UNESCO/IOC – NOAA ITIC Training Program in Hawaii (ITP-Hawaii)
TSUNAMI EARLY WARNING SYSTEMS
AND THE PACIFIC TSUNAMI WARNING CENTER (PTWC) ENHANCED PRODUCTS
TSUNAMI EVACUATION PLANNING AND UNESCO IOC TSUNAMI READY PROGRAMME
7-18 August 2023, Honolulu, Hawaii USA

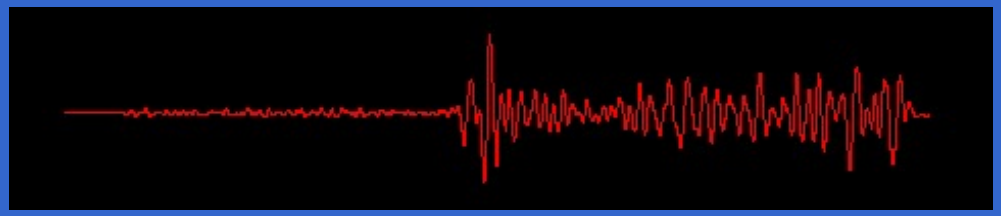
Earthquake Seismology for Tsunami Warning:
Nomenclature, Faulting, Magnitude

Dr. Charles McCreery
Director, PTWC

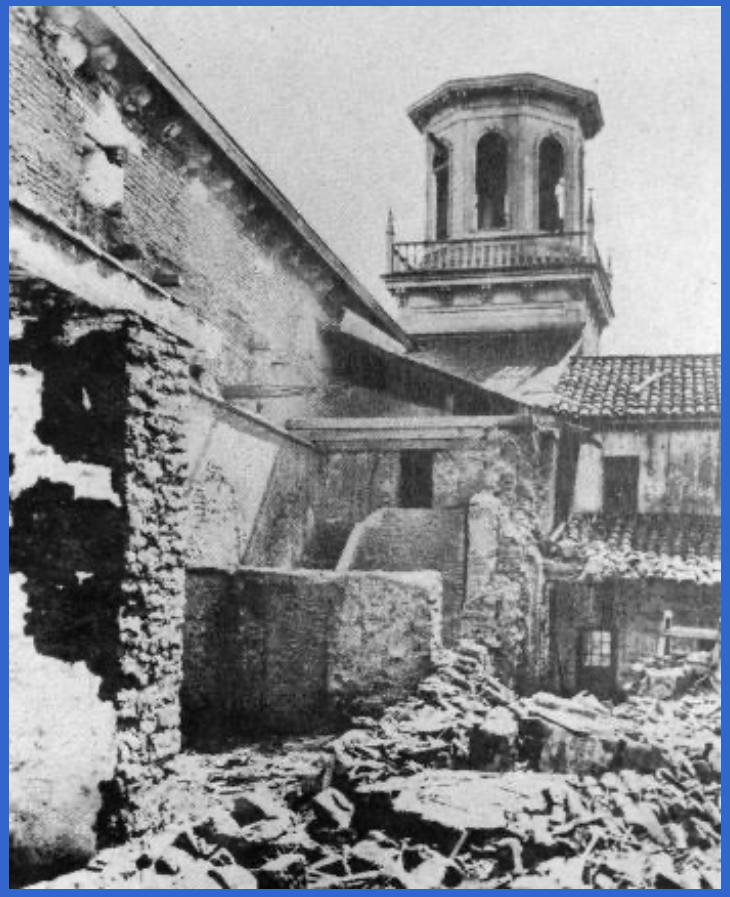
What is an Earthquake

What is an Earthquake?

- Instrumentally recorded (or felt) ground shaking, normally a result of underground movement on a fault

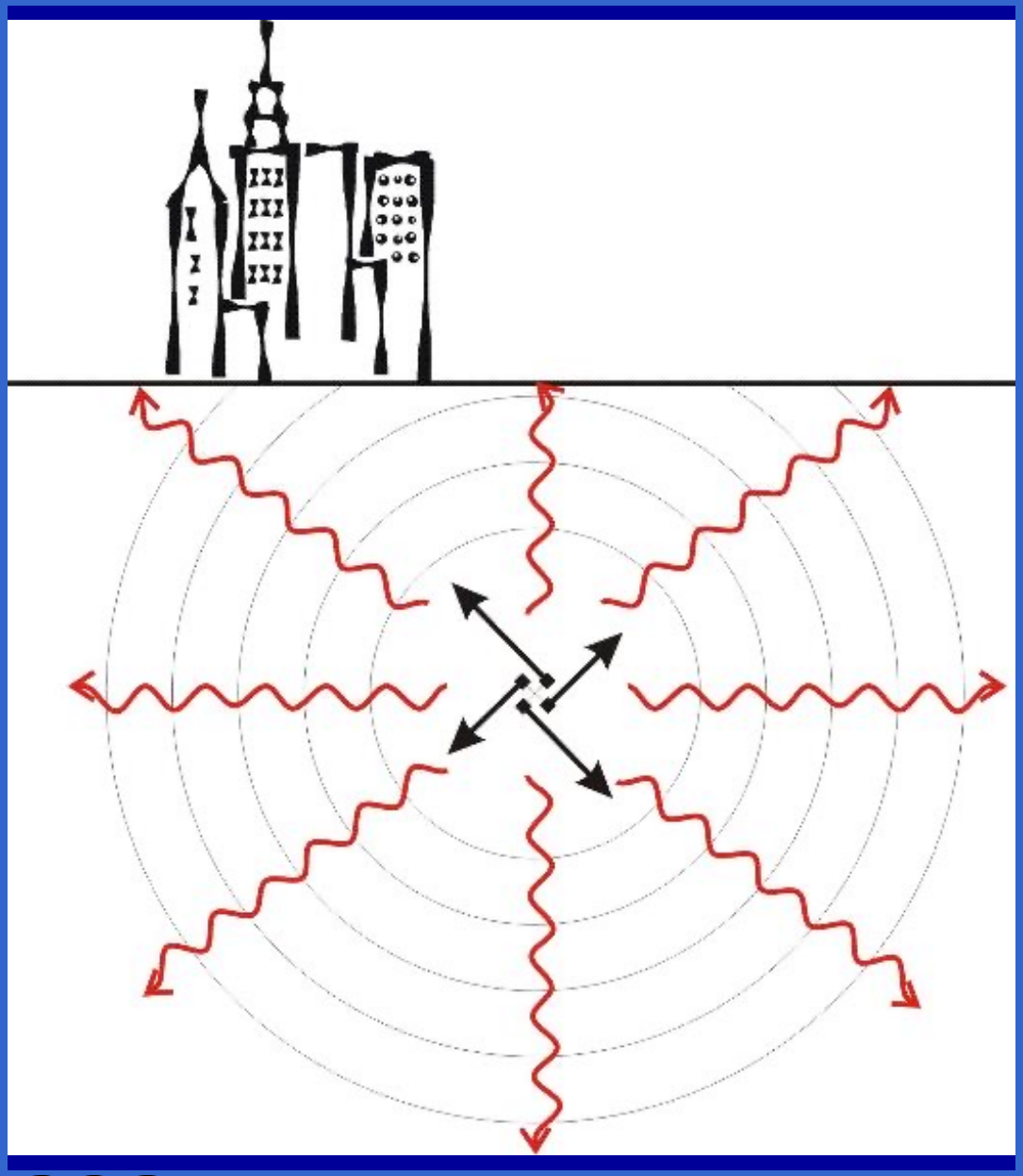


Seismogram of the 1906 earthquake recorded in Germany



San Francisco 1906 (USGS)

USGS
science for a changing world



USGS

Broadband seismometer

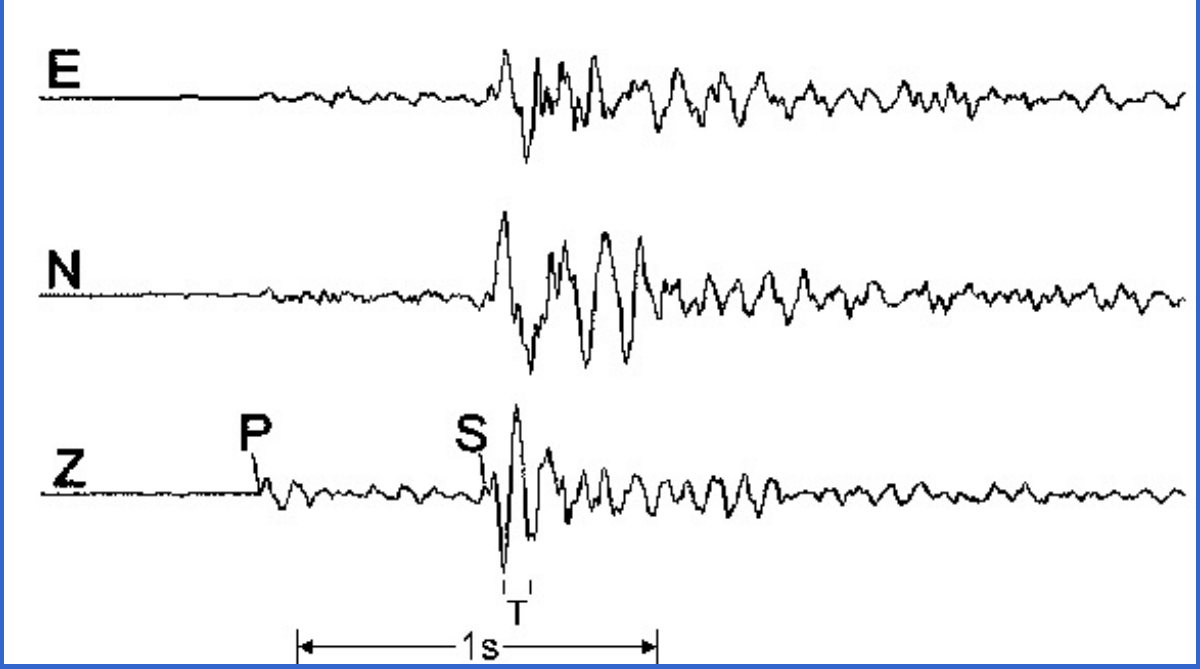
Faulting

↓

Seismic waves

USGS
science for a changing world

Types of Seismic Wave



Three-components of a seismometer record proportional to ground velocity of the P and S waves from a local aftershock of the Killari-Latur EQ, India (1993), at a hypocentral distance of 5.3 km

USGS
science for a changing world

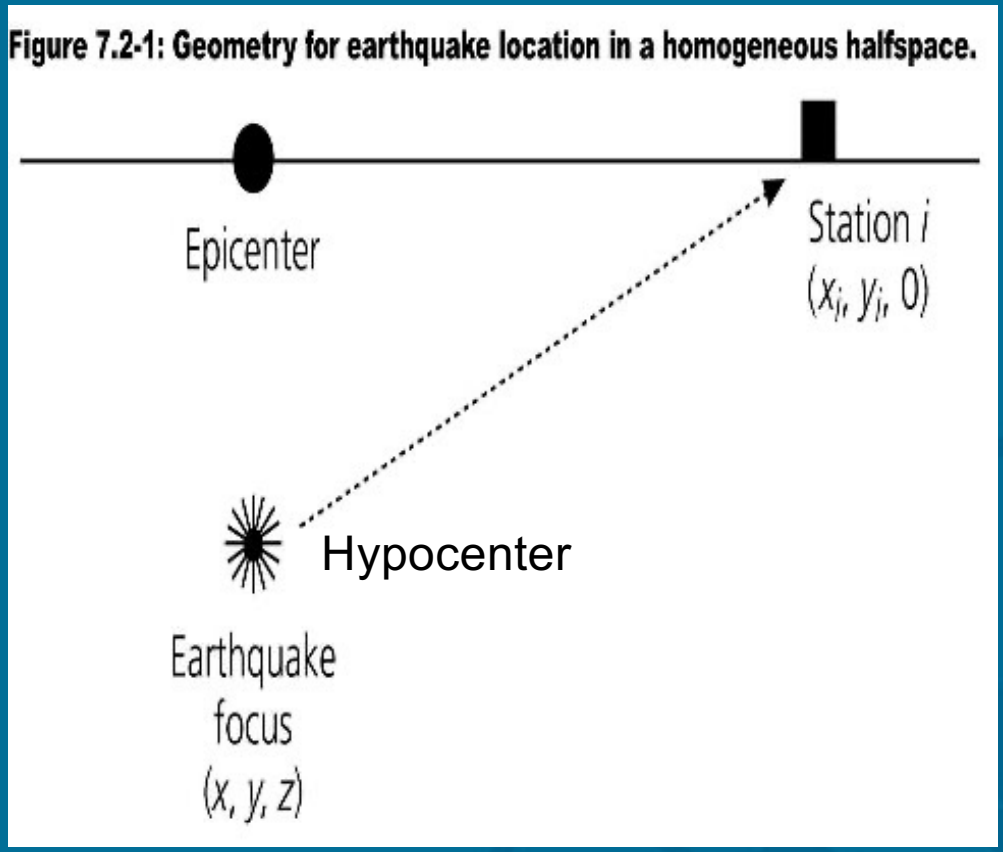
P. Bormann. 2002. New Manual of Seismological Observatory Practice (NMSOP)

Earthquake Nomenclature

Described by Time (t) and Location (x,y,z)

Hypocenter (Focus):
Origin Time,
Latitude, Longitude,
Depth
Location in Earth where energy in the rock being strained is released

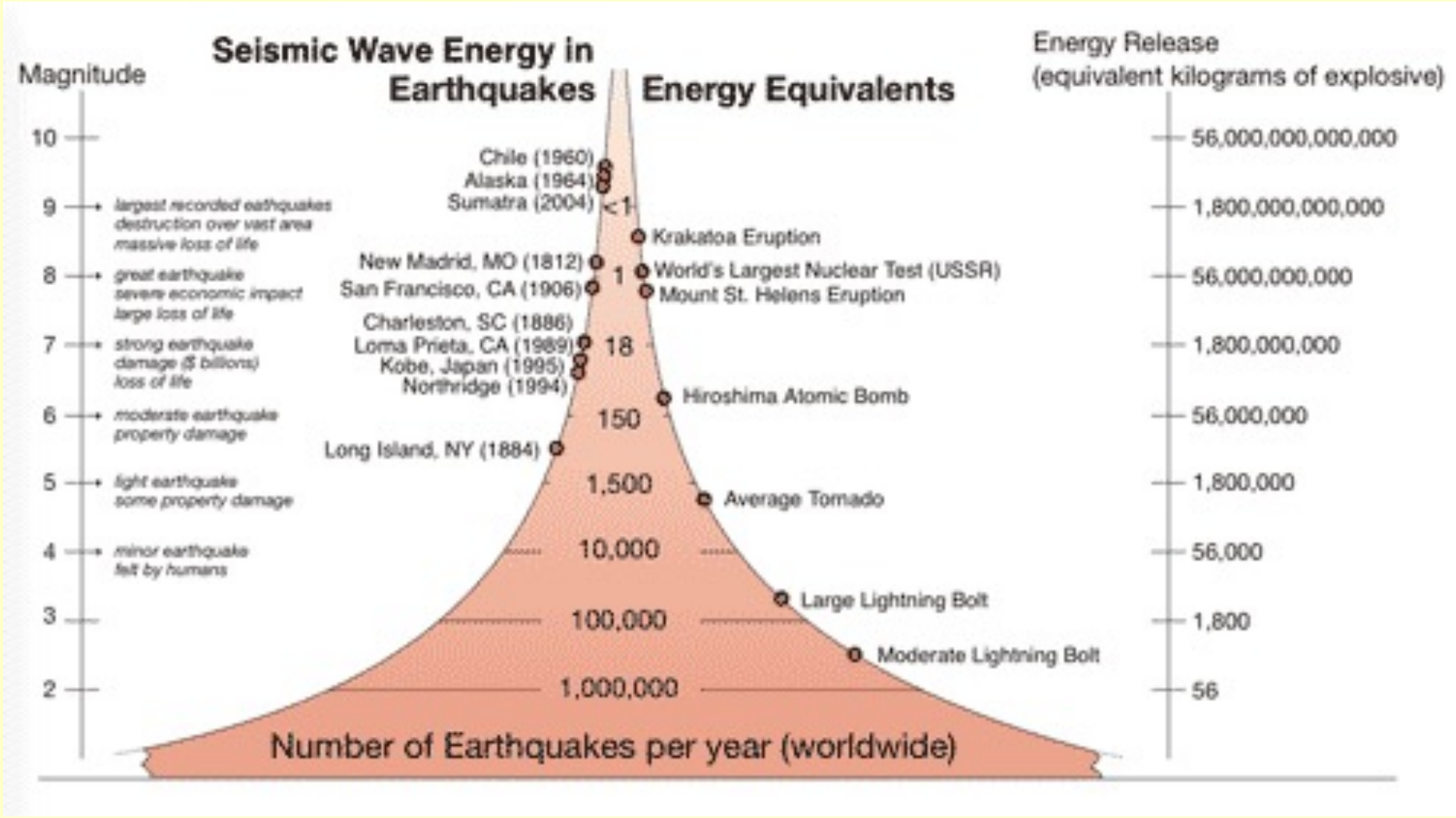
Epicenter:
Latitude, Longitude
Point on Earth's surface directly above Hypocenter



Comparing an earthquake to the breaking of a chopstick

- Failure - breaks at weakest point
- Build-up of stress (strain energy)
- Difficult to predict time and place
- Sometimes hear precursors
- Sound of breaking same as seismic waves

USGS
science for a changing world



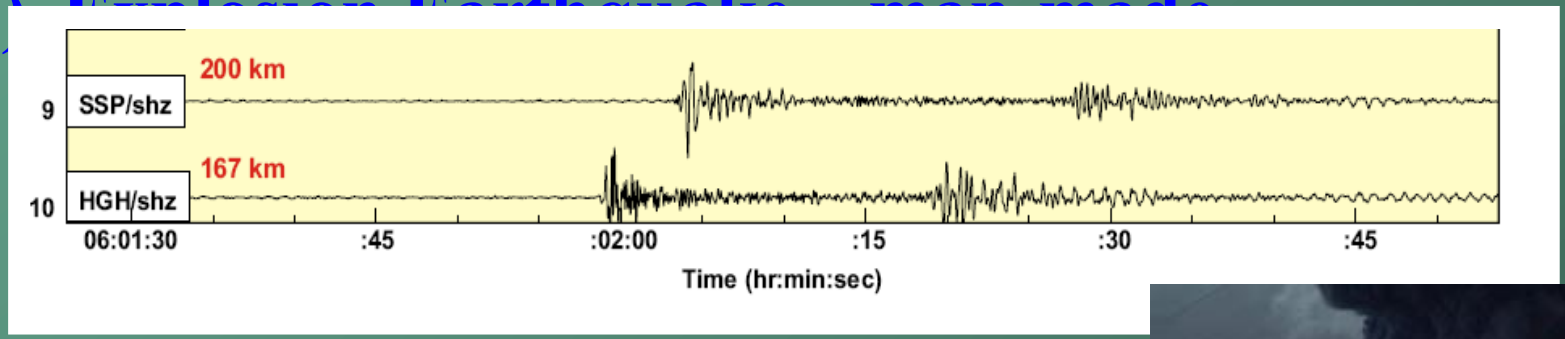
USGS
science for a changing world

Hagiwara, 1964

Earthquake faulting

TYPES OF EARTHQUAKES

1) Tectonic Earthquake – MOST COMMON (FAULTS)
2) Volcanic Earthquake – magma movement, eruptions
3) Collapse Earthquake – cave collapse, rock fall
4) Explosion Earthquake – man made



BGS recordings of an explosion at an oil storage depot near London Dec 16, 2005.
Equivalent to M2.4 earthquake

USGS
science for a changing world

Types of Earthquake Faulting - Tectonic

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

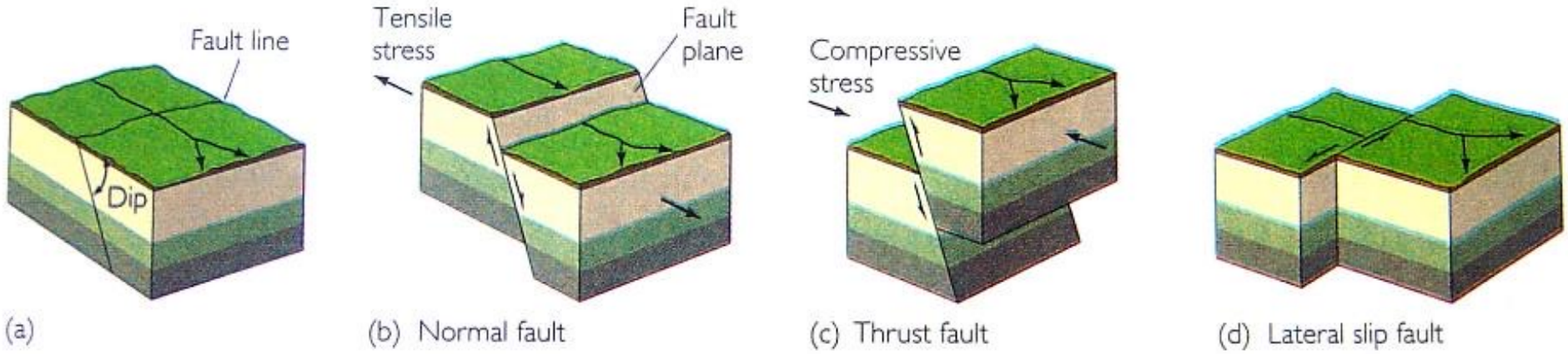


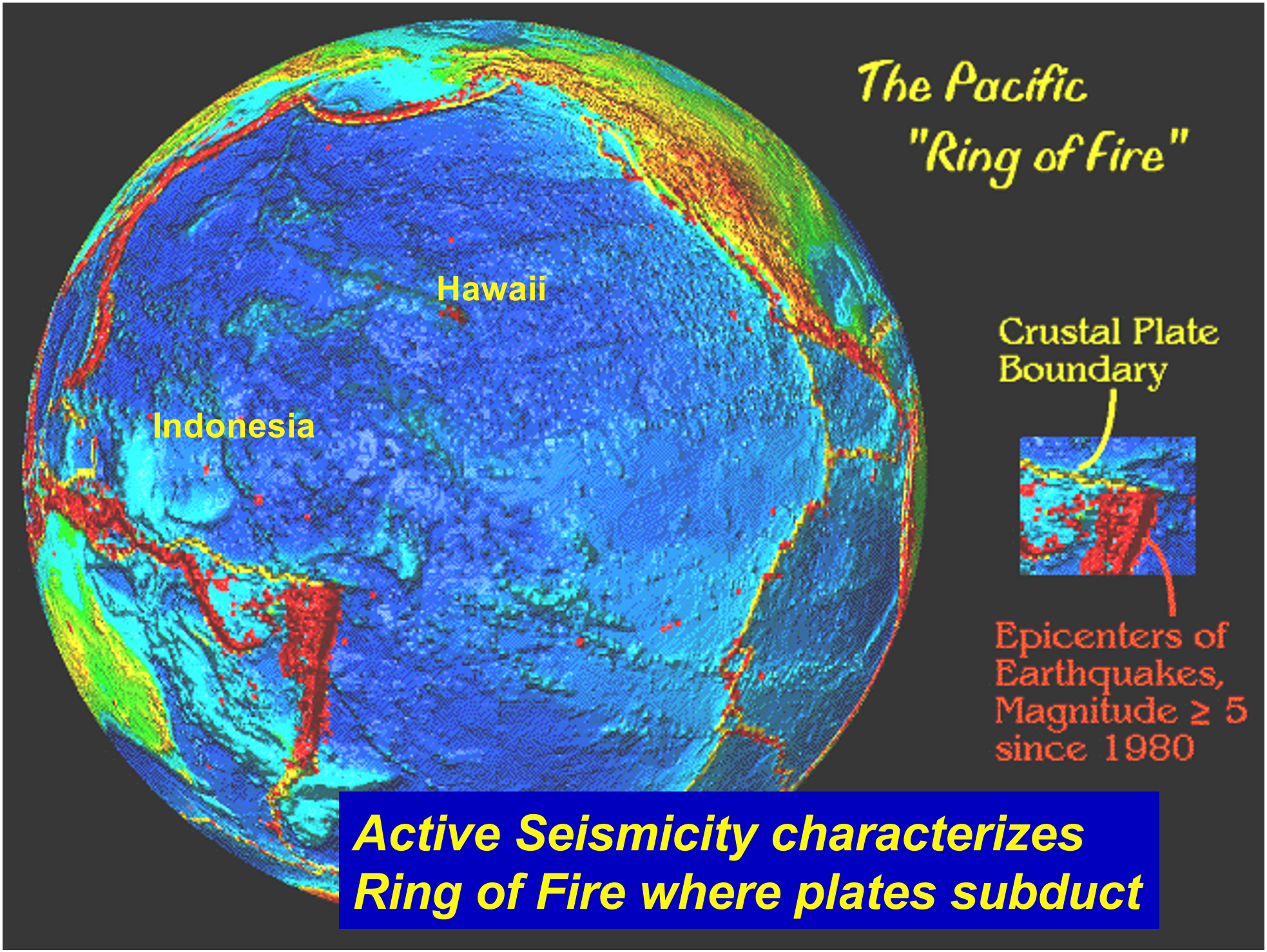
FIGURE 18.12 The three main types of fault movements that initiate earthquakes, and the stresses that cause them: (a) situation before movement takes place; (b) normal fault due to tensile stress; (c) thrust (or reverse) fault due to compressive stress; (d) lateral slip (or strike-slip) fault due to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

Normal fault Regime

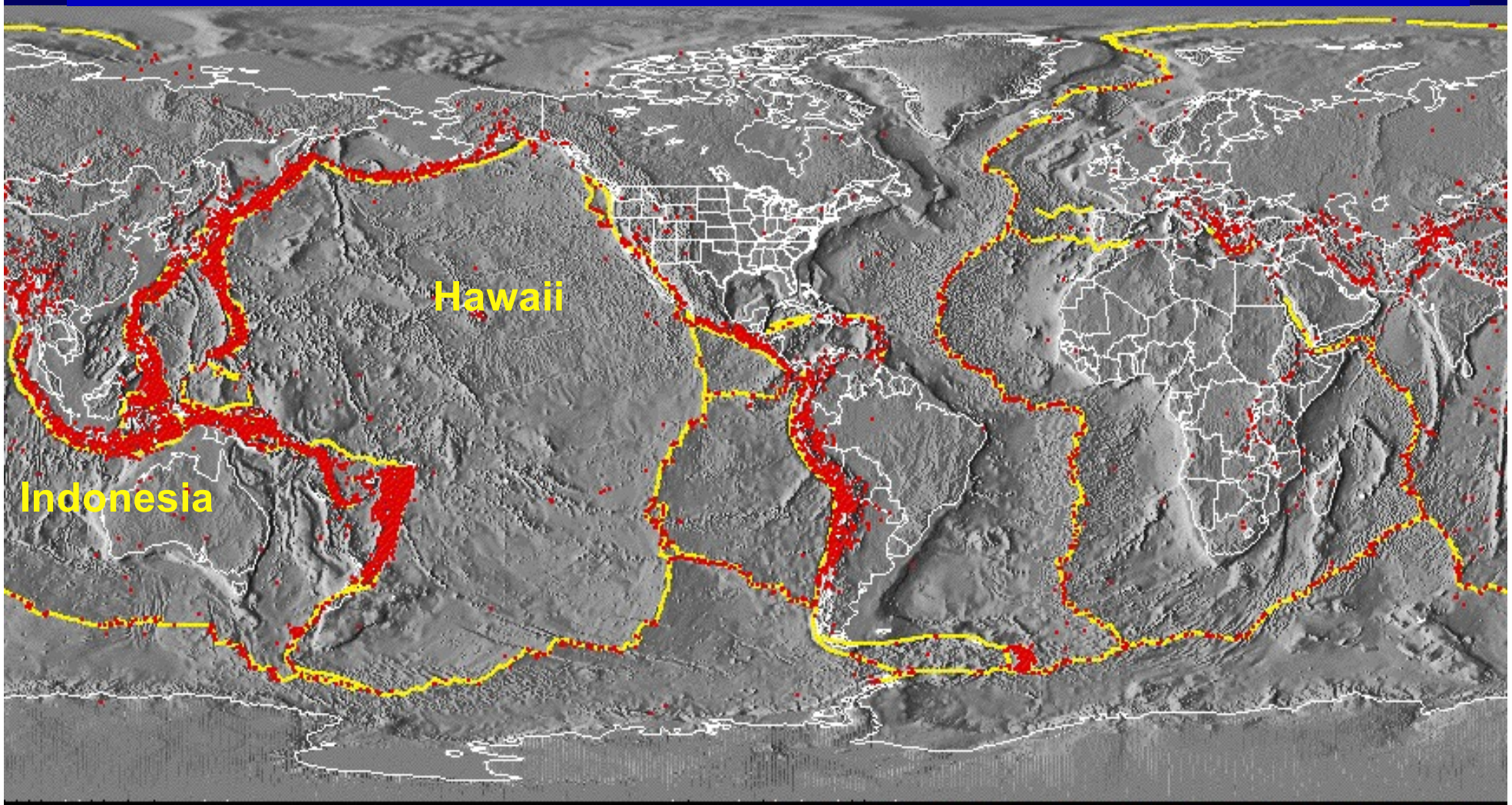
Thrust fault Regime

Strike-slip fault Regime

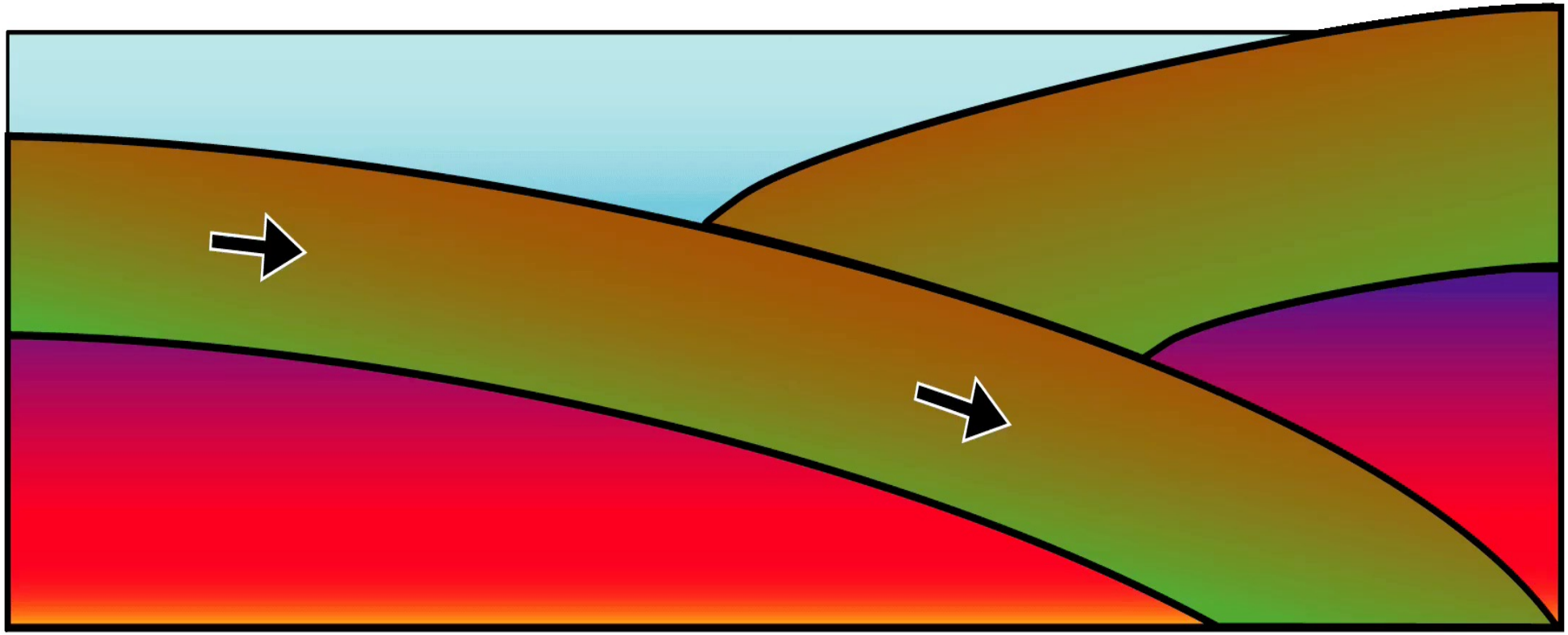
USGS
science for a changing world


The Pacific
"Ring of Fire"
Hawaii
Indonesia
Crustal Plate
Boundary
Epicenters of
Earthquakes,
Magnitude ≥ 5
since 1980
Active Seismicity characterizes
Ring of Fire where plates subduct

Earthquakes delineate Crustal Plate boundaries

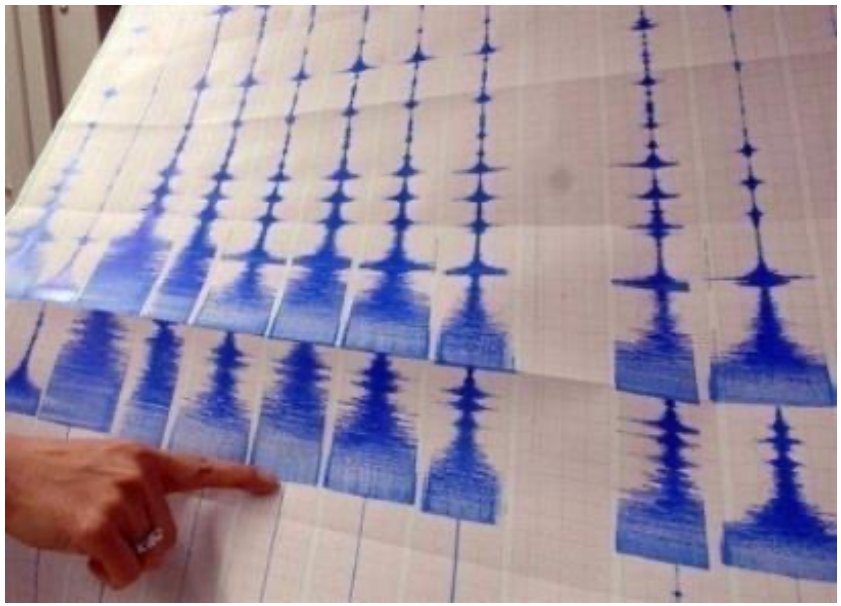


Most Tsunamis are caused by Shallow, Large Earthquakes beneath the Seafloor at Subduction Zones



Earthquake Magnitude

M7, PNG earthquake



Measuring Earthquake size

- **Historical measures (Macroscopic) – pre-1900**
  - 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

Modified Mercalli Scale		Richter Scale	
I.	Felt by almost no one.	2.5	Generally not felt, but recorded on seismometers.
II.	Felt by very few people.		
III.	Tremor noticed by many, but they often do not realize it is an earthquake.	3.5	Felt by many people.
IV.	Felt indoors by many. Feels like a truck has struck the building.		
V.	Felt by nearly everyone; many people awakened. Swaying trees and poles may be observed.		
VI.	Felt by all; many people run outdoors. Furniture moved, slight damage occurs.	4.5	Some local damage may occur.
VII.	Everyone runs outdoors. Poorly built structures considerably damaged; slight damage elsewhere.		
VIII.	Specially designed structures damaged slightly, others collapse.	6.0	A destructive earthquake.
IX.	All buildings considerably damaged, many shift off foundations. Noticeable cracks in ground.		
X.	Many structures destroyed. Ground is badly cracked.	7.0	A major earthquake.
XI.	Almost all structures fall. Bridges wrecked. Very wide cracks in ground.	8.0 and up	Great earthquakes.
XII.	Total destruction. Waves seen on ground surfaces, objects are tumbled and tossed.		

Giuseppe Mercalli (1850-1914)

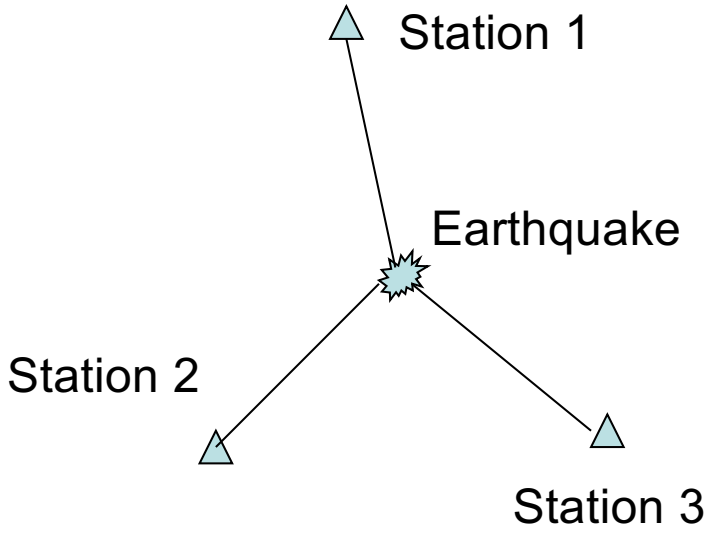
http://encarta.msn.com/media_461531420/earthquake_scales_modified_mercalli_and_richter.html

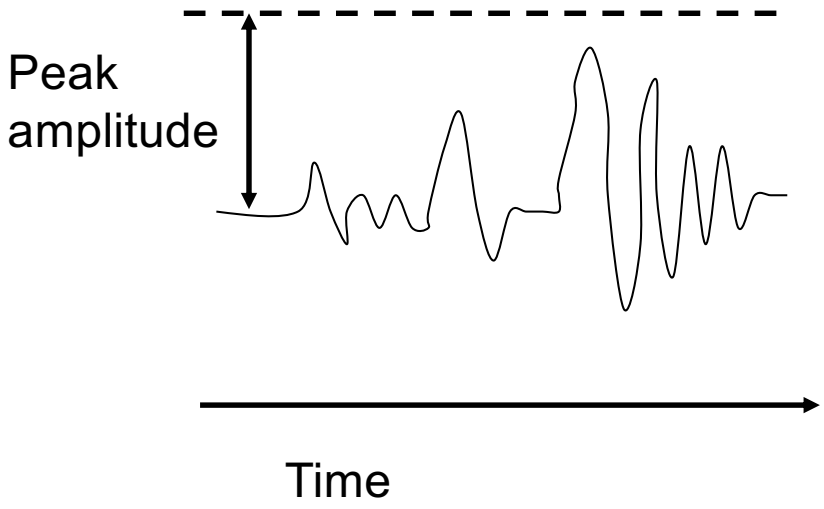
Instrumental Magnitude – since 1935

- **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**

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

- 1st magnitude scale by Charles Richter (1935) to measure California earthquakes.
- Now, many scales for various observational conditions.





Magnitude Scales – wave type, period

			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
M_w	Moment magnitude	teleseismic surface waves	> 200 sec
M_{wp}	P-wave moment magnitude	teleseismic P waves	10-60 sec
M_m	Mantle magnitude	teleseismic surface waves	> 200 sec

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

EARTHQUAKE ENERGY

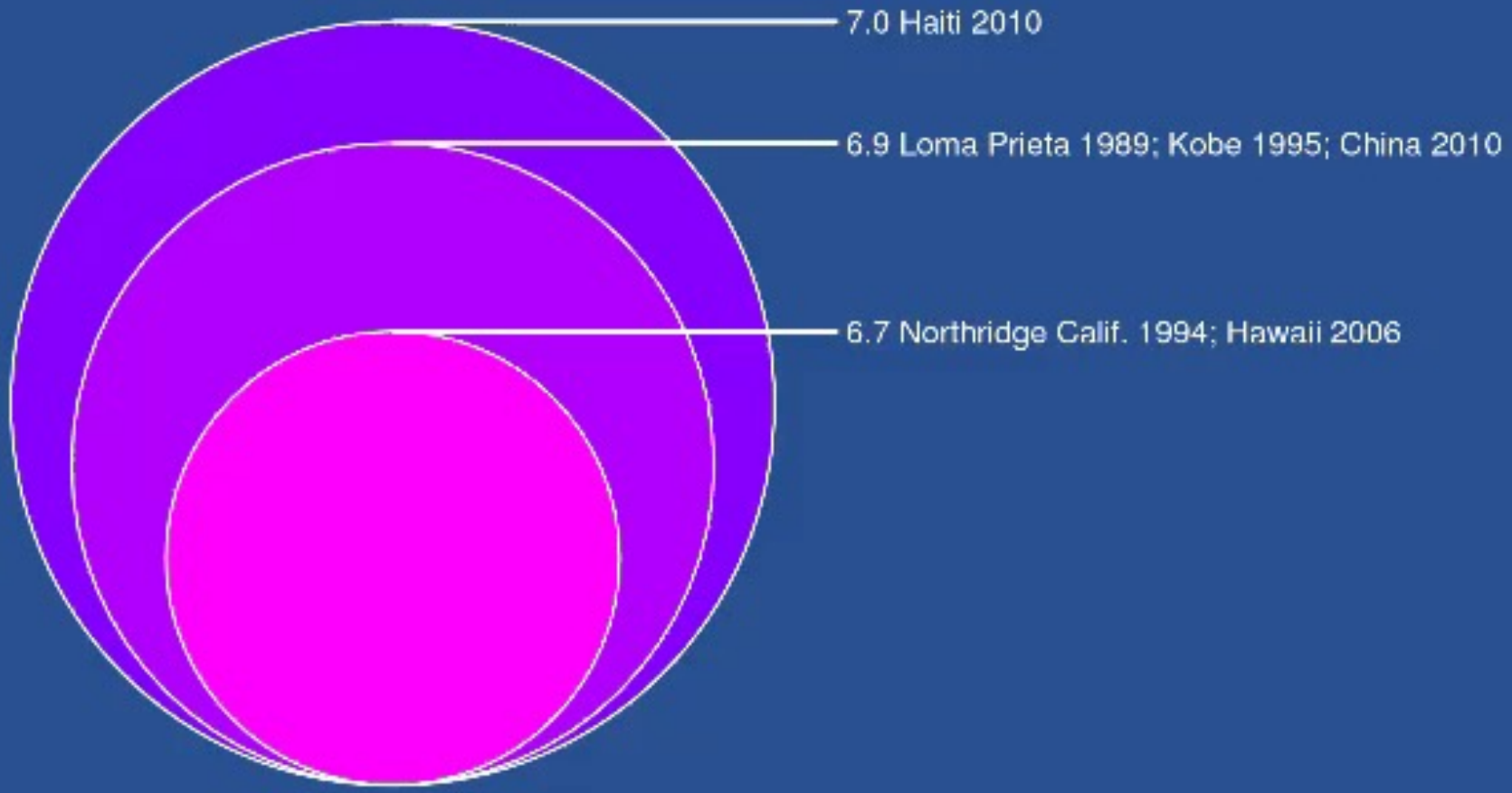
Use Mw to find real energy release

- 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



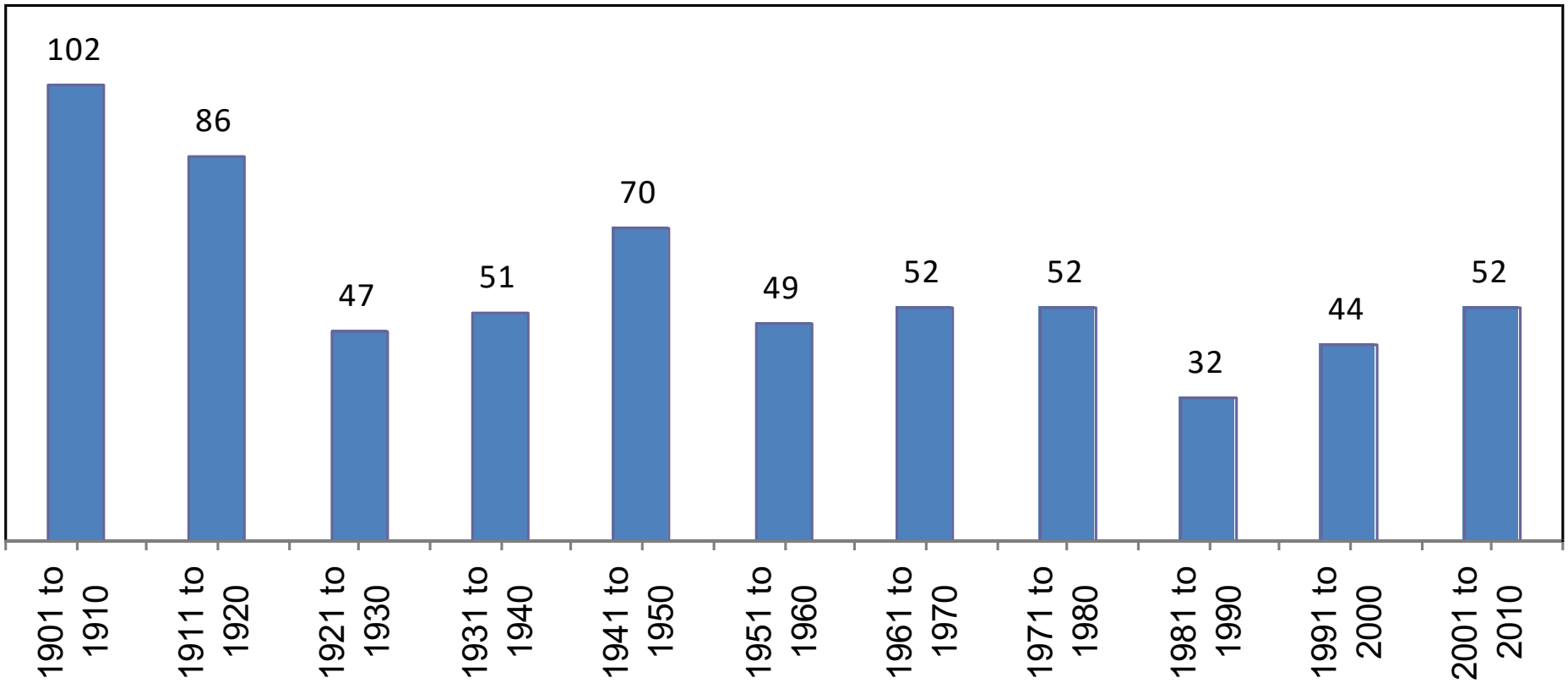
Earthquake and Tsunami Statistics

Magnitude	Earthquake Effects	Est Nbr / Year
2.5 or less	Usually not felt, but can be recorded by seismograph.	**900,000**
2.5 to 5.4 (Small (3-5) to Moderate (5-6)	Often felt, but only causes minor damage.	**30,000**
5.5 to 6.0 (Moderate)	Slight damage to buildings and other structures.	**500**
6.1 to 6.9 (Strong)	May cause a lot of damage in very populated areas.	**100**
7.0 to 7.9 (Major)	Major earthquake. Serious damage.	**20**
8.0 or greater (Great)	Great earthquake. Can totally destroy communities near the epicenter.	**several every 5-10 years**

Are Earthquakes Increasing?

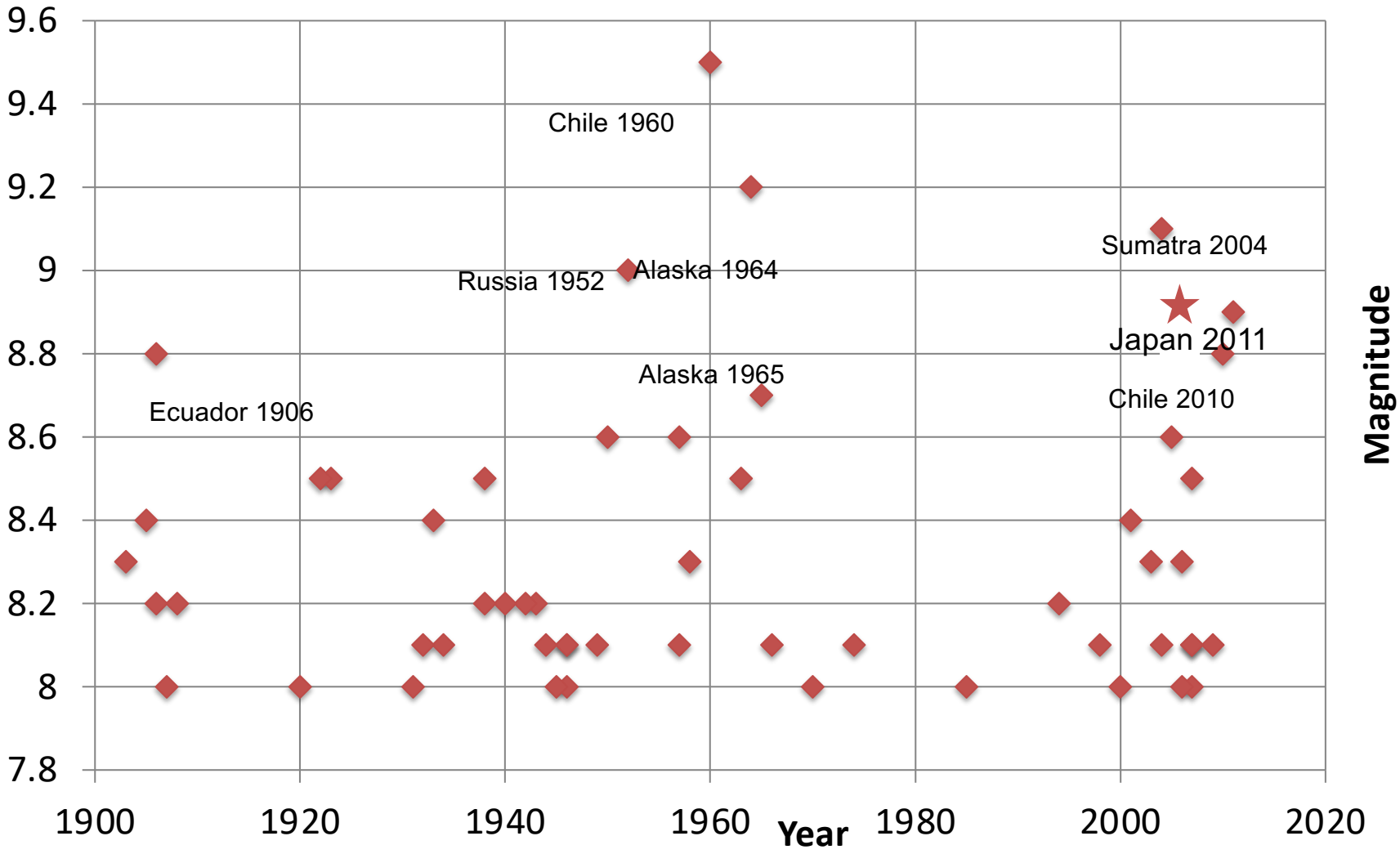
~50-60 per decade

Number of Earthquakes > 7.5 Magnitude



Total # of M7.5 EQS / decade remains consistent

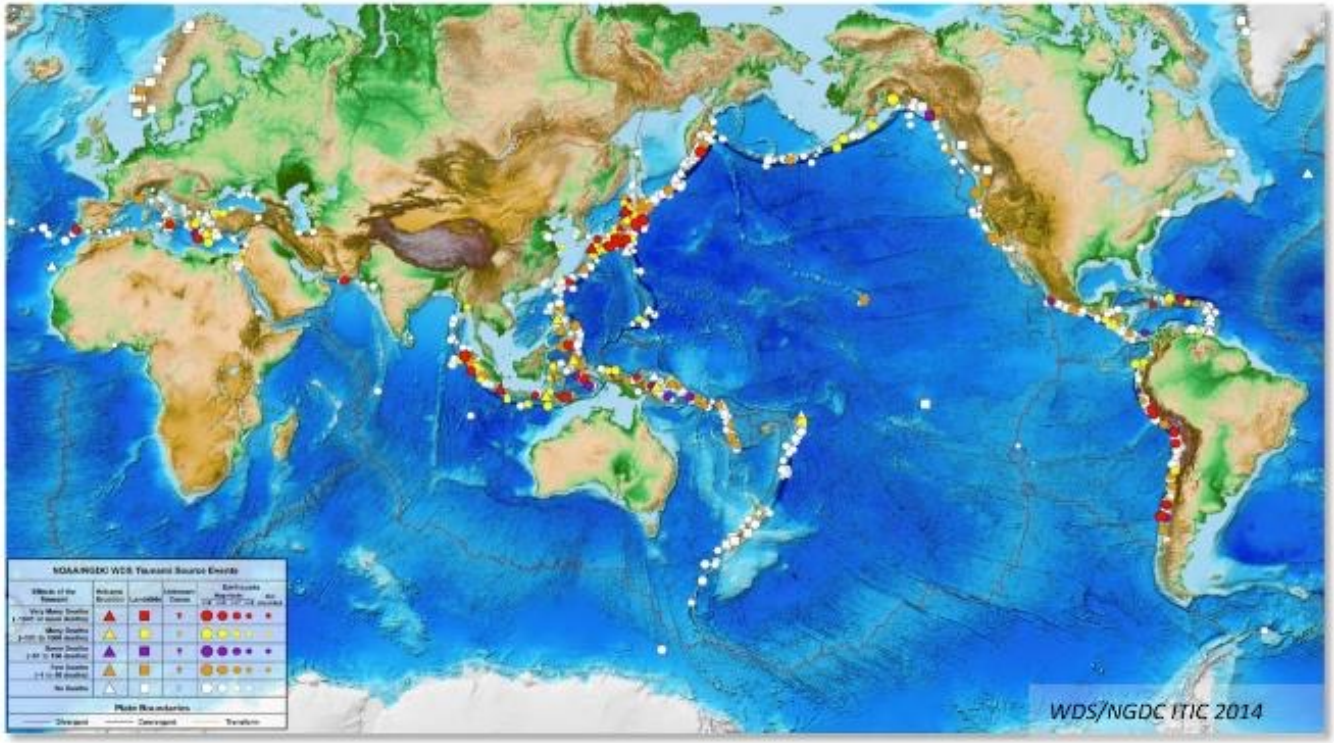
Great (M>8) Earthquakes since 1900 (avg 2.1/yr)



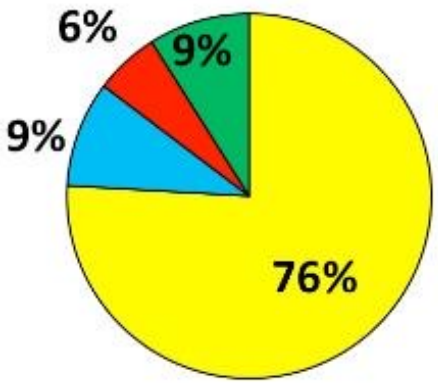
R. Butler, 2011

TSUNAMI SOURCES 1610 B.C. to A.D. 2016

FROM EARTHQUAKES, VOLCANIC ERUPTIONS, LANDSLIDES, AND OTHER CAUSES

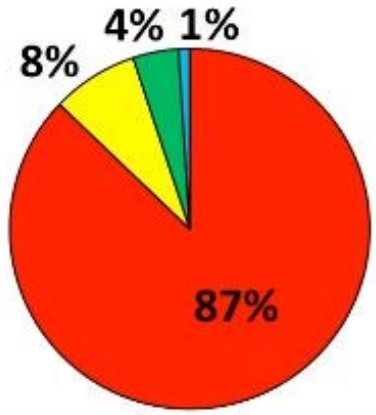


- ***1,235 Confirmed Tsunamis***
- ***249 Deadly Tsunamis***



SOURCE LOCATION

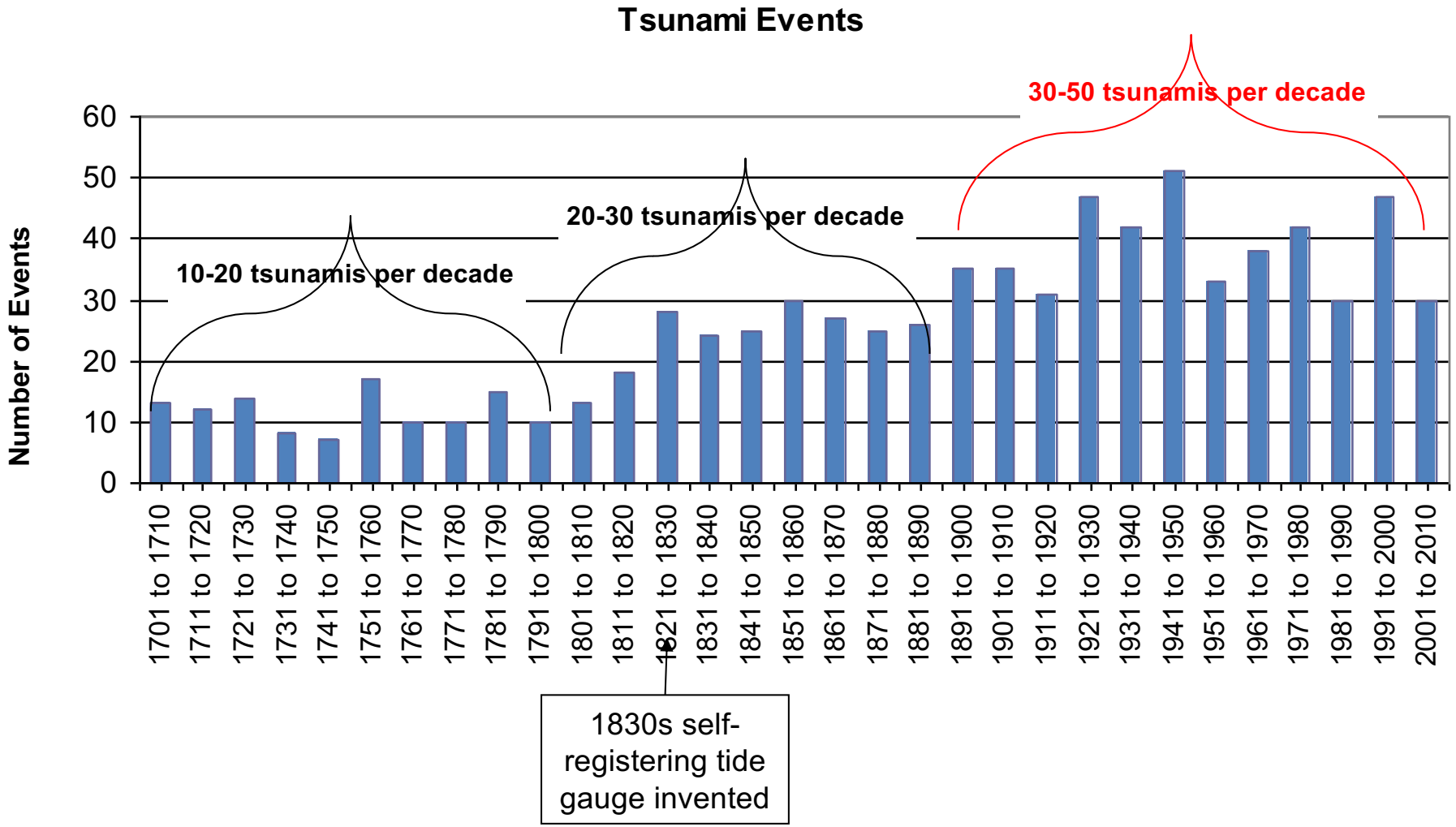
- Pacific Ocean
- Indian Ocean & Red Sea
- Atlantic Ocean & Caribbean Sea
- Mediterranean Sea



SOURCE TYPE

- Earthquakes
- Volcanic Eruptions
- Landslides
- Other causes

Are Tsunamis Increasing?



Total # tsunamis not increasing (due to improved reporting)

Thank You

Name
Organization