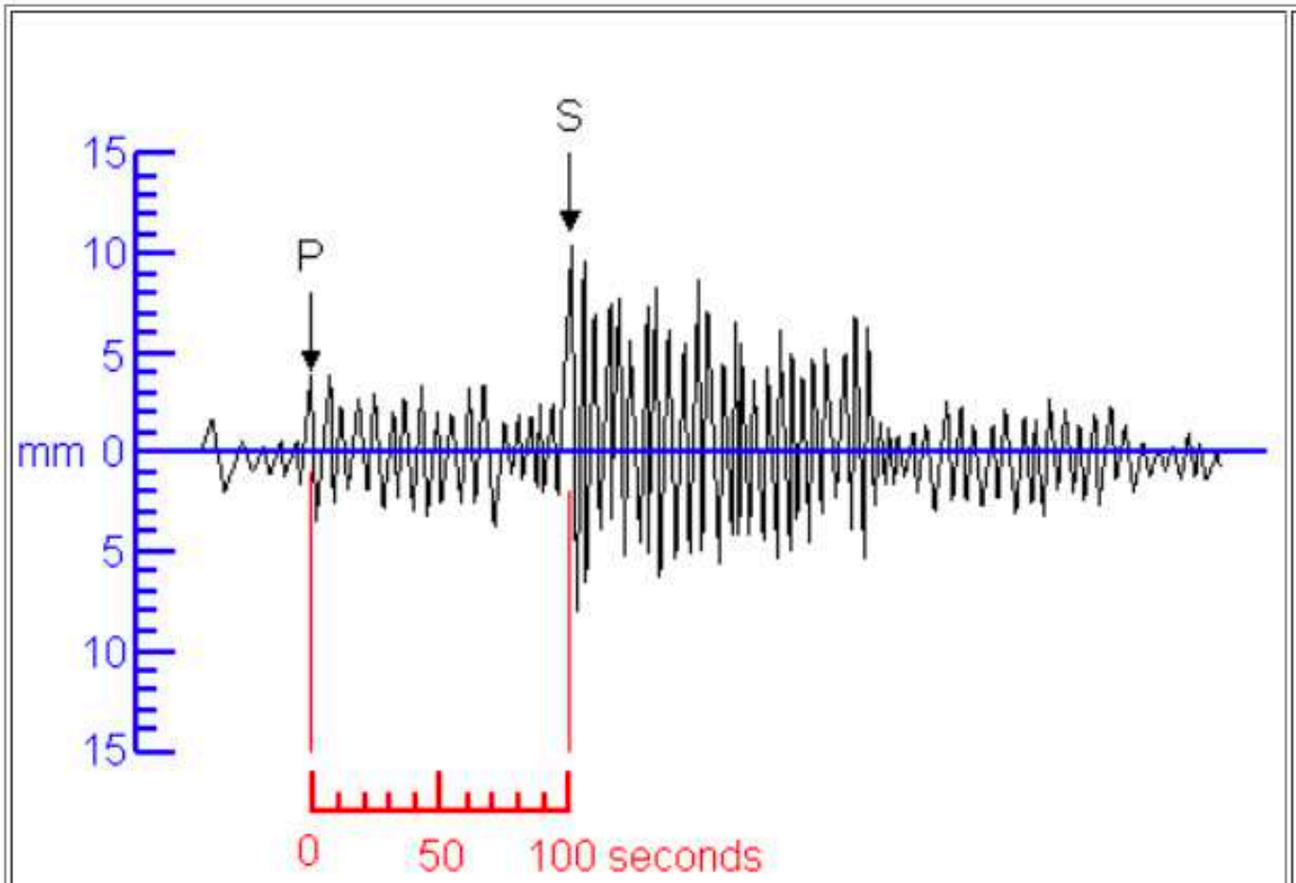



Fig. 1: Seismogram

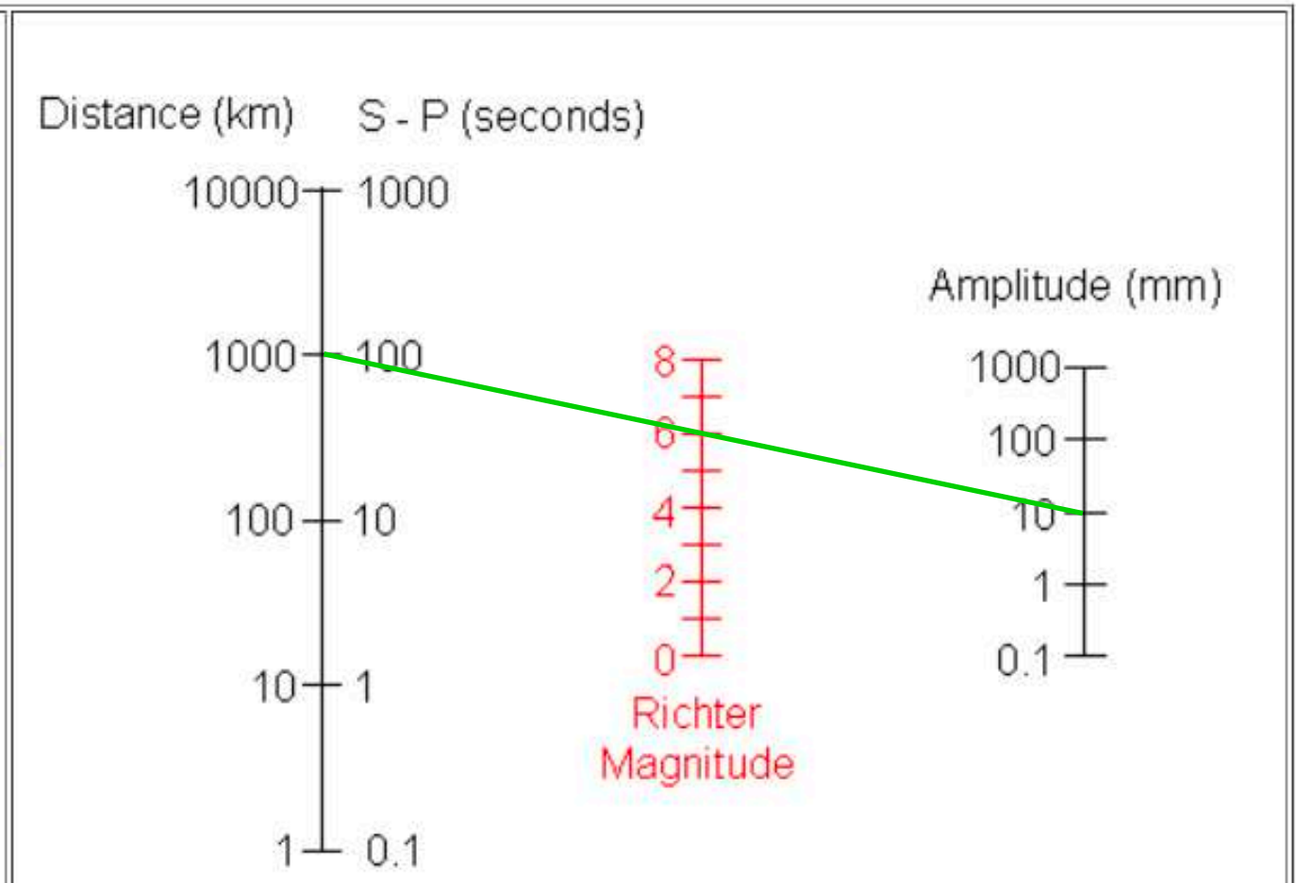



Fig. 2: Nomogram

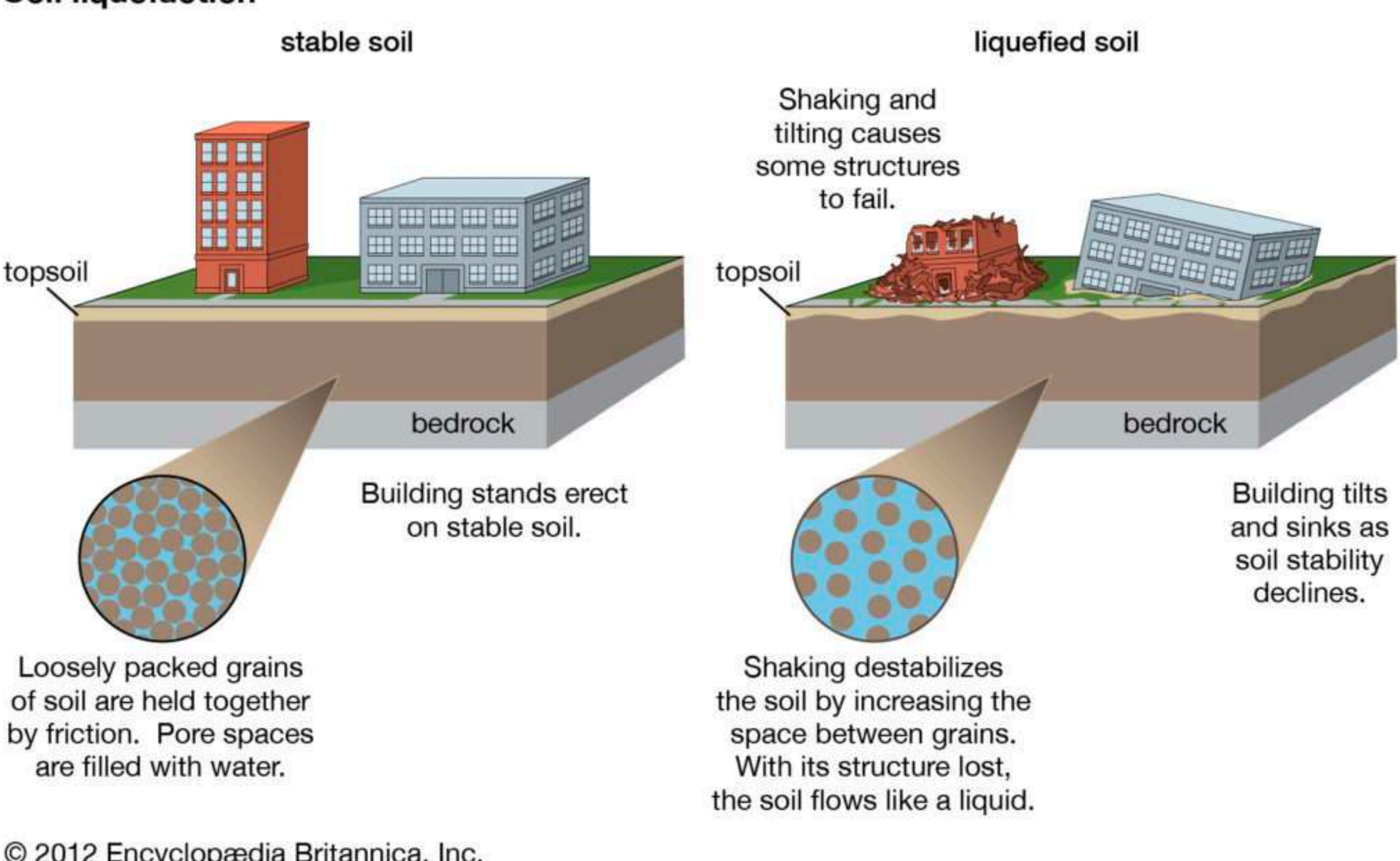
# Hazards

Earthquake Hazards:

- Ground Shaking
- Fault rupture
- Liquefaction of sediment (quicksand)
- Landslides
- Tsunamis
- Dam failure
- Fires
- Others…

Hazards

# Liquefaction



Hazards

# Liquefaction

https://www.youtube.com/watch?v=cSaatSdS4Sk

Hazards

# Liquefaction

Japan, 1964

New Zealand, 2011

Hazards

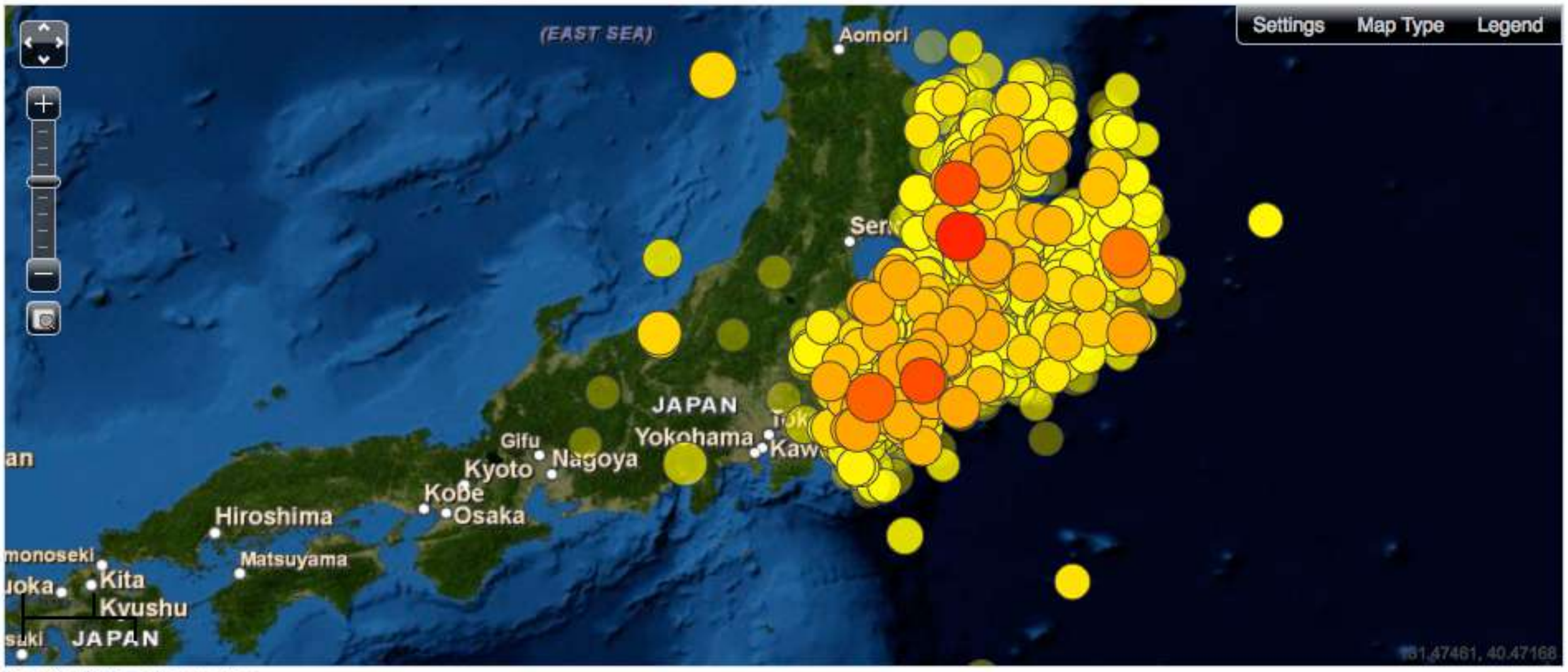
# Fault Rupture


Taiwan, 1999

Hazards

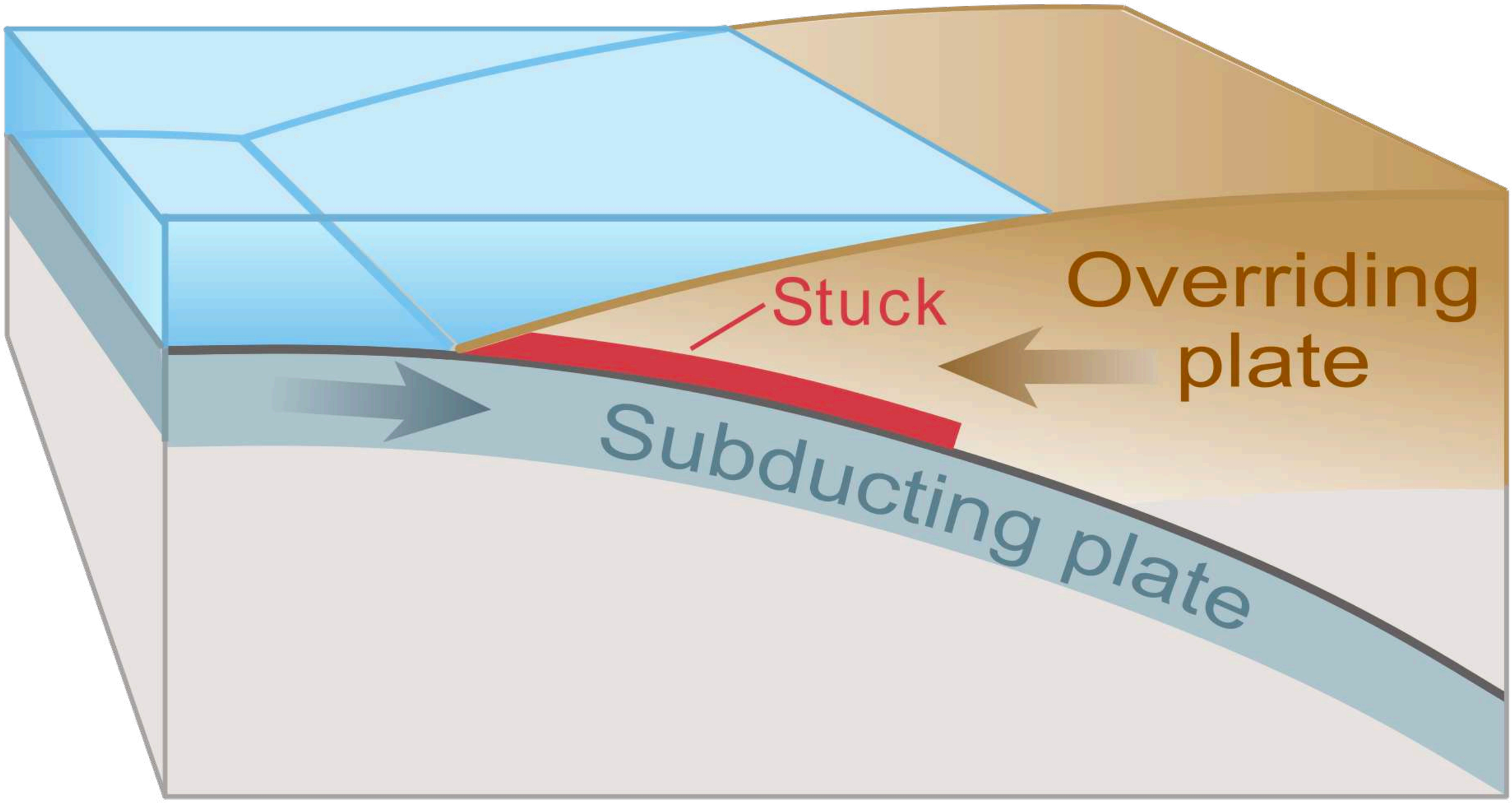
# Tohoku Earthquake (Sendai Japan 2011)
# 5th largest ever M= 9.0

Aftershock Map Tohoku Earthquake

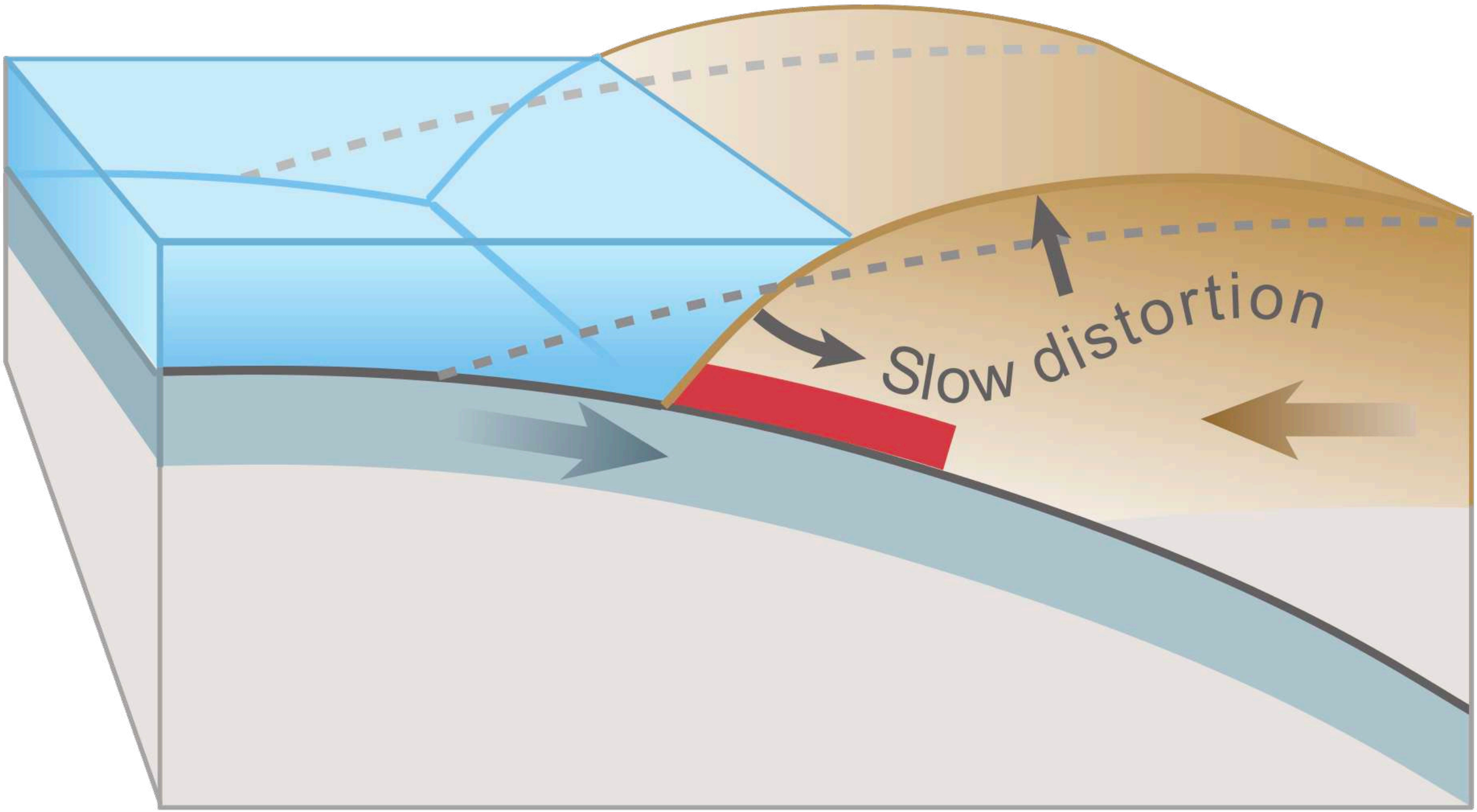



Showing 851 earthquakes

# Hazards

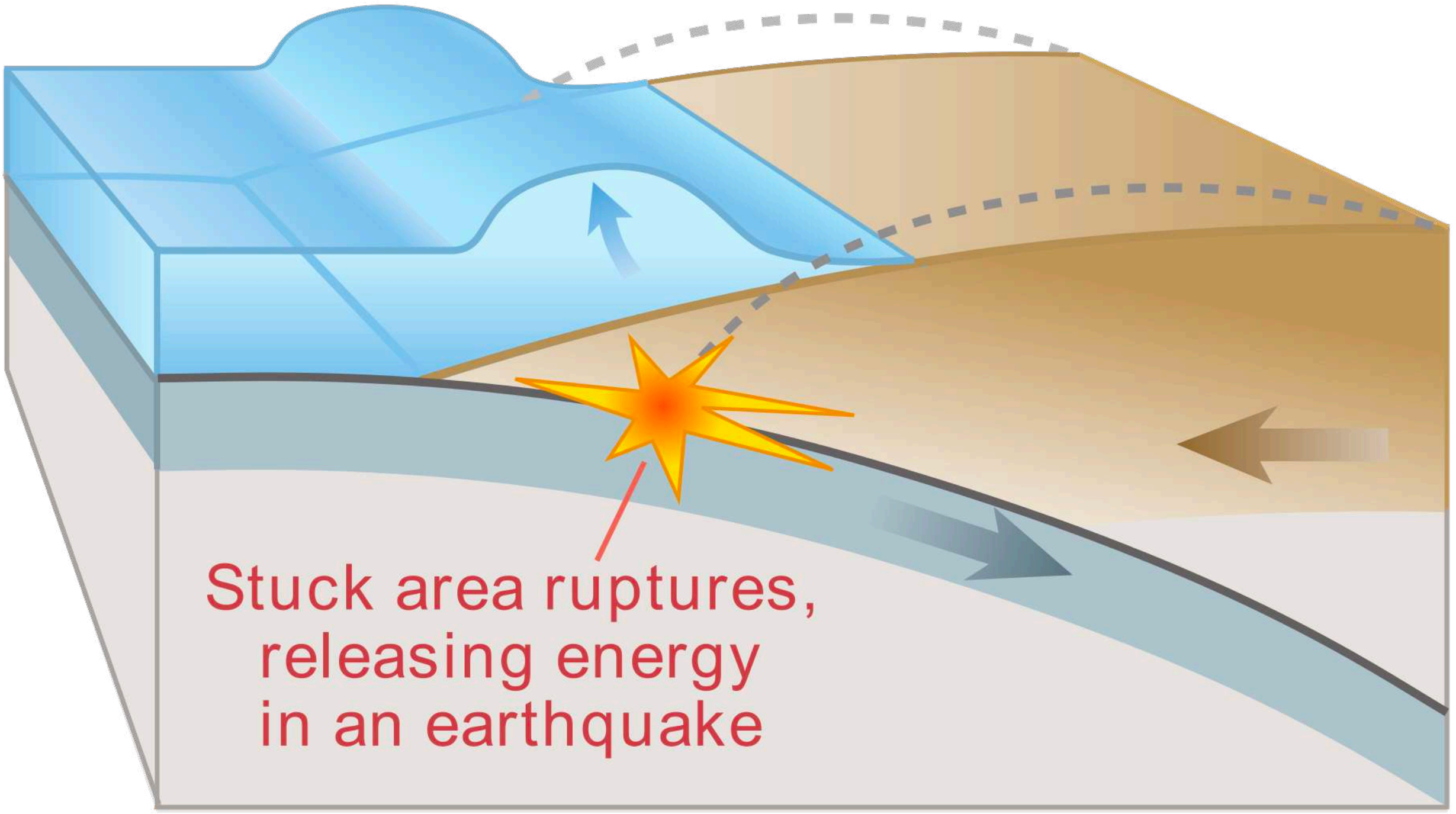


# Hazards

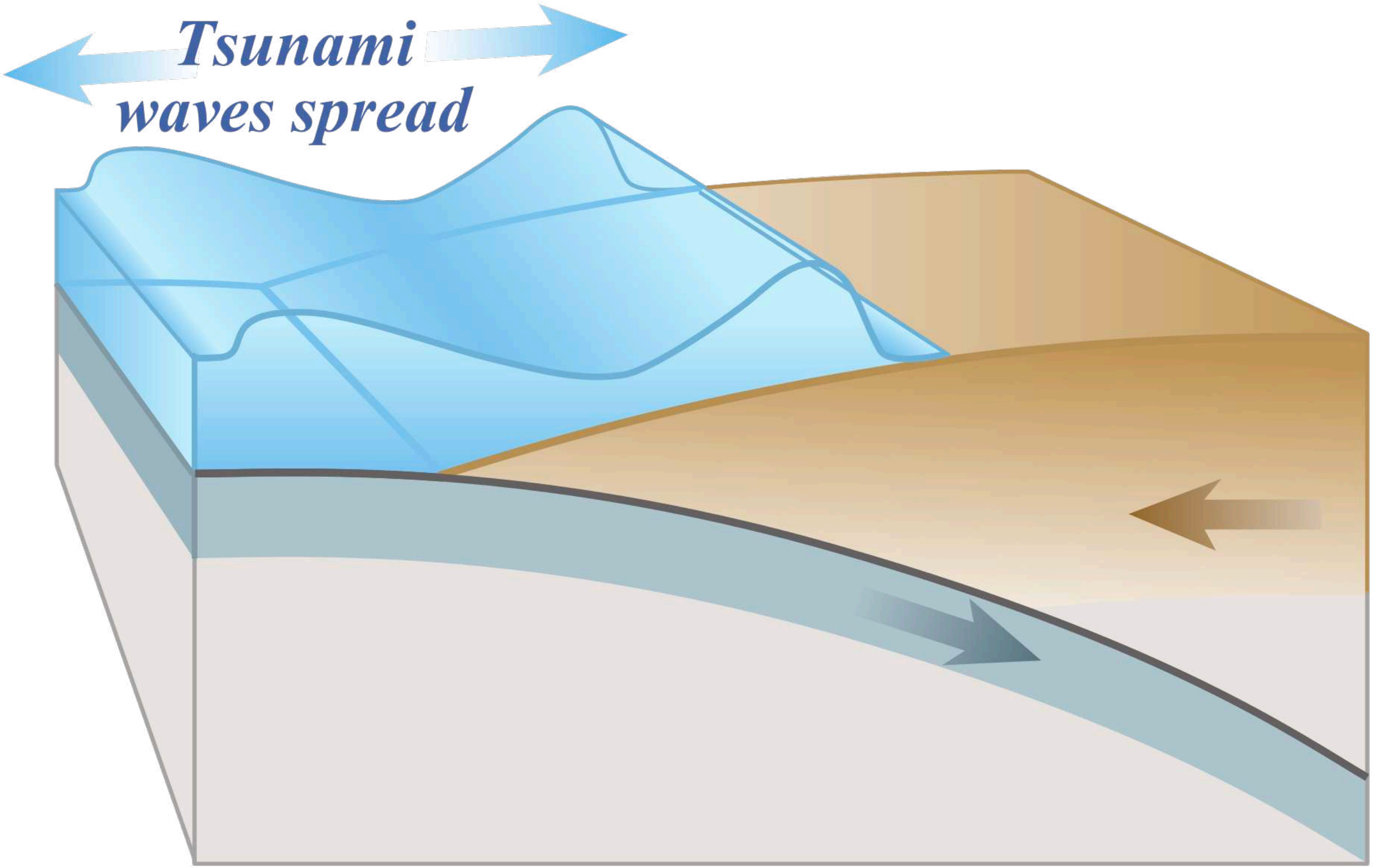


Hazards

# *Tsunami starts during earthquake*

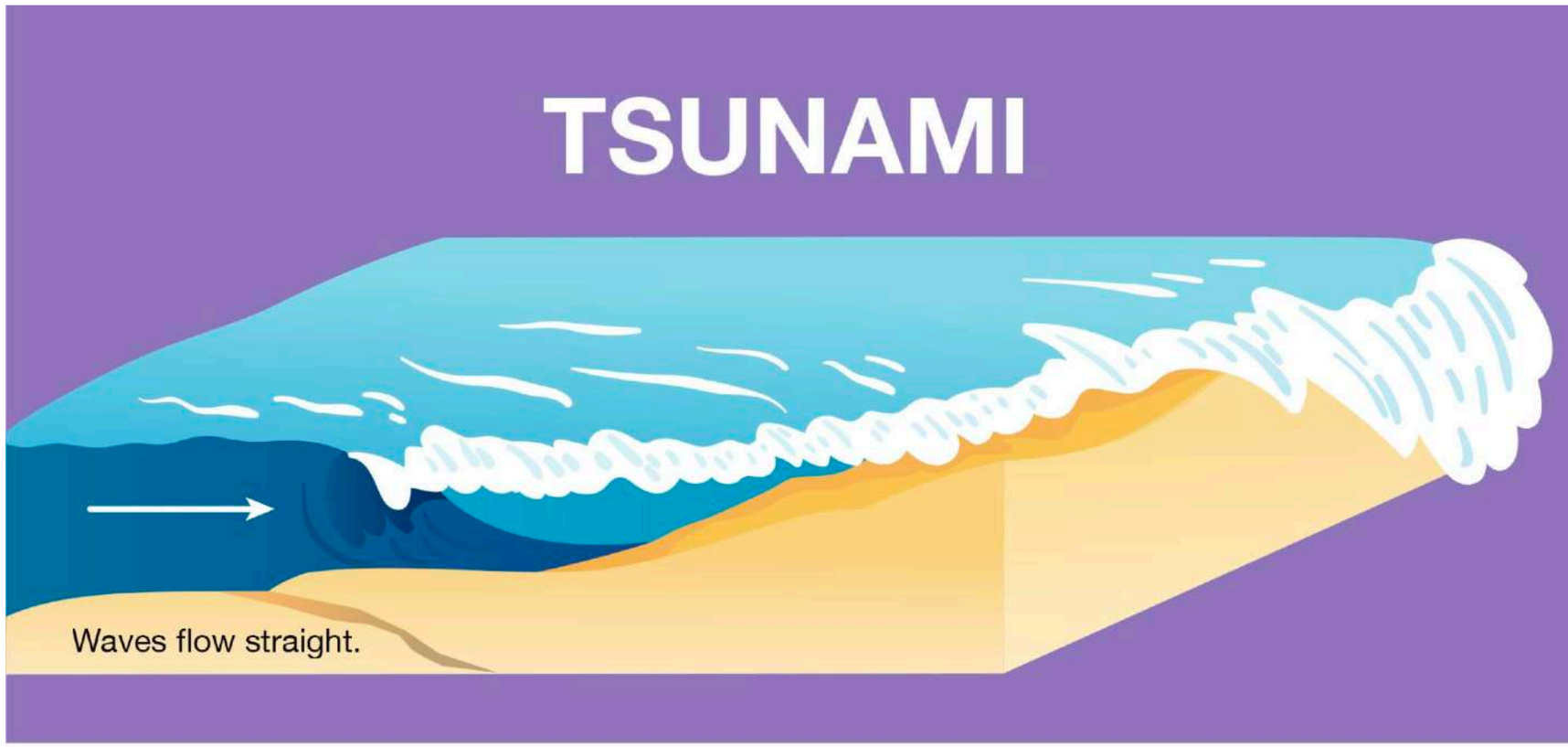


# Hazards

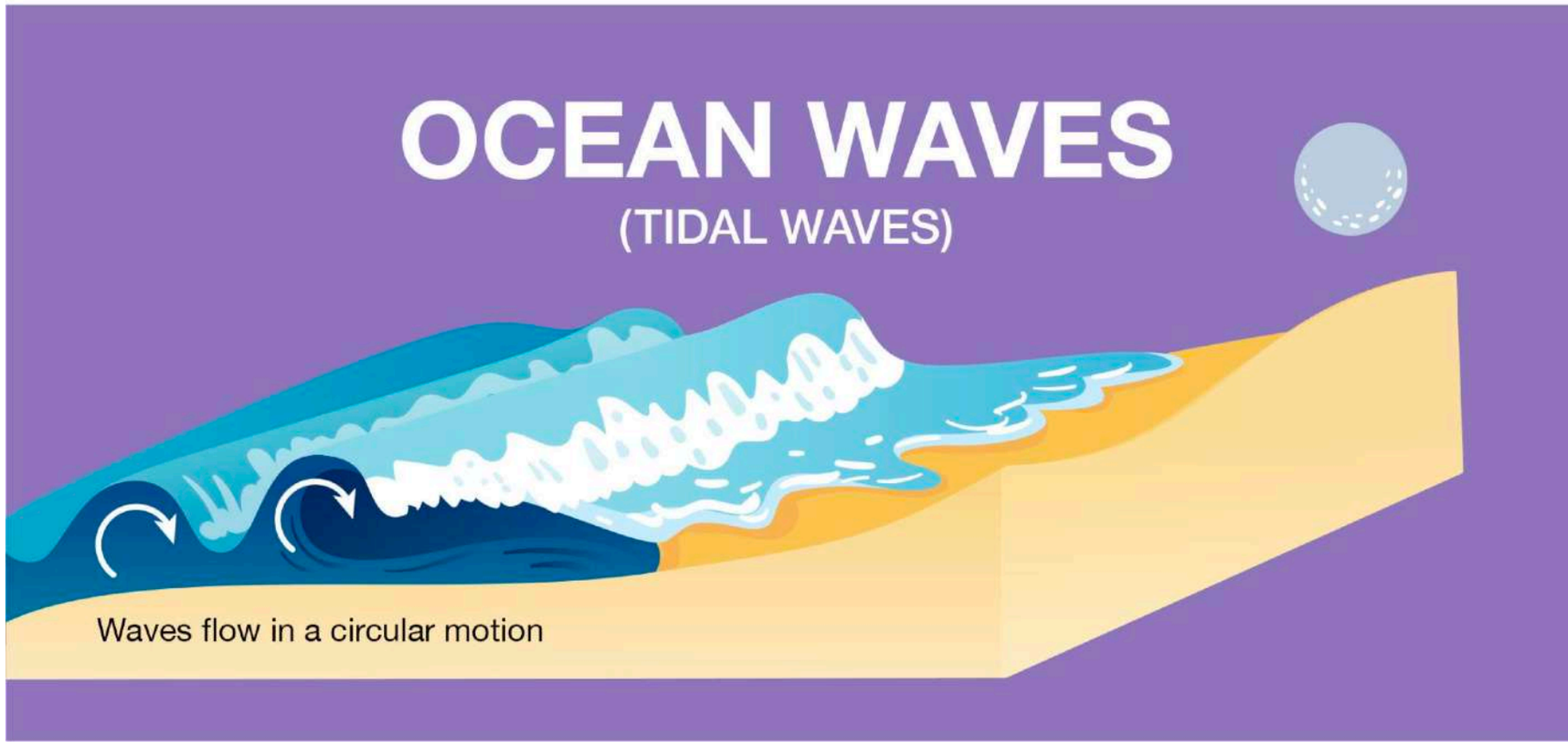


# Hazards

- Tsunamis are not giant walls of water as often depicted




- They look like a very rapidly rising tide



# Hazards

https://www.youtube.com/watch?v=jvIGFhqbe0c

# Hazards

https://www.youtube.com/watch?v=jvIGFhqbe0c

**This is not a tsunami!**

# Hazards

https://www.youtube.com/watch?v=4d-EYIZAqXc

**This is much closer to a real tsunami!**

# Hazards

**These are real tsunamis**

https://www.youtube.com/watch?v=noq8FYvRqgs

https://www.youtube.com/watch?v=spg62-MrYpQ

# Hazards

**These are real tsunami**

https://www.youtube.com/watch?v=noq8FYvRqgs

https://www.youtube.com/watch?v=spg62-MrYpQ