

Topic 5: Earthquakes and Plate Tectonics

<https://geowiki.ucsd.edu/sio15>



for-credit test #1 on Canvas TODAY!

Homework1 due TOMORROW,
submit single pdf on Gradescope,
assign page # to each problem #

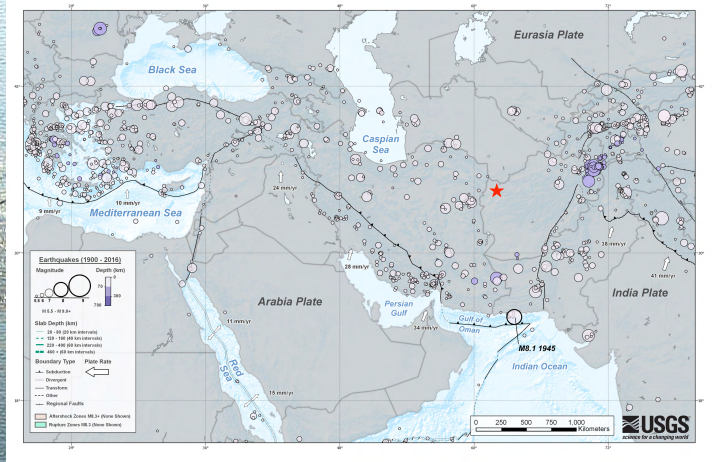
optional discussion session
today 4 pm, York 3030

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Friday/Saturday - Earthquakes

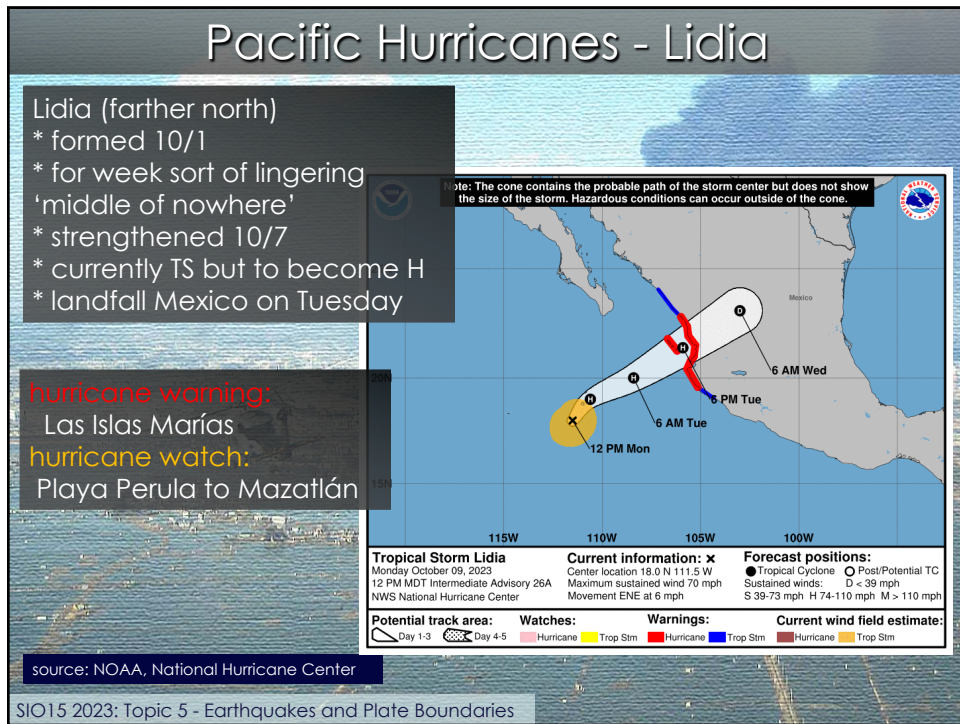
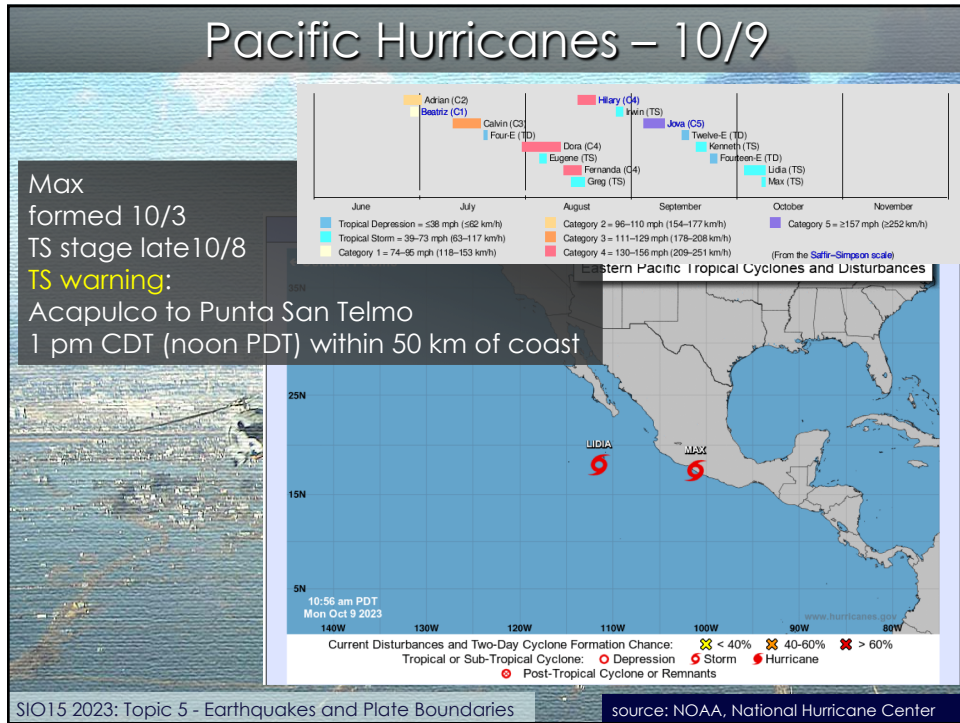
Afghanistan

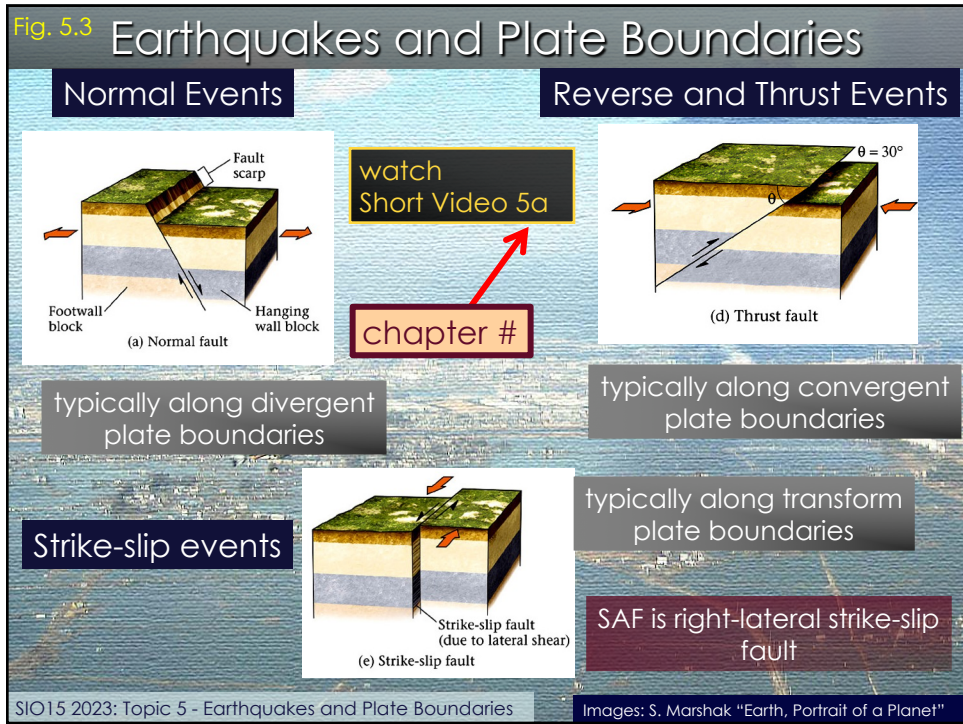
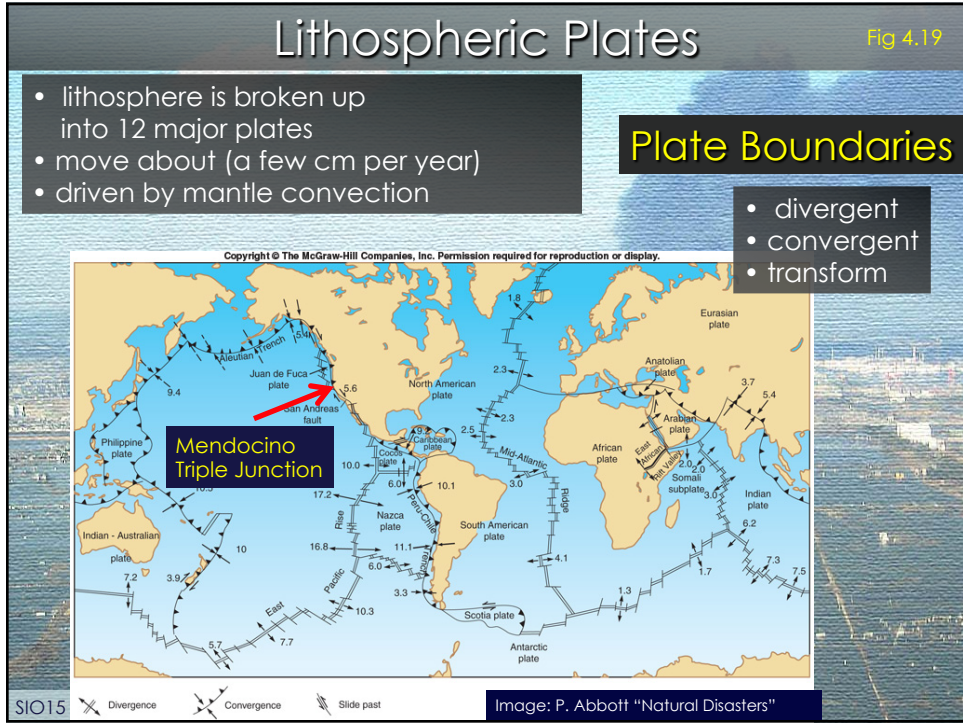
- at least 4 quakes $M > 5.5$
- 1000+ fatalities



source: USGS

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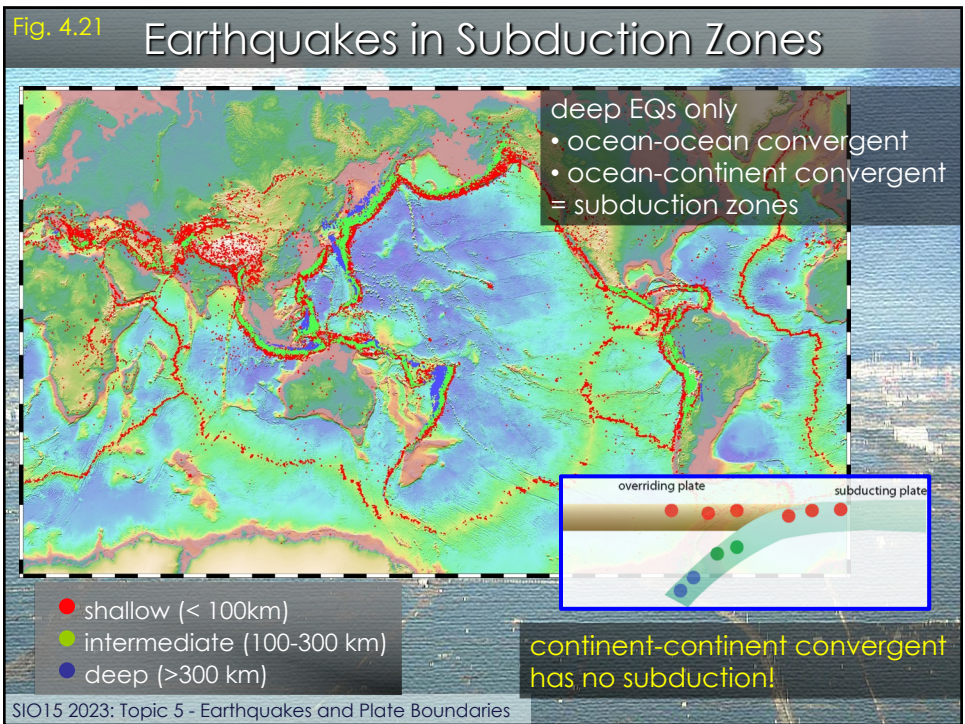
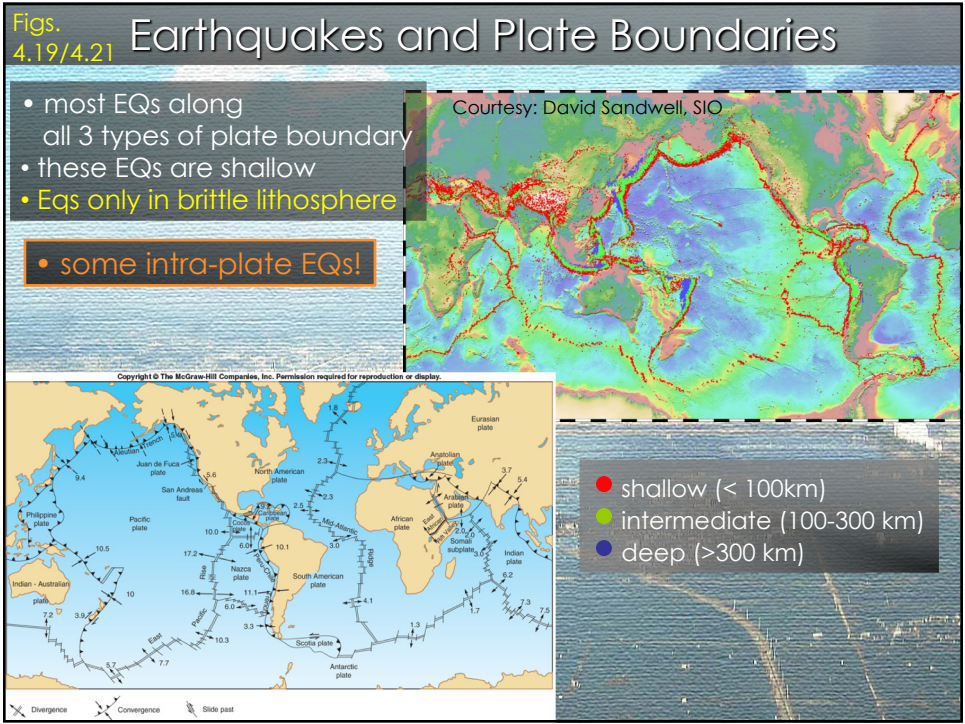
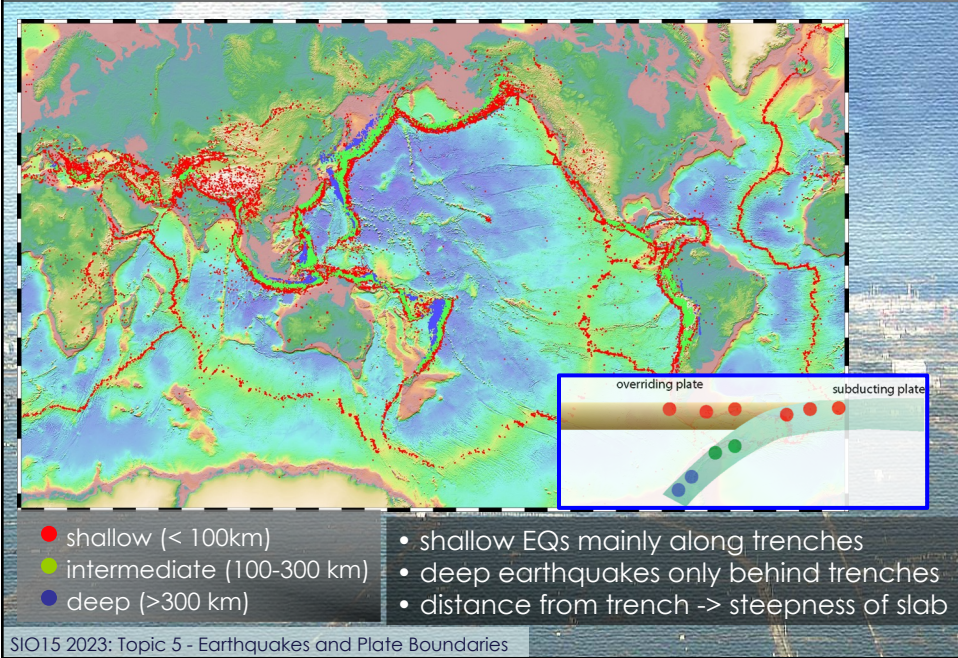
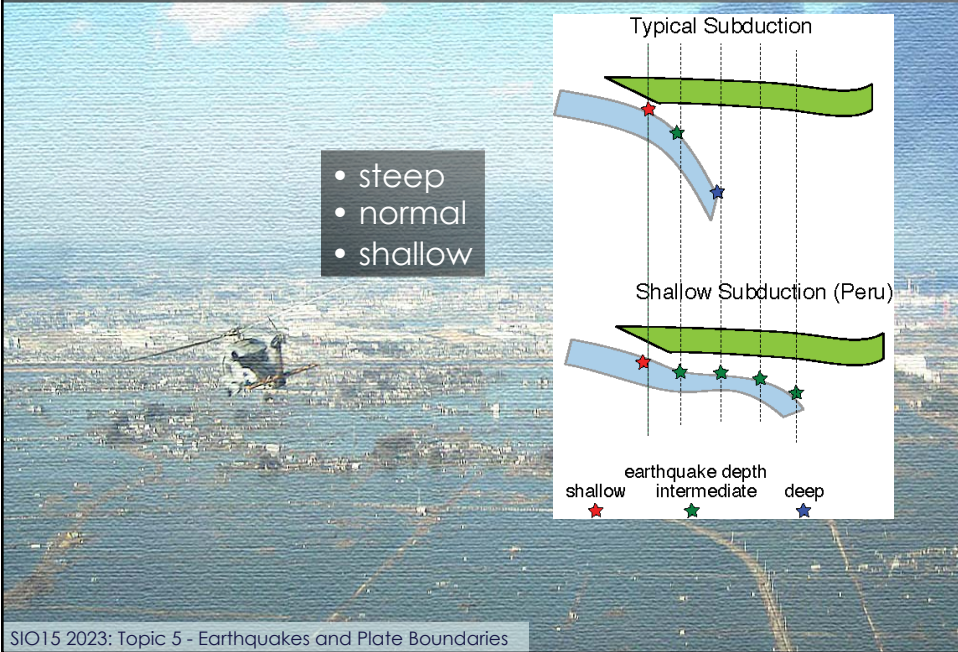


Fig. 4.21 Earthquakes in Subduction Zones




Earthquakes in Subduction Zones

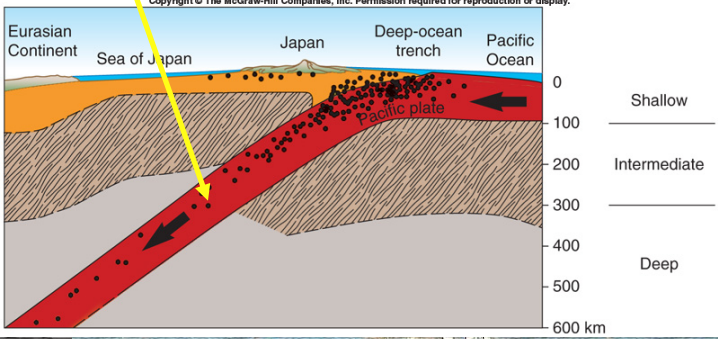


The Wadati-Benioff Zone

- earthquakes trace the subduction slab
- Wadati-Benioff zone
- most EQ near top of slab
- shallow EQs behind trench in OVERRIDING plate



Kiyoo Wadati (1902-1995)



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0
Shallow

100


200
Intermediate

300

400

500

600 km
Deep



Hugo Benioff (1899-1968)

slab: part of the subducting plate that is already in the mantle

Caltech Archives Earthquakes and Plate Boundaries

Fig. 4.21 Earth's Deepest Quakes

- deep earthquakes occur only to 670 km
- below pressure too high for cracks in crust
- deepest EQ due to phase transformations

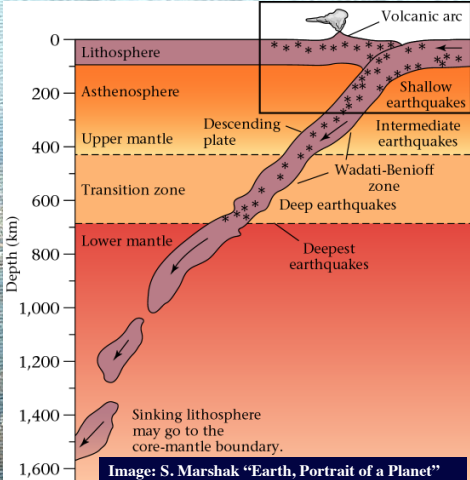


Image: S. Marshak "Earth, Portrait of a Planet"

subducting plate heats up
→ no longer brittle but ductile

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Earth's Largest Quakes

Table 5.1 The 16 Largest Earthquakes in the World since 1900⁽⁹⁾

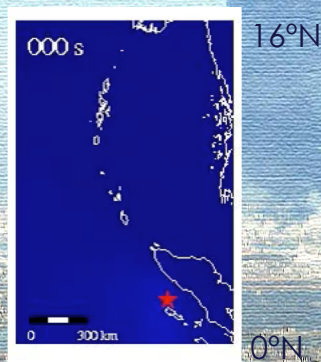
Rank	Location	Date	Magnitude	Plate Boundary
1	Valdivia, Chile	22 May 1960	9.5	<u>Nazca (plate) subduction</u>
2	Prince William Sound, Alaska "Good Friday Earthquake"	28 Mar 1964	9.2	<u>Pacific subduction</u>
3	Sumatra-Andaman, Indonesia	26 Dec 2004	9.1	<u>Indian subduction</u>
4	Tohoku, Japan	11 Mar 2011	9.0	<u>Pacific subduction</u>
5	Kamchatka	04 Nov 1952	9.0	<u>Pacific subduction</u>
6	Maule, Chile	27 Feb 2010	8.8	<u>Nazca subduction</u>
7	Off the Coast of Ecuador	31 Jan 1906	8.8	<u>Nazca subduction</u>
8	Rat Islands, Alaska	04 Feb 1965	8.7	<u>Pacific subduction</u>
9	Northern Sumatra, Indonesia	28 Mar 2005	8.6	<u>Indian subduction</u>
10	Assam, India - Tibet	15 Aug 1950	8.6	<u>India/Asia collision</u>
11	Andreanof Islands, Alaska	09 Mar 1957	8.6	<u>Pacific subduction</u>
12	Southern Sumatra, Indonesia	12 Sep 2007	8.5	<u>Pacific subduction</u>
13	Banda Sea, Indonesia	01 Feb 1938	8.5	<u>Pacific/Indian subduction</u>
14	Kamchatka	03 Feb 1923	8.5	<u>Pacific subduction</u>
15	Chile-Argentina Border	11 Nov 1922	8.5	<u>Nazca subduction</u>
16	Kuril Islands	13 Oct 1963	8.5	<u>Pacific subduction</u>

the largest EQs in the last 100 year occurred in subduction zones

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The Fault Length and the Size of an EQ

rupture propagation
of 2004 Sumatra-Andaman EQ



- the largest EQs occurred along long faults
- large EQs along short faults are unlikely

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Poll

Q1 Where in the U.S. do we find the greatest earthquake hazard?

Single Choice Multiple Choice

California
Alaska
Hawaii
Oklahoma
South Carolina

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Poll

Q1 Where in the U.S. do we find the greatest earthquake hazard?

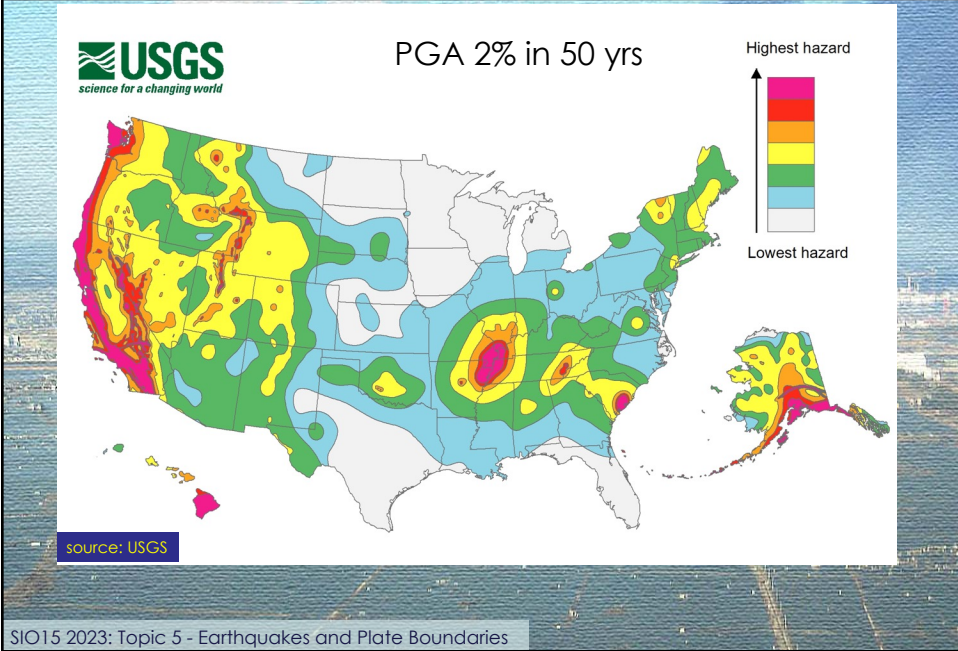
no simple answer

Single Choice Multiple Choice

California	high population density
Alaska	greatest EQs
Hawaii	some Eqs/tsunami risk
Oklahoma	even here
South Carolina	some EQs

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Fig. 6.26 updated Earthquakes in Plate's Interior



New Madrid: Earthquakes in Plate's Interior?

Mag 7.9/8.0, 1811/1812;
Largest U.S. EQ outside of Alaska
(together with 1857 Fort Tejon, CA)

Earthquakes recorded
between 1974 and
1995

Mercalli Intensity

Short Video 5b

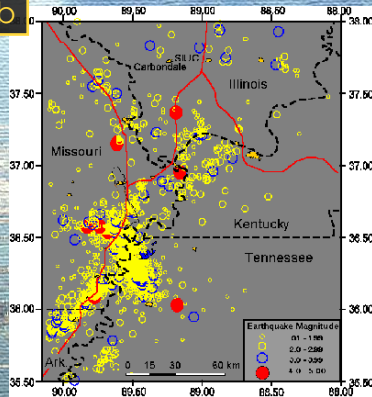
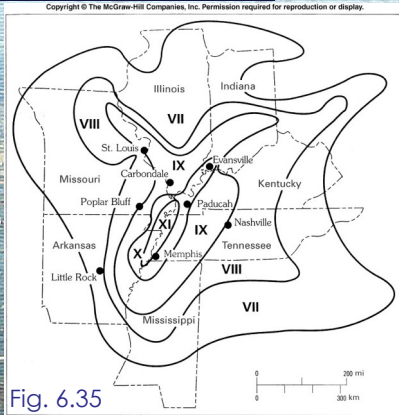
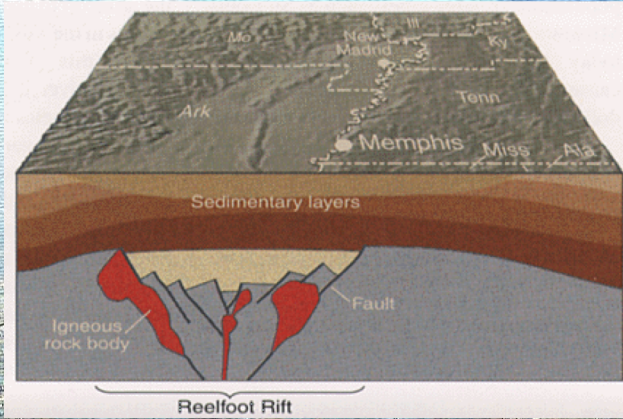


Fig. 6.35

Failed Ancient Rift (~550 my ago)!

New Madrid: Earthquakes in Plate's Interior?

Fig. 6.36



Failed Ancient Rift (~550 my ago)! now buried with sediments
-> faults/weak zone
-> still active today even without active plate boundary

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The East African Rift

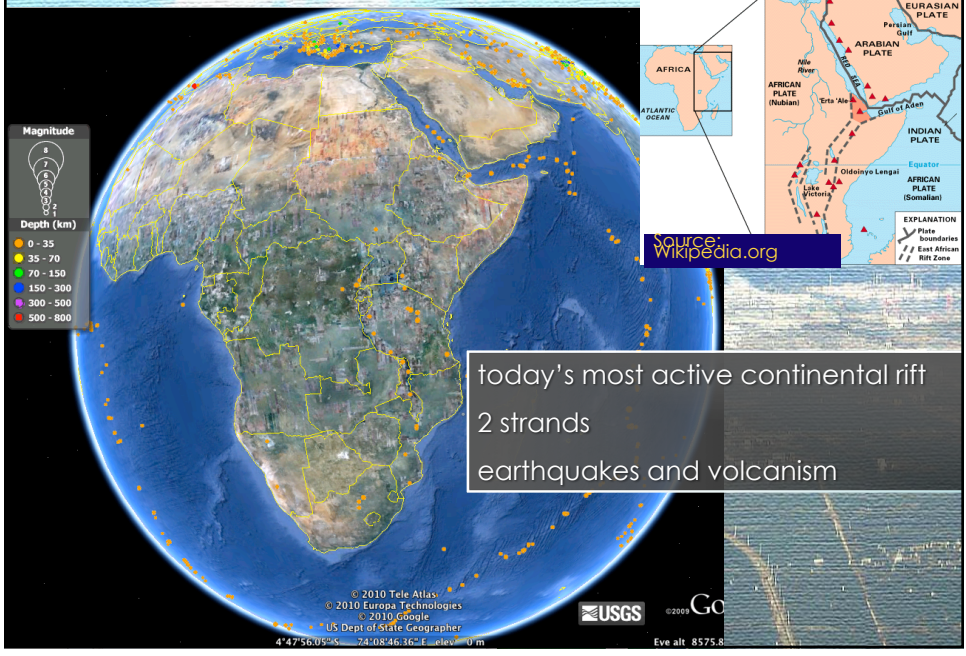
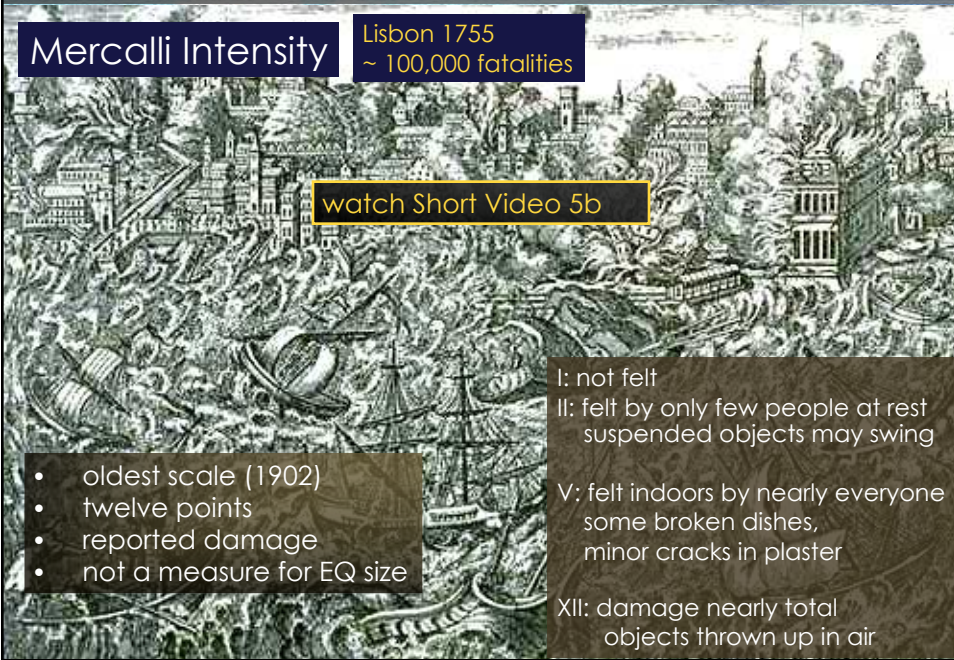


Fig. 5.9 Earthquake Intensities and Magnitudes

Mercalli Intensity

Lisbon 1755
~ 100,000 fatalities



watch Short Video 5b

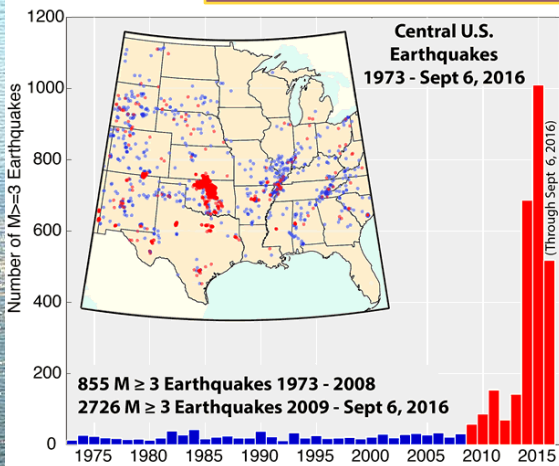
- oldest scale (1902)
- twelve points
- reported damage
- not a measure for EQ size

I: not felt
 II: felt by only few people at rest
 suspended objects may swing
 V: felt indoors by nearly everyone
 some broken dishes,
 minor cracks in plaster
 XII: damage nearly total
 objects thrown up in air

Induced Seismicity - Oklahoma

typically < M4

Waste water injection from
Shale Oil Production



but:
 - exponential increase in last 10 years

9/3/16:
 M 5.8 strike-slip
 (most likely natural)

2011: M 5.6; \$1M

tied with 2011 Virginia; strongest in 70 years

855 M ≥ 3 Earthquakes 1973 - 2008

2726 M ≥ 3 Earthquakes 2009 - Sept 6, 2016

problem: no EQ building code

Image: wikipedia/USGS

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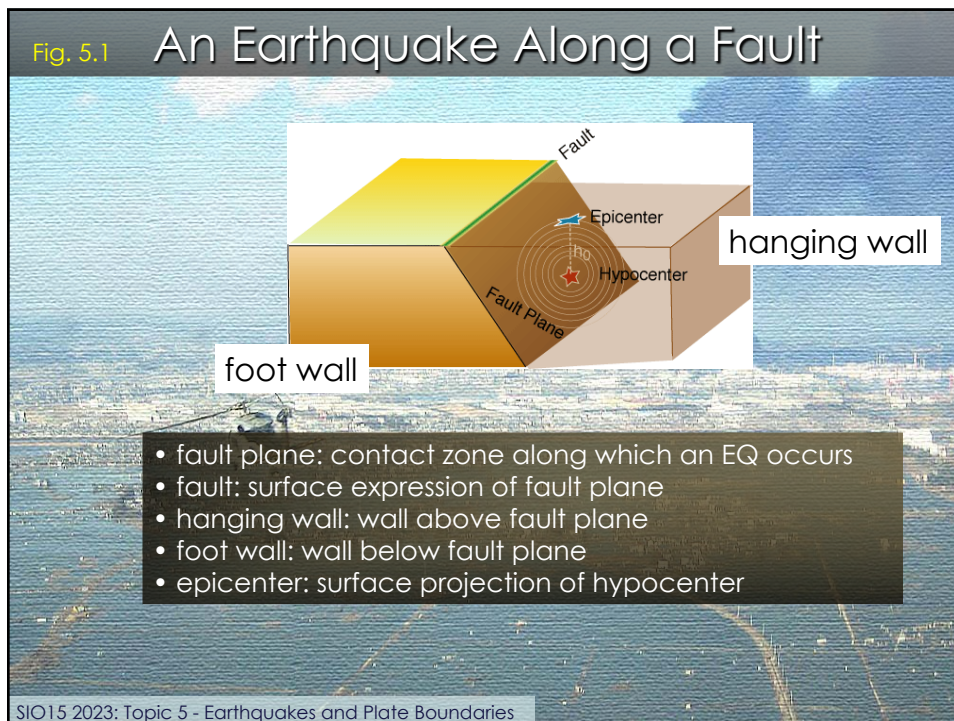
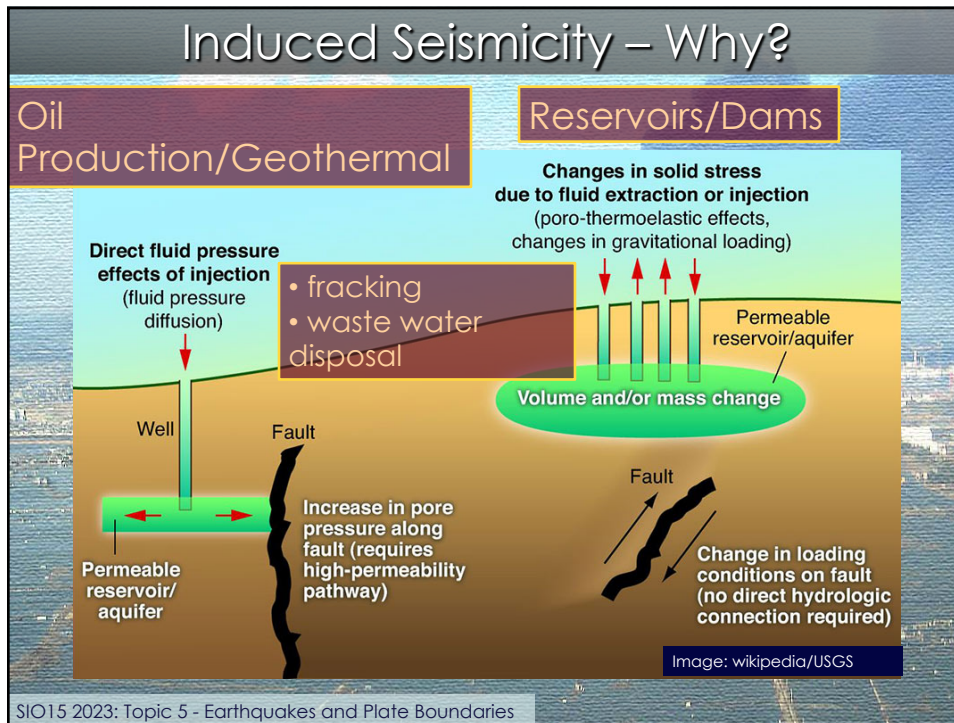
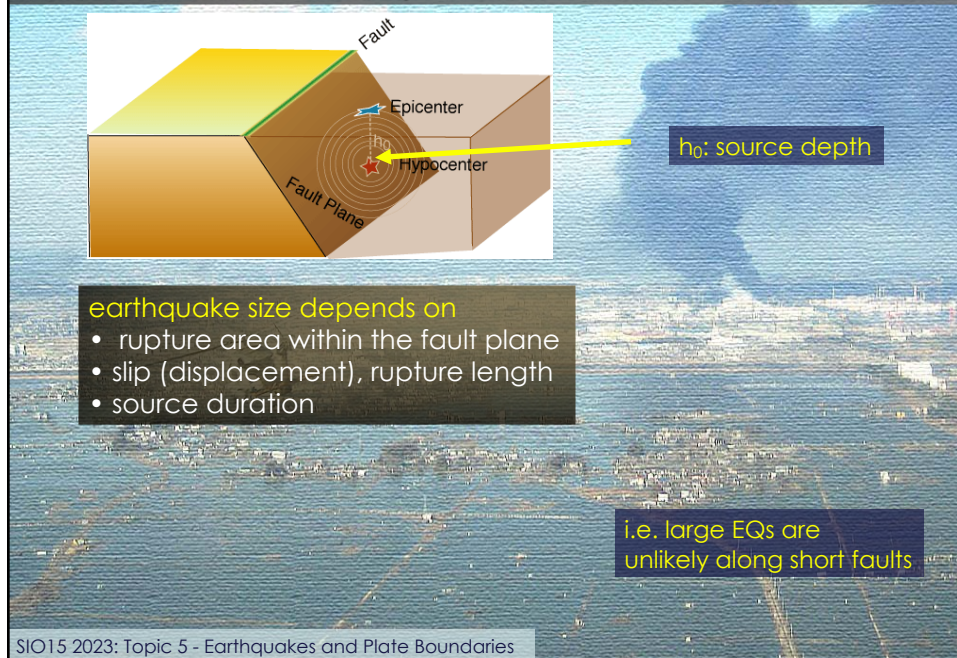


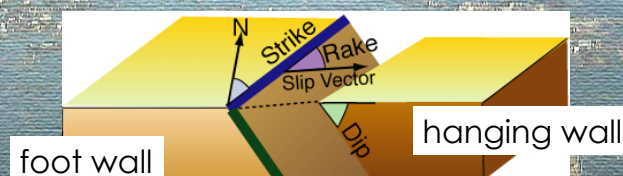
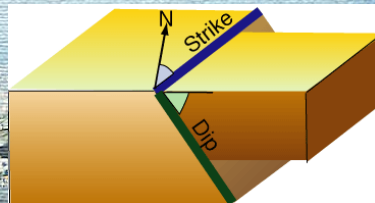
Fig. 5.1 Fault Geometry and the Size of an EQ



Parameters of an Earthquake Along a Fault

Fig. 5.2

- **strike** (direction of surface trace)
- **dip** (dip of fault plane)
- **rake** (direction of motion of hanging wall)
- **slip vector** (motion of block)



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How Often Do Earthquakes Occur?

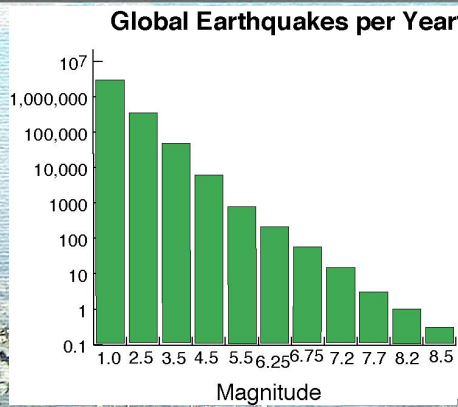
Table 5.5 Annual Worldwide Seismicity by Moment Magnitude (modified from ⁽³⁾)

Magnitude	# of EQs/year	Estimated Radiated Seismic Energy ($\times 10^{17}$ J)
8.5 and up	0.3	11.1
8.0-8.4	1	5.0
7.5-7.9	3	2.7
7.0-7.4	15	2.4
6.6-6.9	56	1.7
6.0-6.5	210	1.4
5.0-5.9	800	0.59
4.0-4.9	6200	0.15
3.0-3.9	49,000	0.04
2.0-2.9	350,000	0.008
0.0-1.9	3,000,000	0.002

- > 3.5 Mio per year
- small events often
- large events rare

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Earthquake Recurrence Time Fig. 5.13



Get recurrence time from # of EQ per year

E.g. 3 Mio EQ/year -> 1 EQ every 10.5s
 0.3 EQ/year -> 1 EQ every 3.3 years

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