Great earthquakes and new insights into subduction seismogenesis

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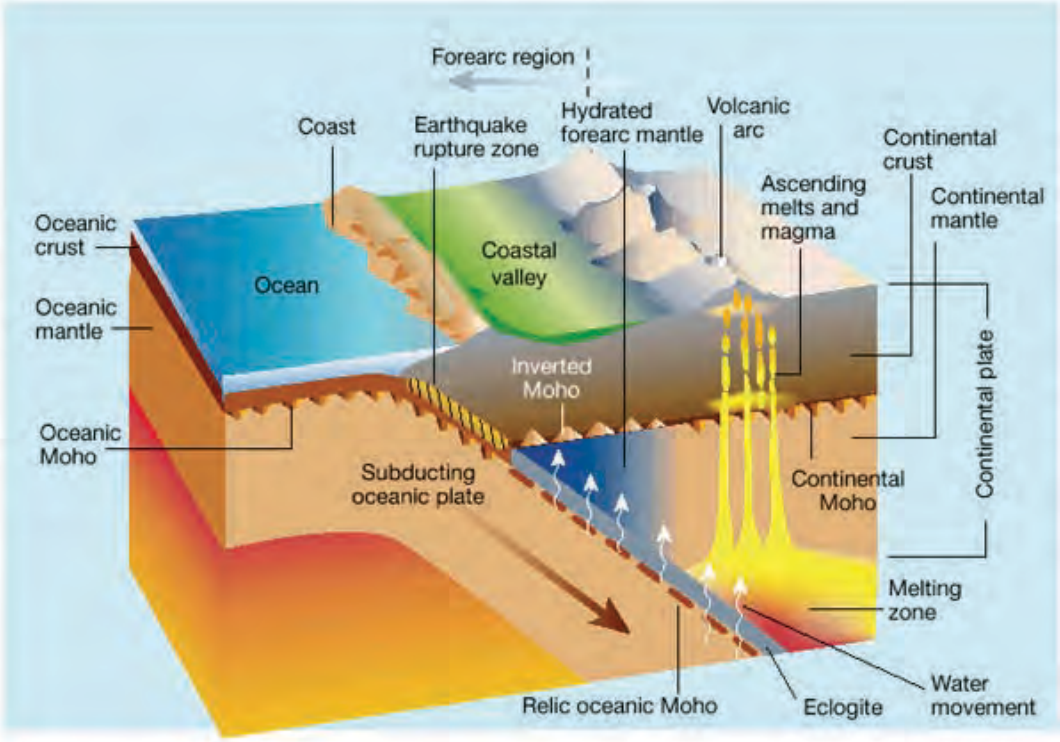
Geodynamic Processes at Rifting and Subducting Margins

The earth, the very emblem of solidity, has moved beneath our feet like a thick crust over a fluid.

- Charles Darwin reflecting on experiencing the Feb. 1835 great Concepción, Chile earthquake
The Voyage of the Beagle, 1845

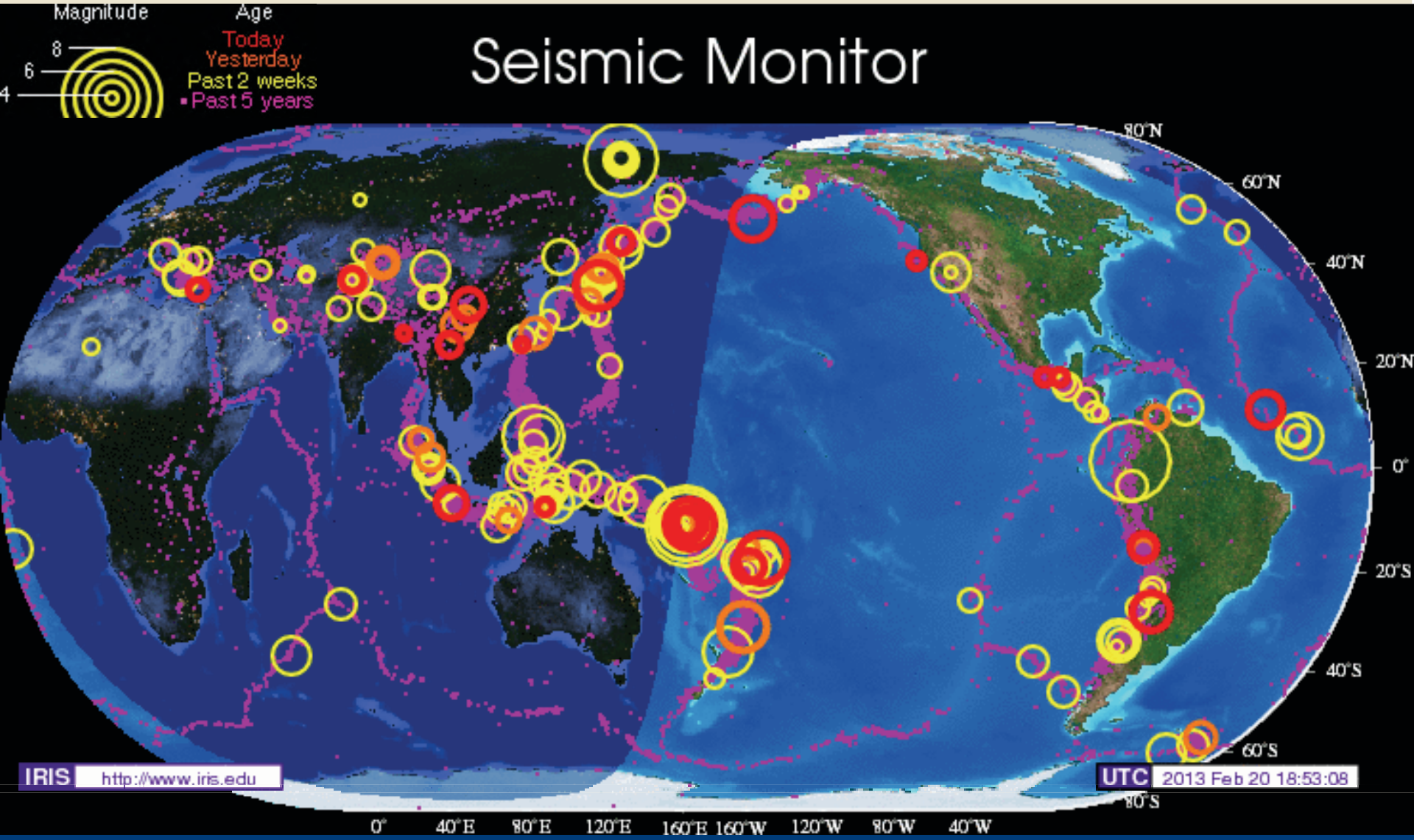
Outline

- Subduction megathrust faults and the seismogenic zone
- Subduction cycles and deformation
  - Outstanding questions
- Great earthquakes
  - Recent insights
  - Future concerns
  - New models

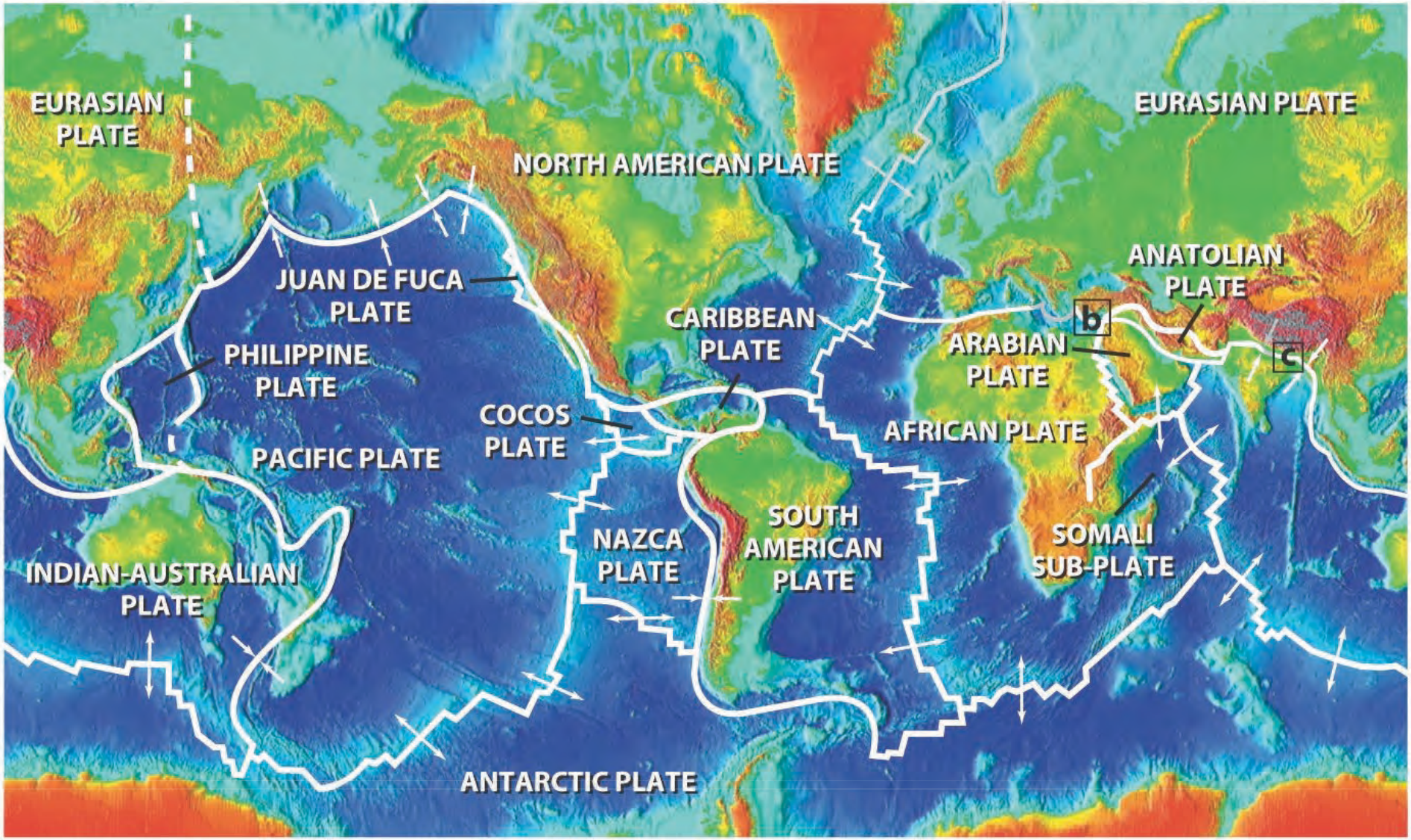


Zandt, 2002

The Active Earth



Plates - *rigid lithosphere riding on a convecting mantle*



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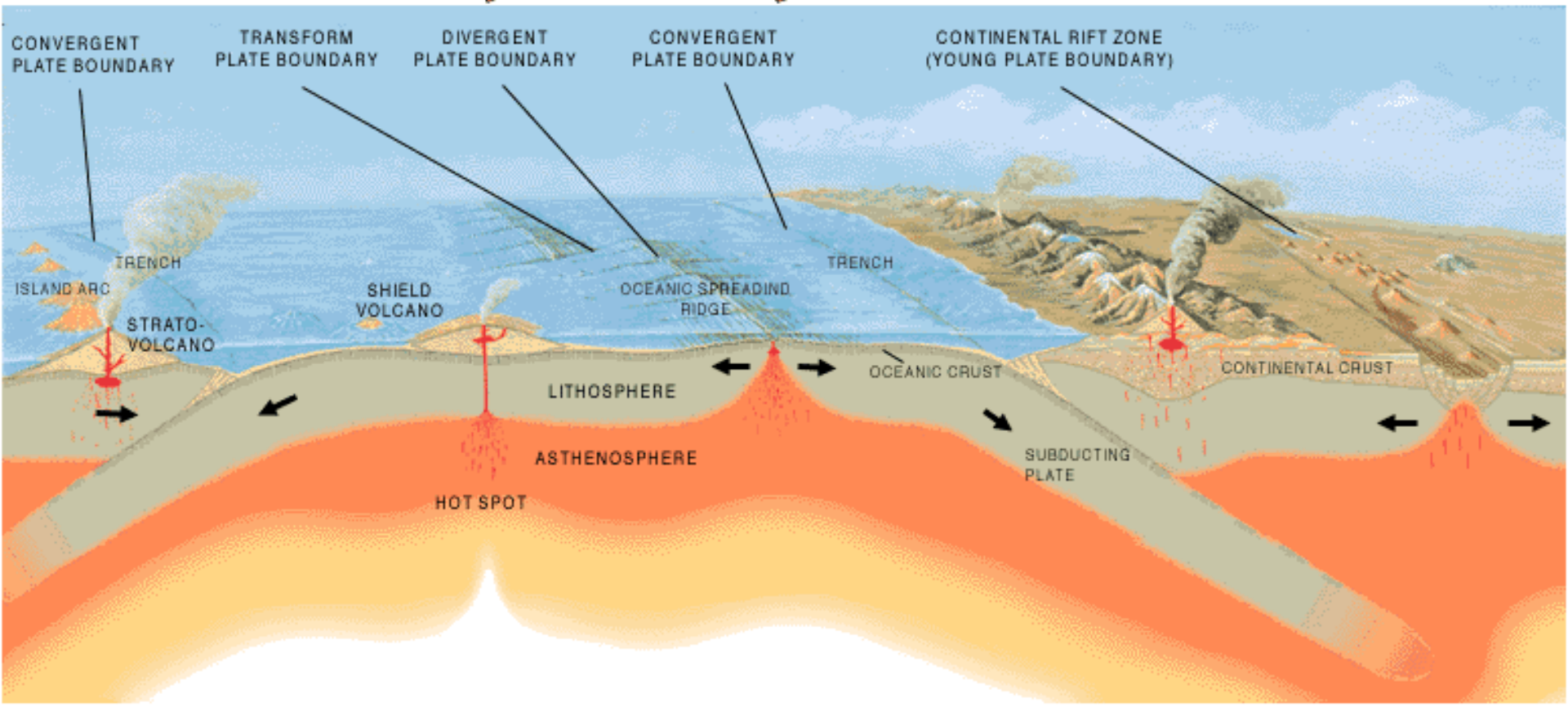
3 Types of Plate Boundaries

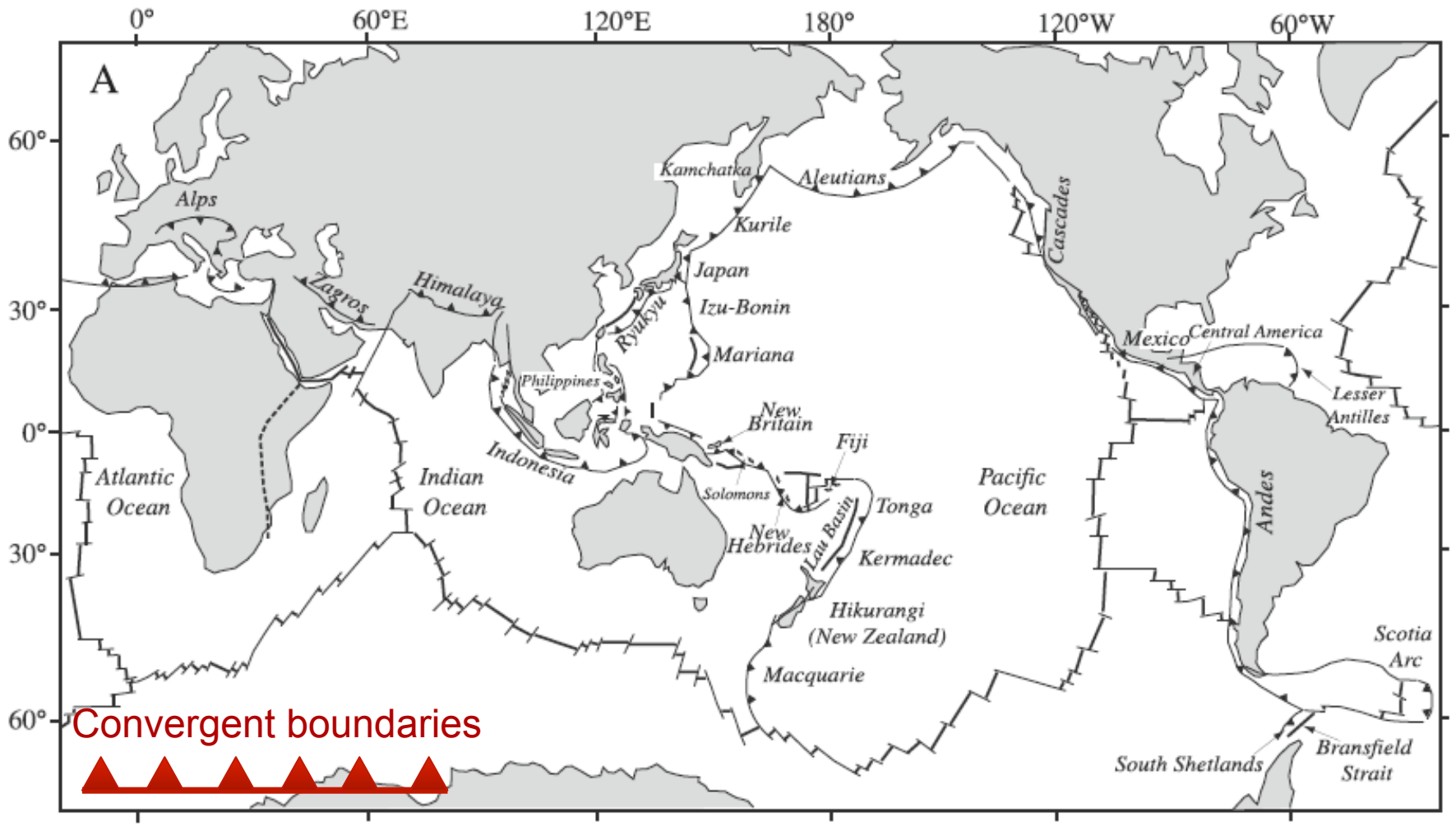
Transform

Divergent

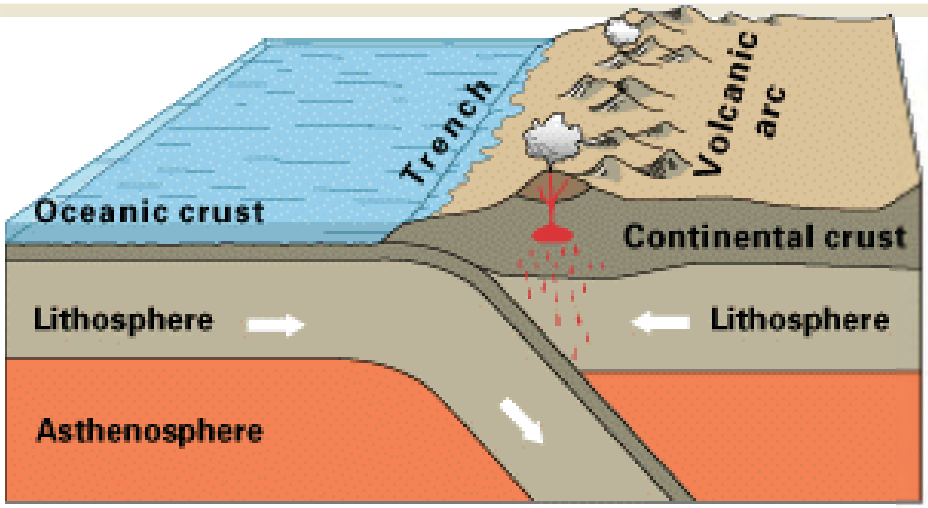
Convergent



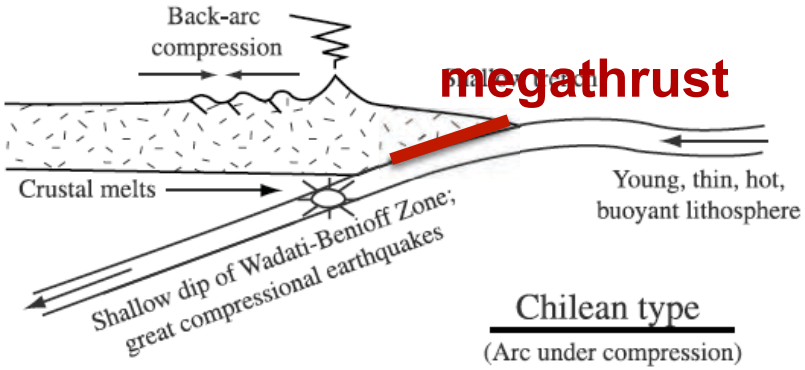
Global distribution of convergent boundaries

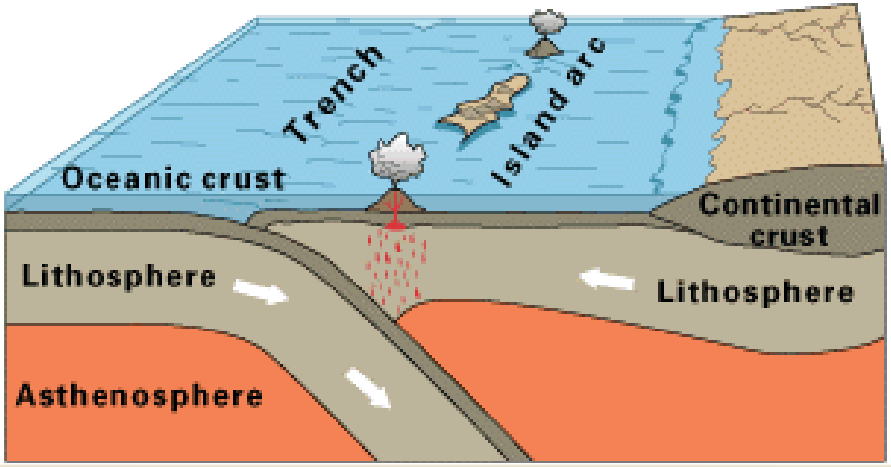


End Member Models of Subduction Zones

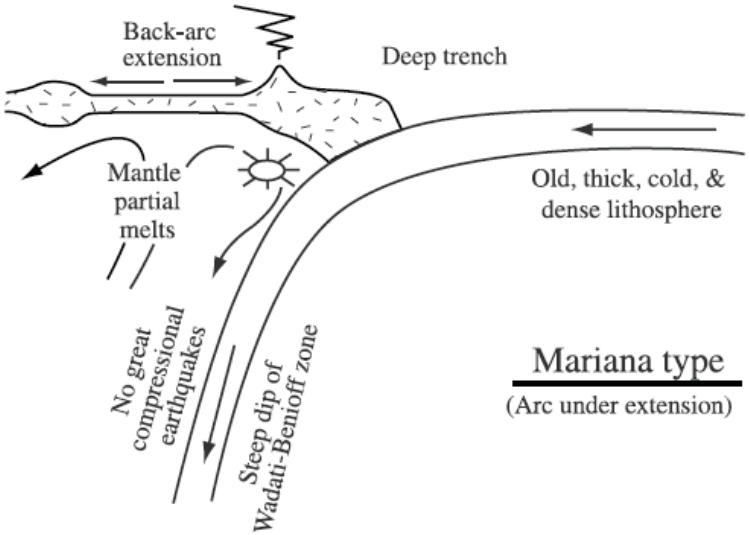


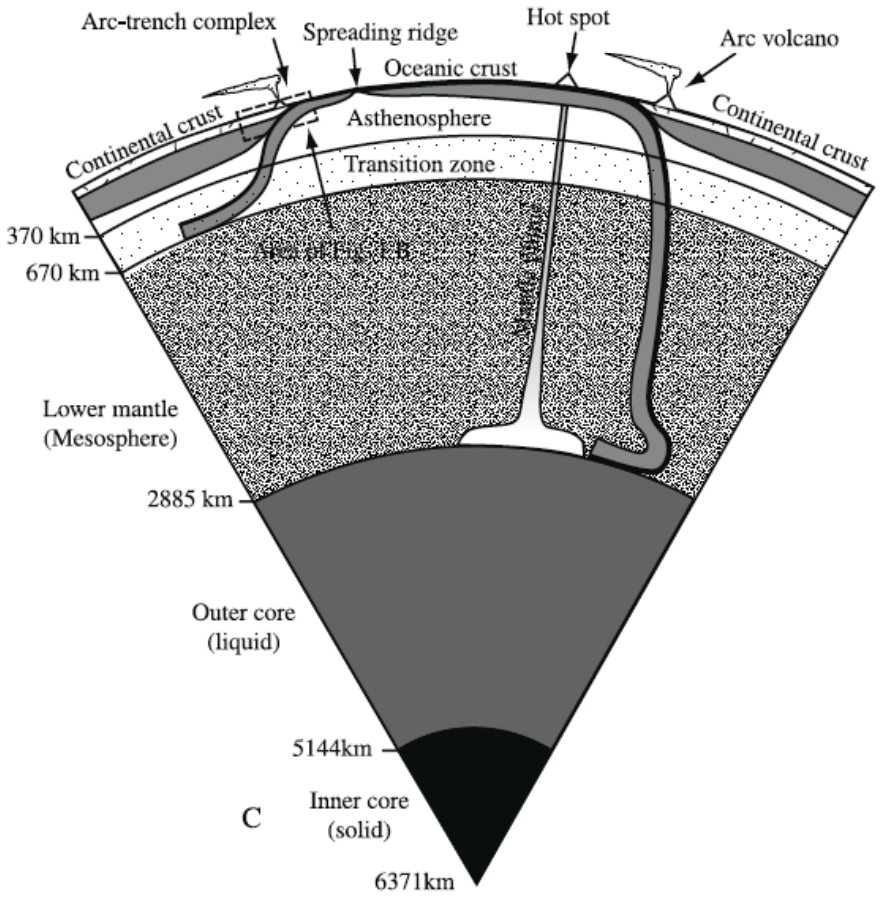
Oceanic-continental convergence





Oceanic-oceanic convergence





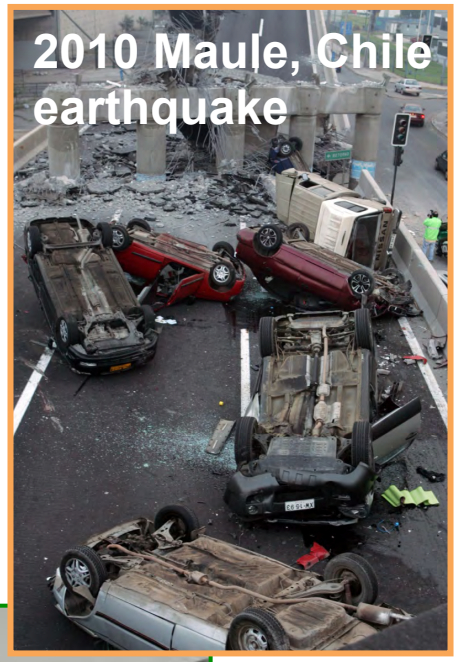
Subduction is part of the mantle convection system

Subduction and arc volcanism are great water recyclers

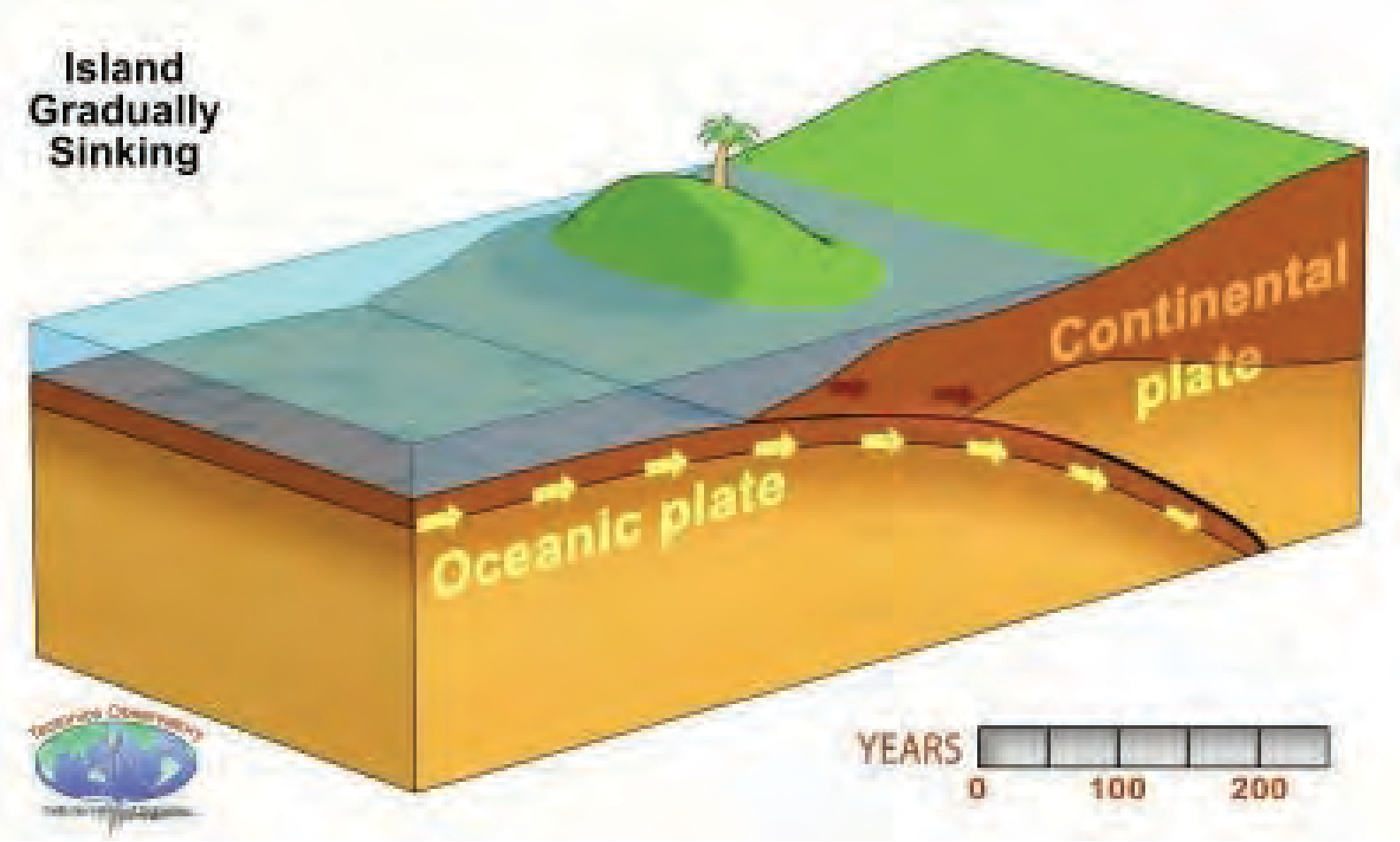
Subduction and arc processes help build continental crust

Stern, 2002

Subduction megathrust faults generate great earthquakes & tsunami



The megathrust and tsunamis

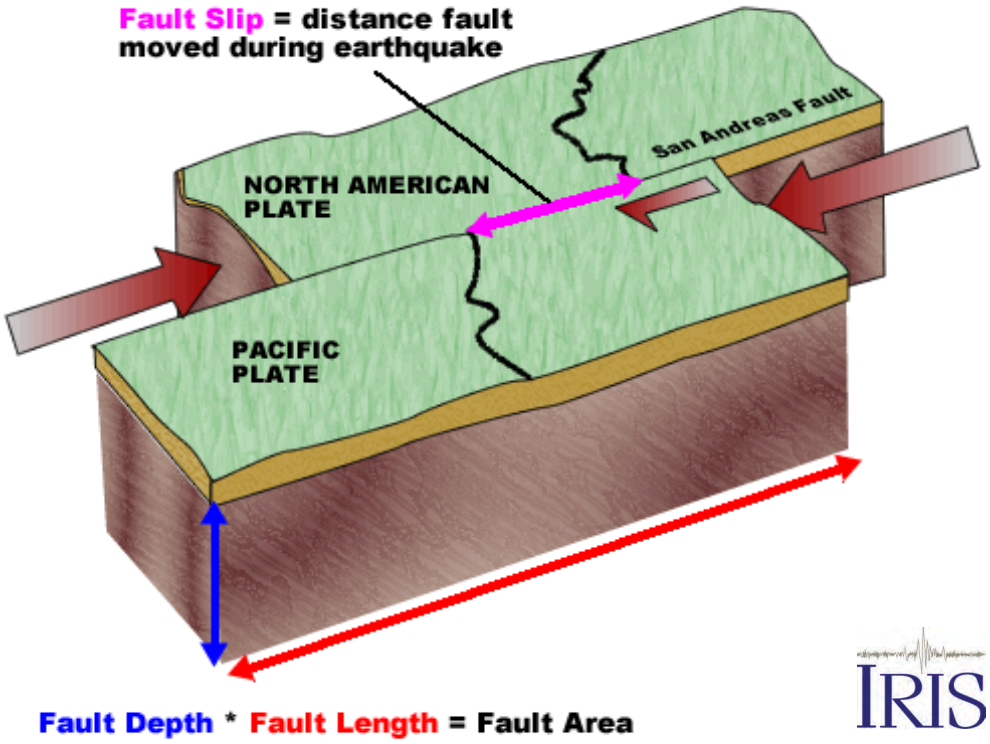


Rupture dimensions and displacement

During an earthquake, slip spreads out from the initiation point (hypocenter) over a finite distance.

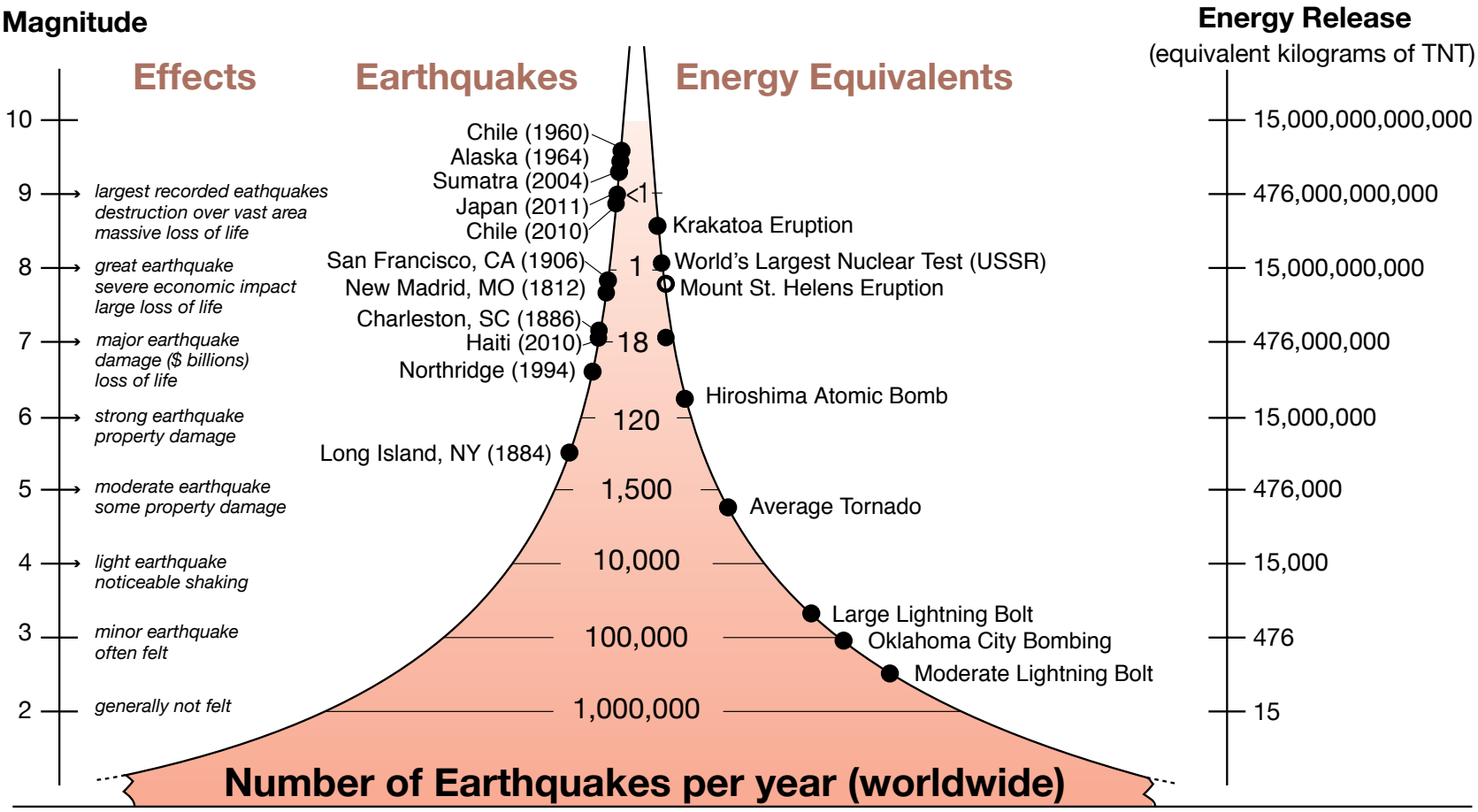
Seismologists calculate seismic moment (a measure of energy) by

$$M_o = A * D * \mu$$

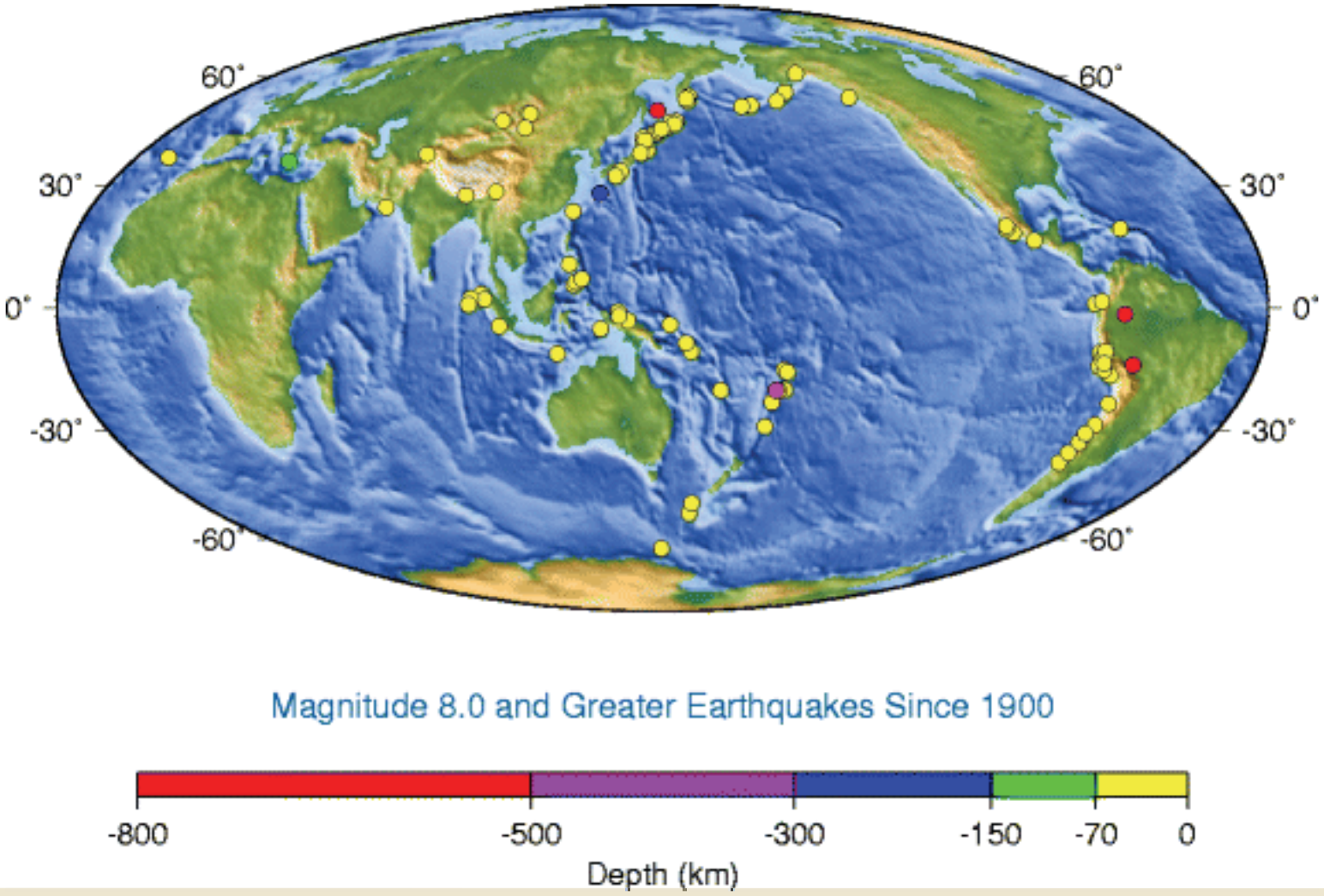


Moment = fault area * average displacement * rigidity

Subduction zones generate the largest earthquakes because megathrusts are long, dipping structures with big fault areas

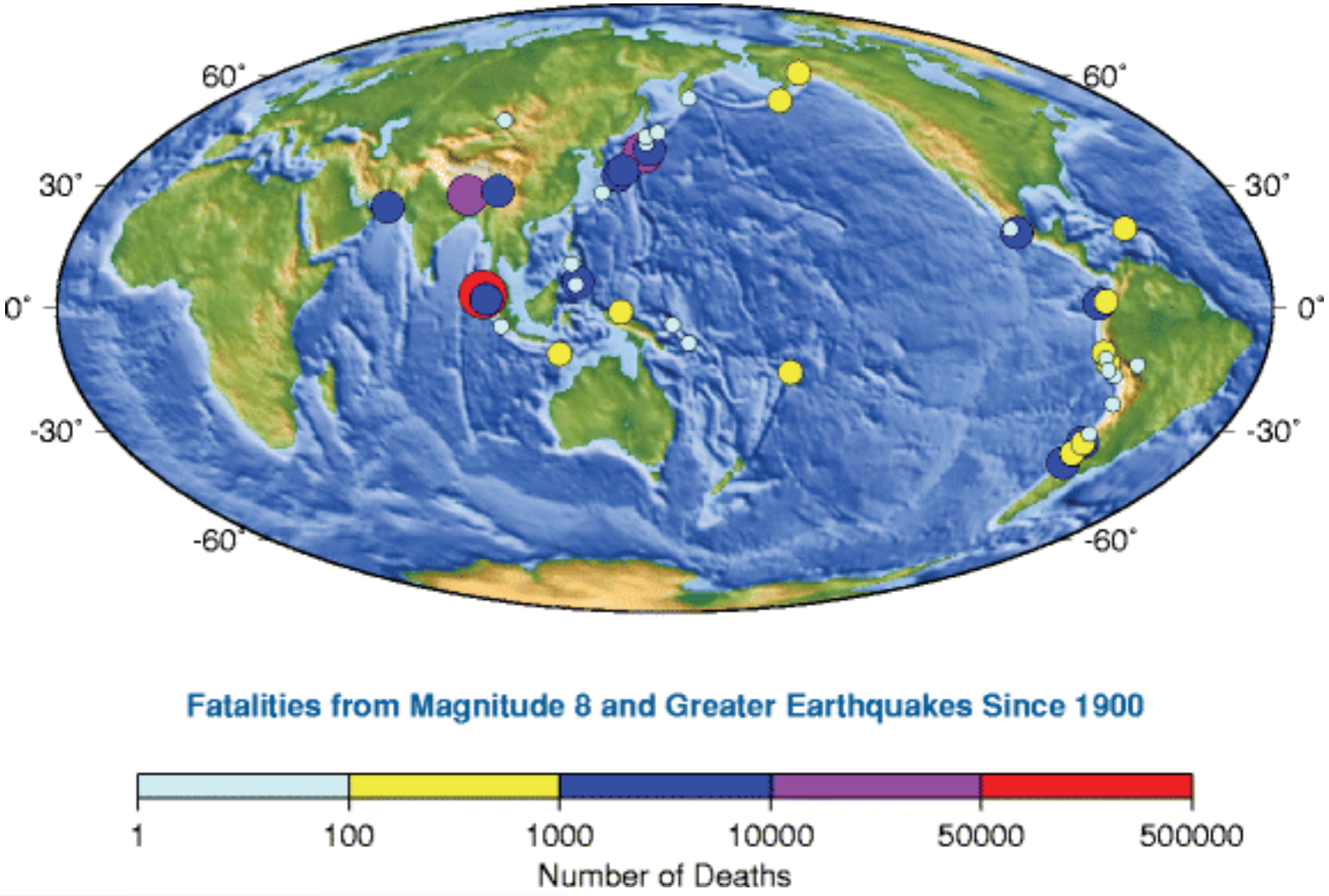


Great earthquakes – $M_W \geq 8$



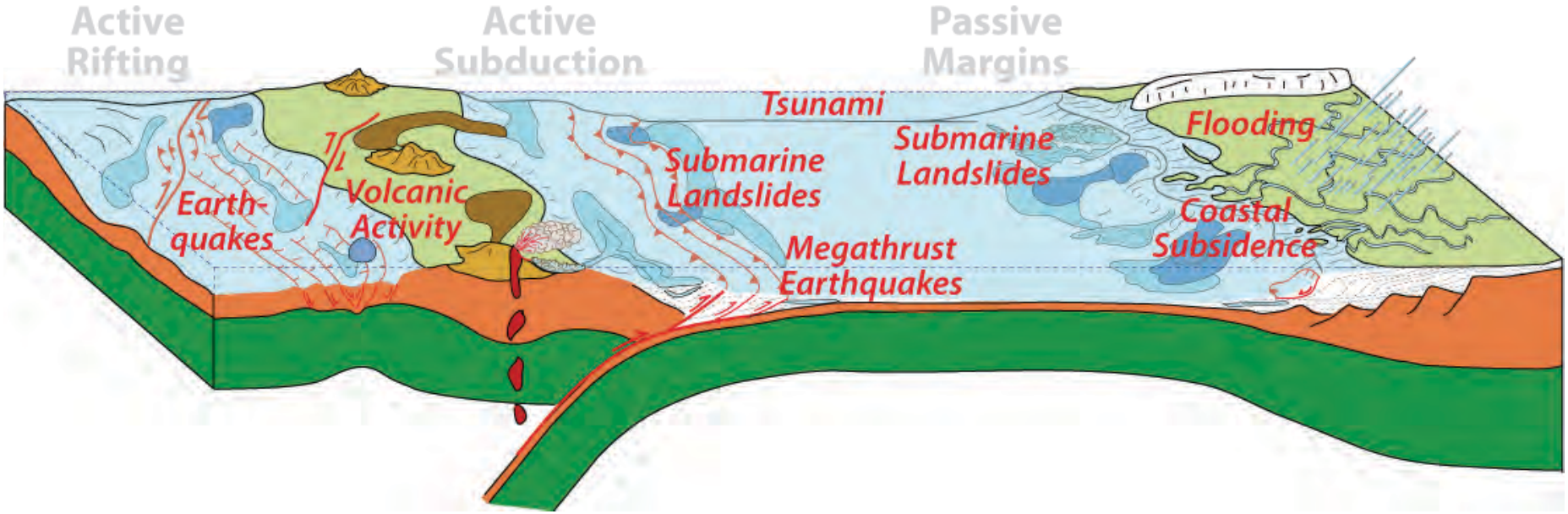
Source: USGS

Magnitude does NOT scale with fatalities



Source: USGS

NSF GeoPRISMS Program

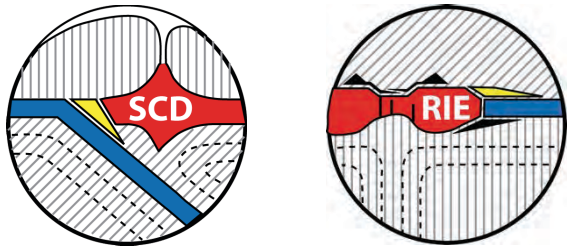


GeoPRISMS investigates the coupled geodynamics, earth surface processes, and climate interactions that build and modify continental margins *over a wide range of timescales (from s to My), and cross the shoreline, with applications to margin evolution & dynamics, construction of stratigraphic architecture, accumulation of economic resources, and associated geologic hazards and environmental management.*

GeoPRISMS Geodynamic Processes at Rifting and Subducting Margins

- **Two broadly integrated initiatives**

Subduction Cycles & Deformation

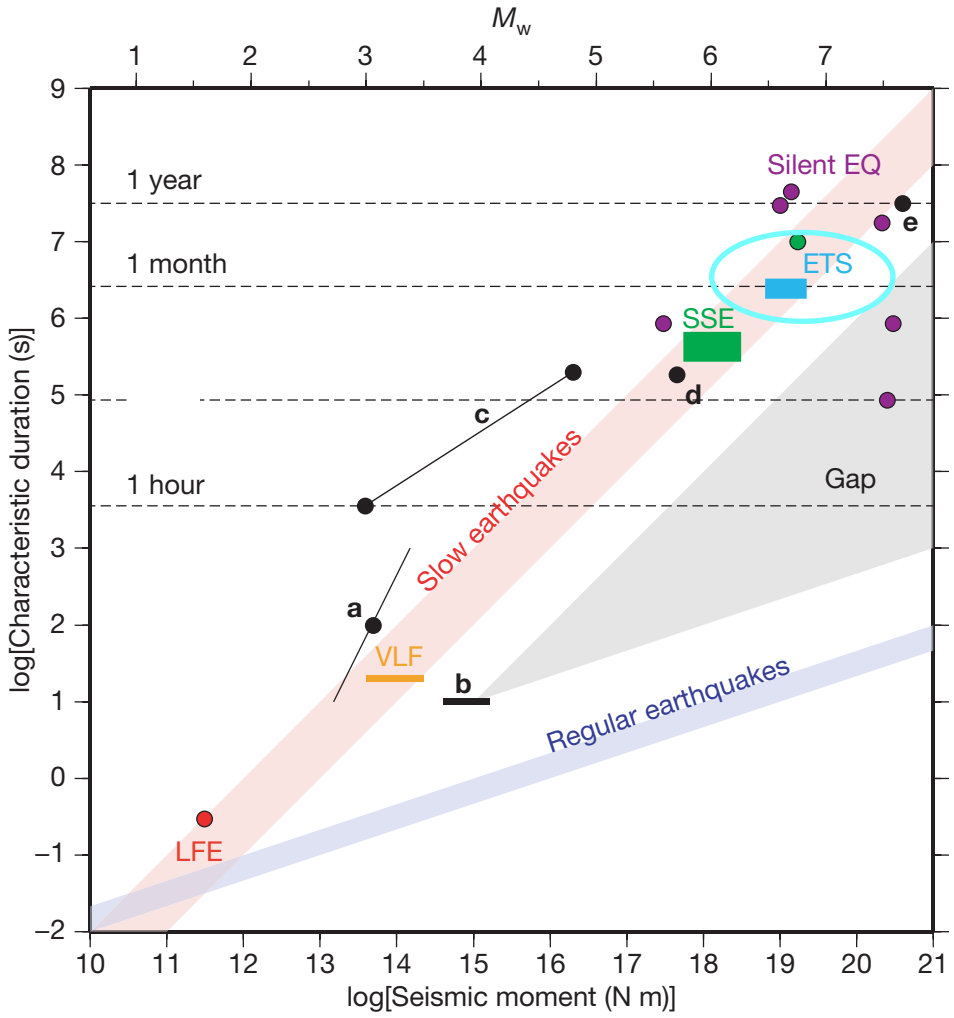


Rift Initiation & Evolution

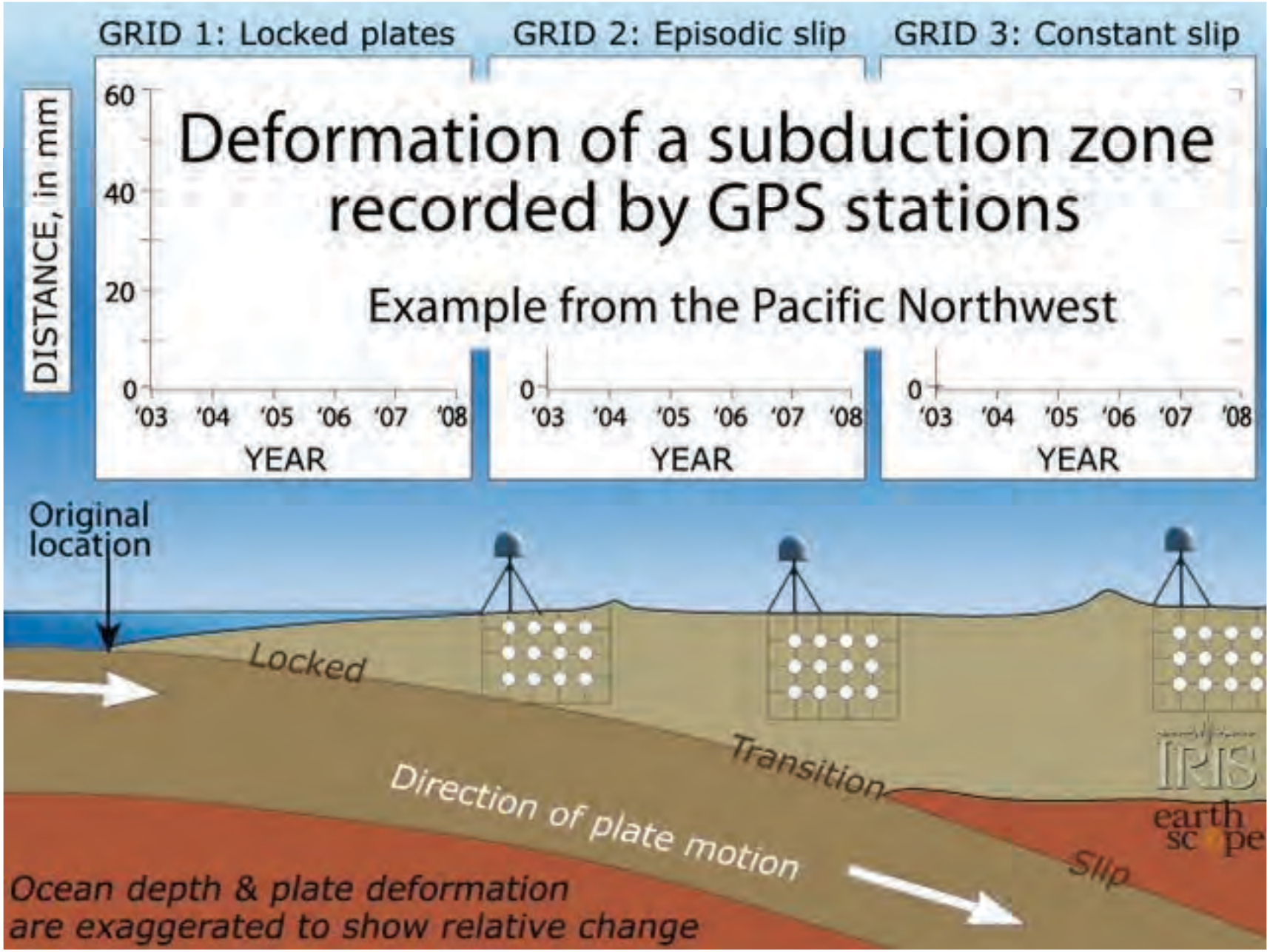
- **Research at Primary Sites & through Thematic Studies**

A Relevant SCD Key Question

What governs the size, location and frequency of great subduction zone earthquakes and how is this related to the spatial and temporal variation of slip behaviors observed along subduction faults?

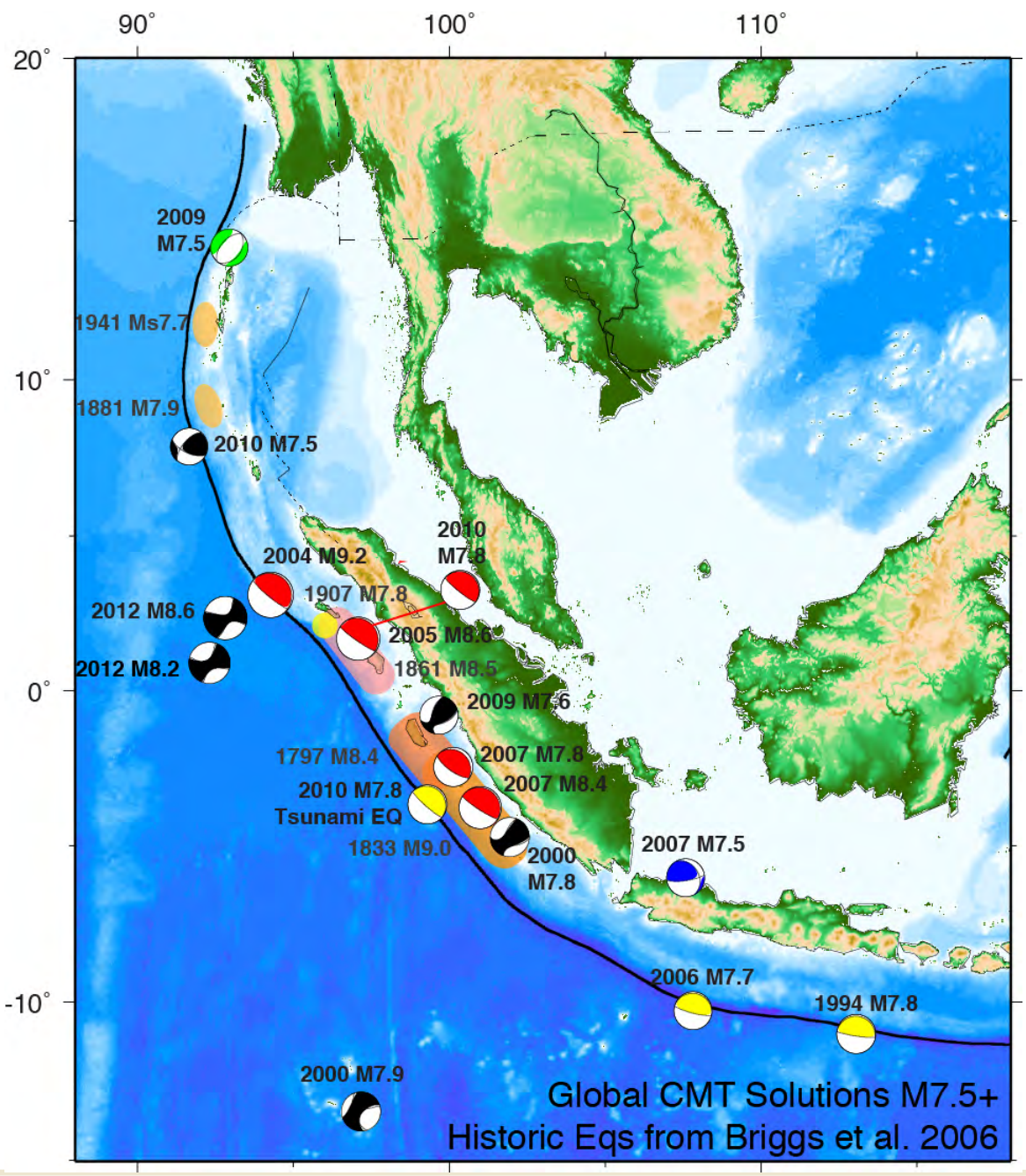


Ide et al. 2007


GRID 1: Locked plates
GRID 2: Episodic slip
GRID 3: Constant slip
Deformation of a subduction zone recorded by GPS stations
Example from the Pacific Northwest
DISTANCE, in mm
60
40
20
0
'03 '04 '05 '06 '07 '08
YEAR
Original location
Locked
Transition
Direction of plate motion
Slip
Ocean depth & plate deformation are exaggerated to show relative change
IRIS
earthscope

Unzipping the Sunda subduction zone

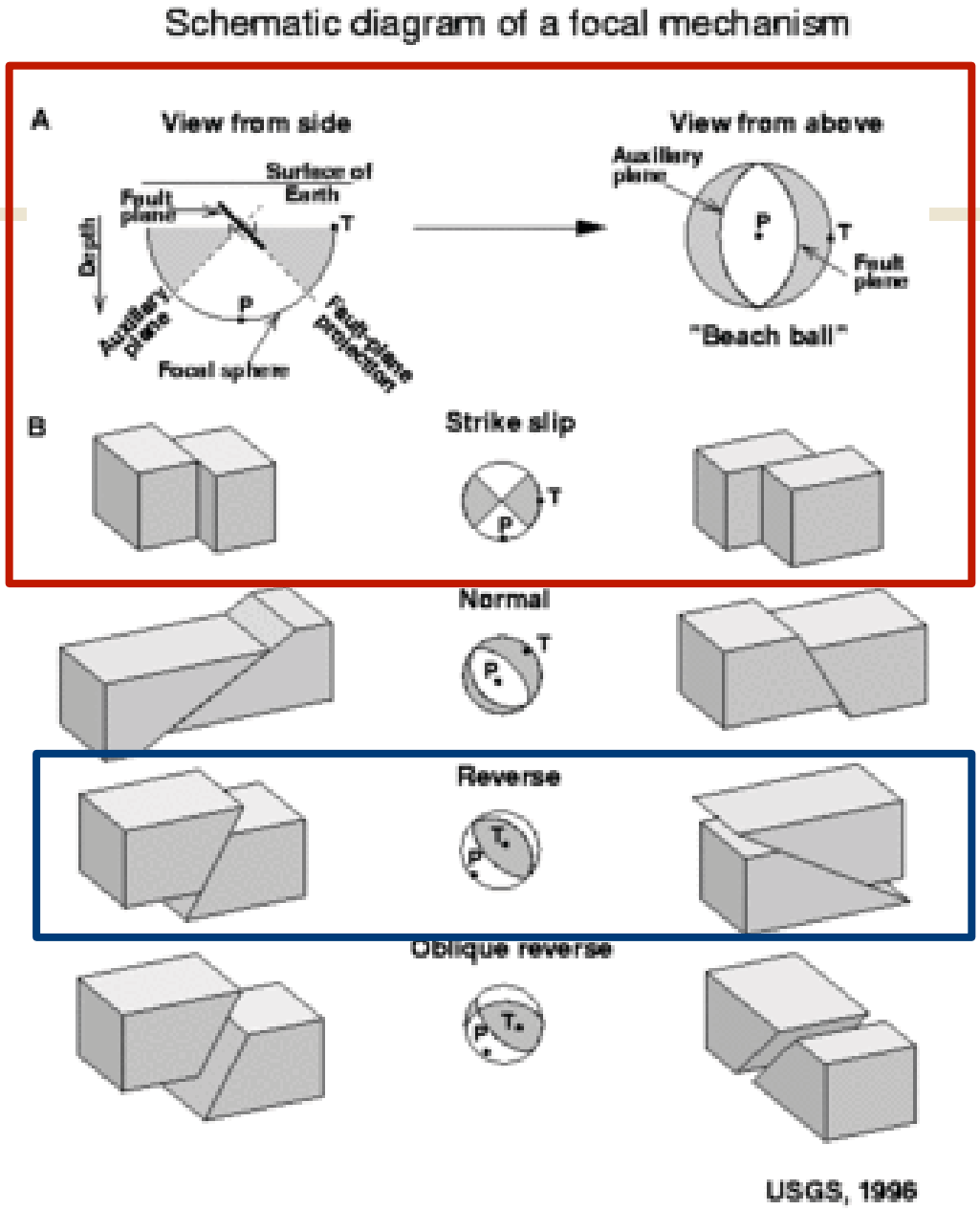
2004-2013



Focal Mechanisms

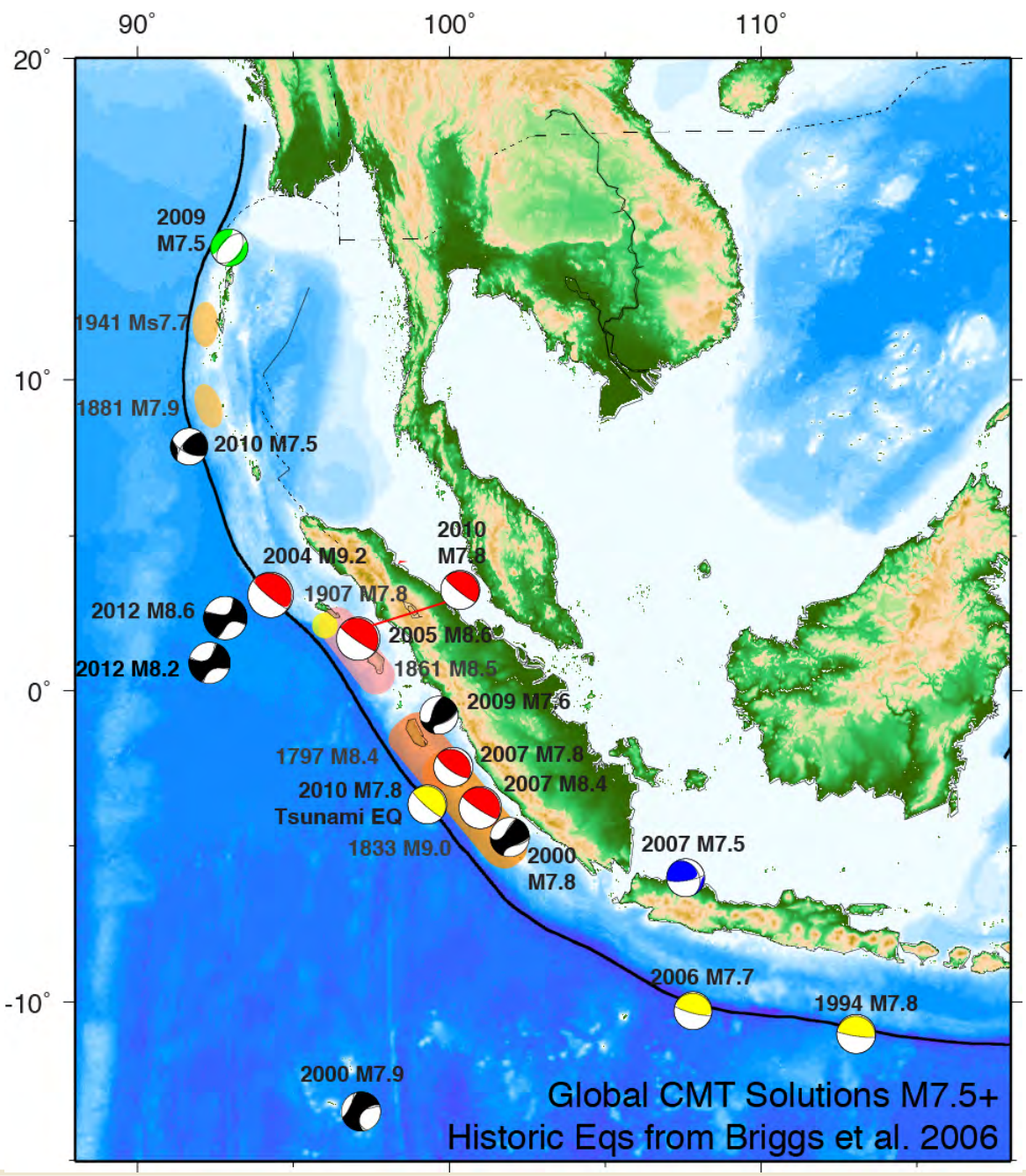
Seismologists represent motion along a fault using lower hemisphere projections – **beachballs**

Reverse faults, like subduction megathrust faults, have the colored quadrant centered in the circle

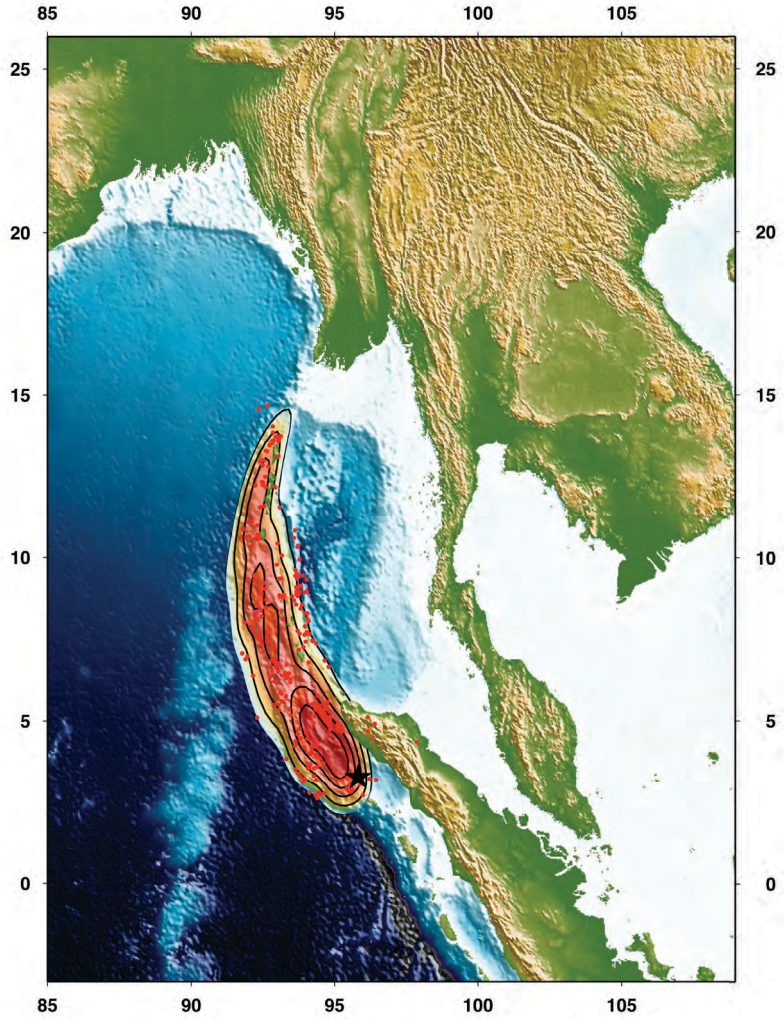


Unzipping the Sunda subduction zone

2004-2013



Backprojection Models: Watching slip happen



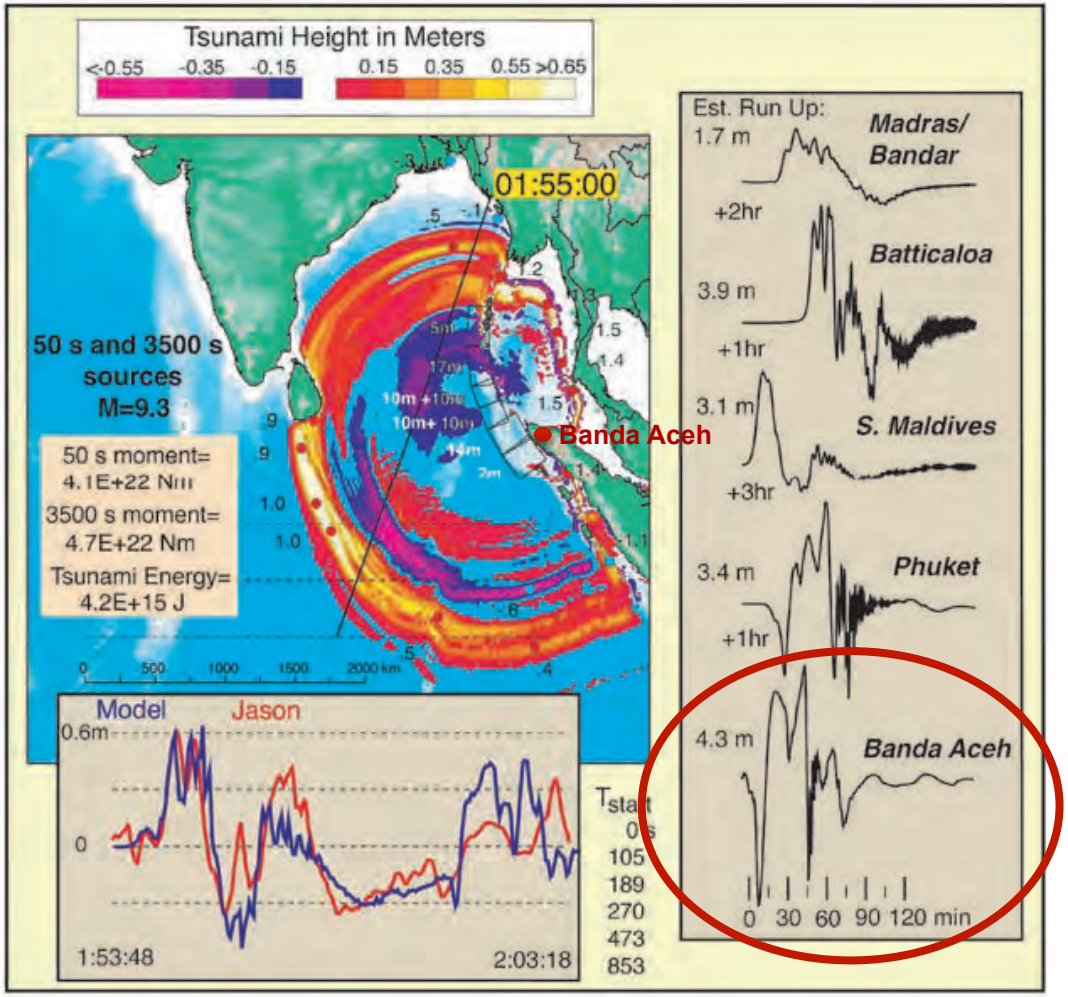
Moment rate function

Ishii et al., 2005

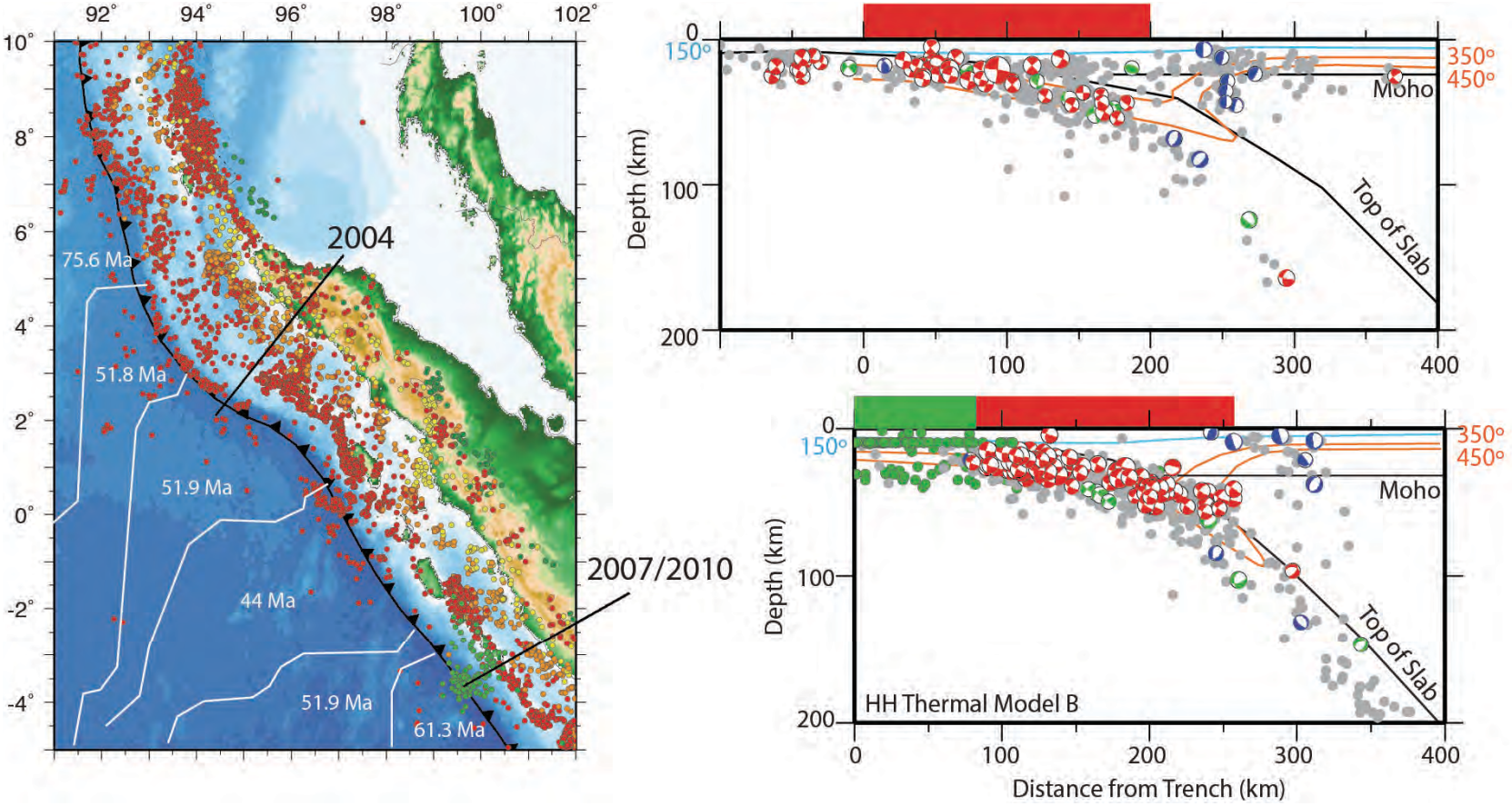
Alex Hutco

The 2004 tsunami

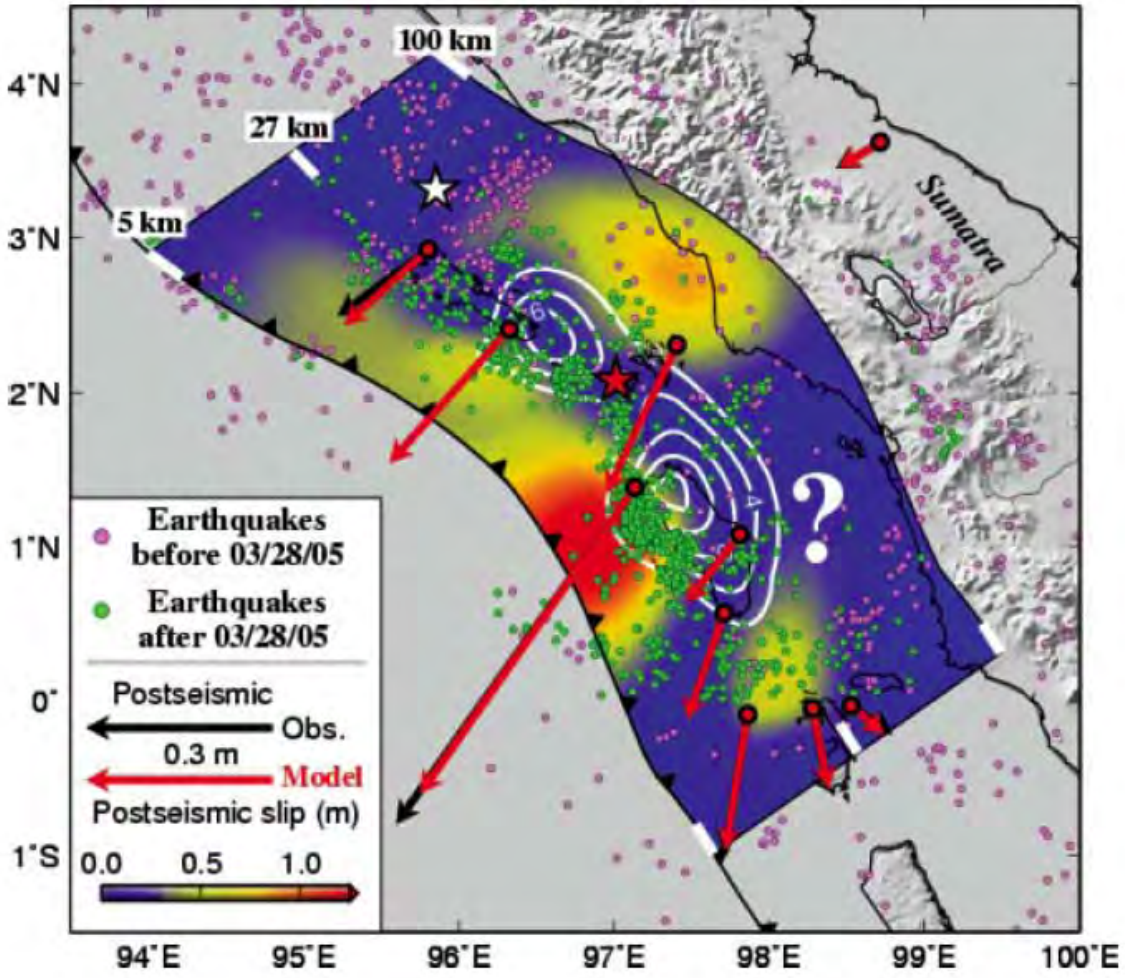
- >250,000 fatalities
- Run-up heights >4 m
- Tsunami last longer than earthquake shaking



2004 M_W 9.2 megathrust earthquake, 2007 M_W 8.4 megathrust earthquake & 2010 M_W 7.8 tsunami earthquake



2005 M_W 8.7 Nias earthquake & Afterslip

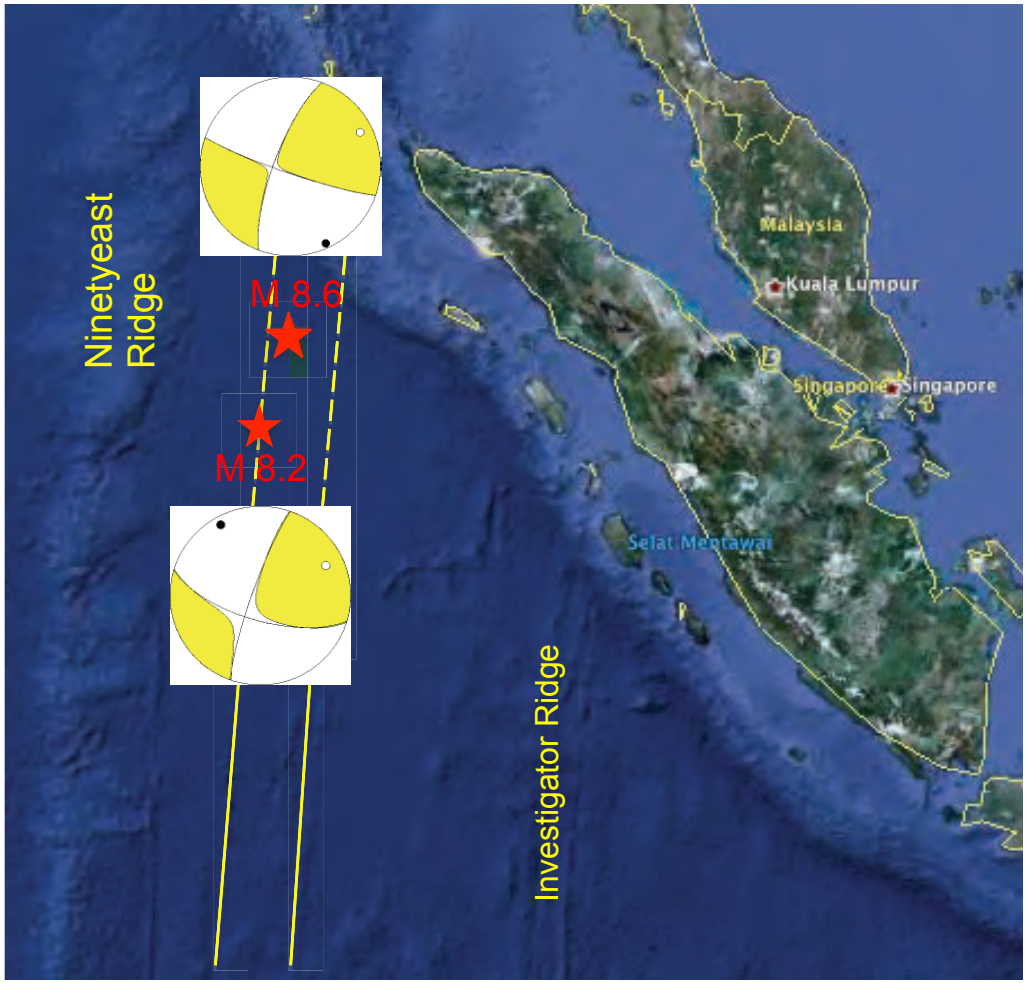


Hsu et al., 2006

Largest intraplate earthquakes ever recorded

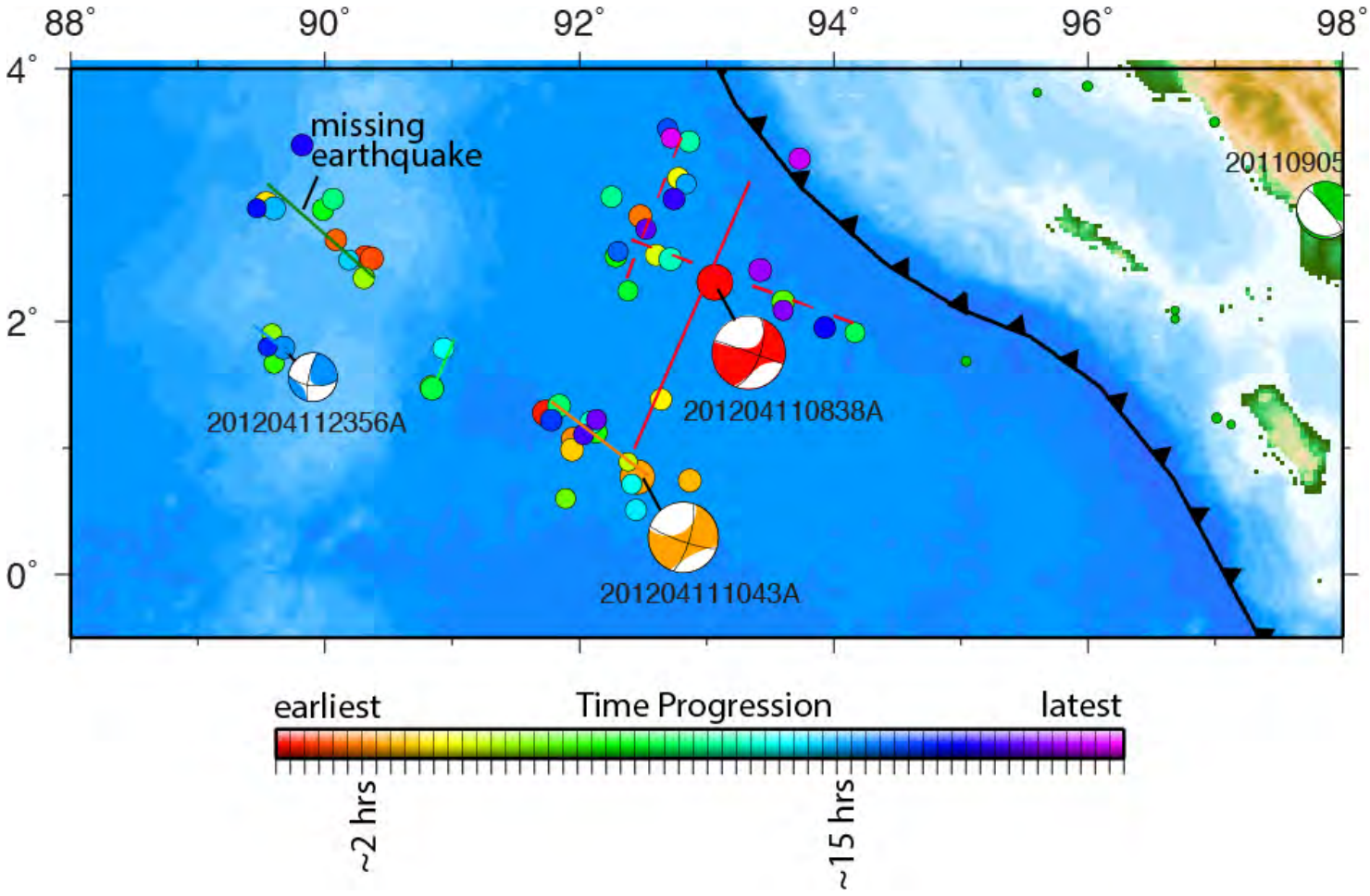
2012-Magnitude 8.6 and 8.2 OFF W COAST NORTHERN SUMATRA

Gut reaction: These intraplate earthquakes were caused by strike-slip faulting within Indian Plate oceanic lithosphere. N – S oriented fracture zones project into the area of the earthquakes and are the likely faults offset during these events.

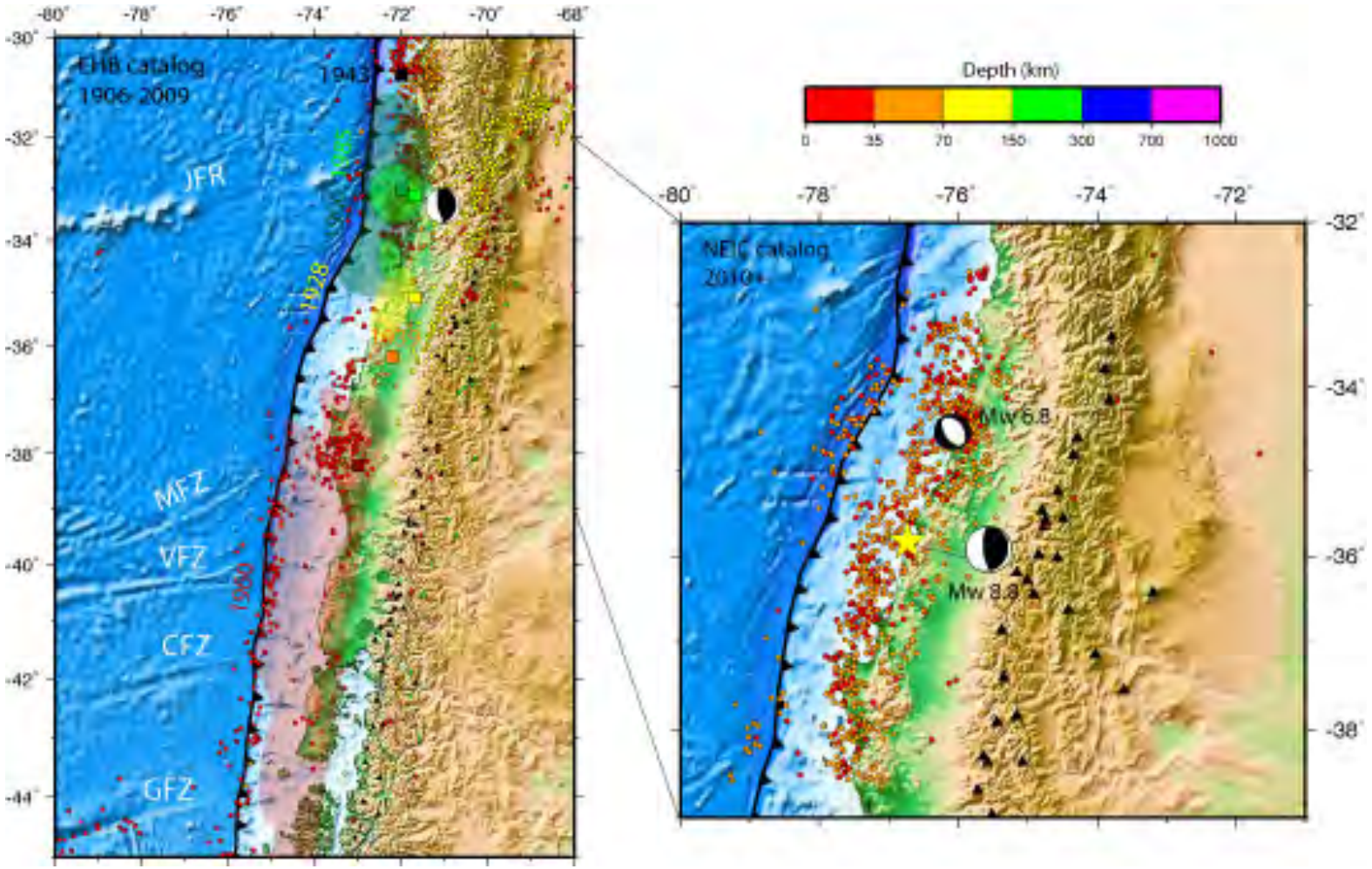


IRIS
Teachable Moments

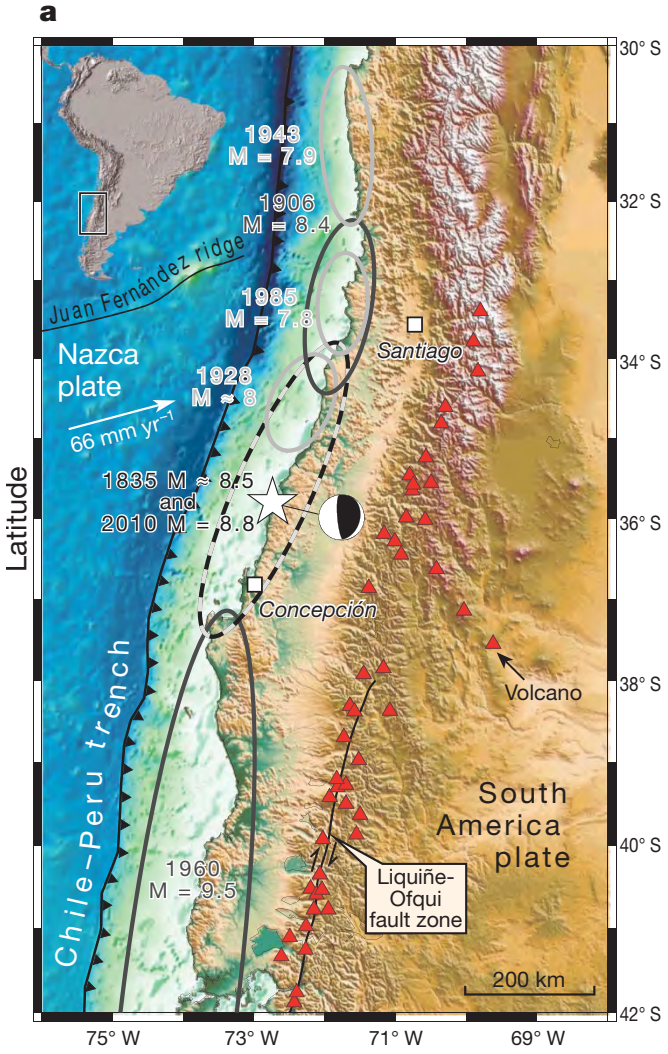
Aftershocks and backprojection results soon tell a different story

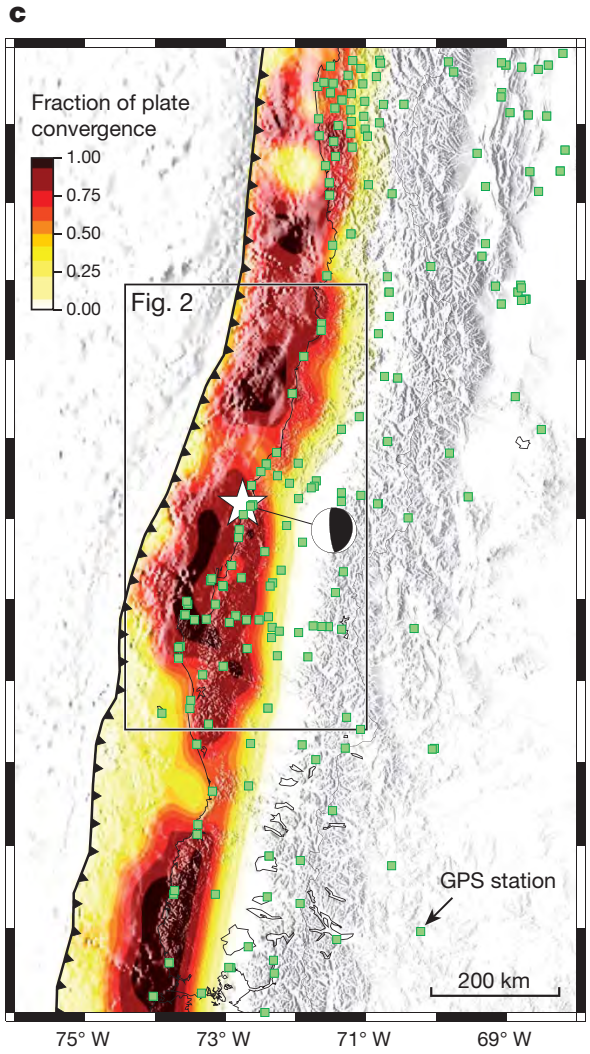


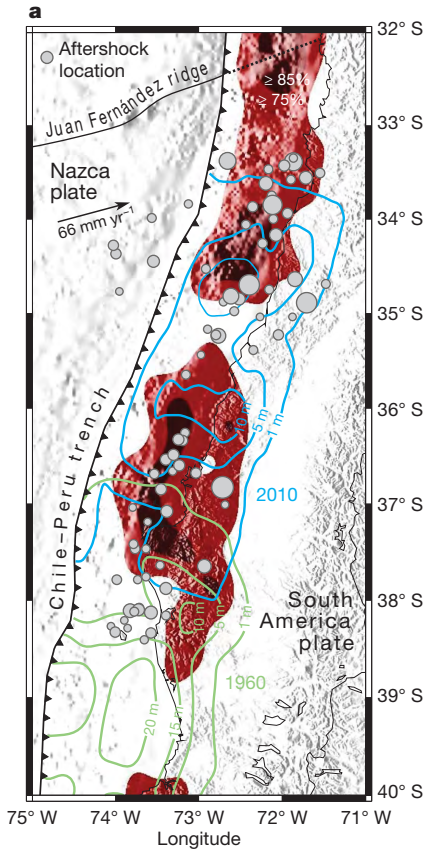
2010 M_W 8.8 Maule, Chile earthquake



Interseismic plate coupling – predictive value?

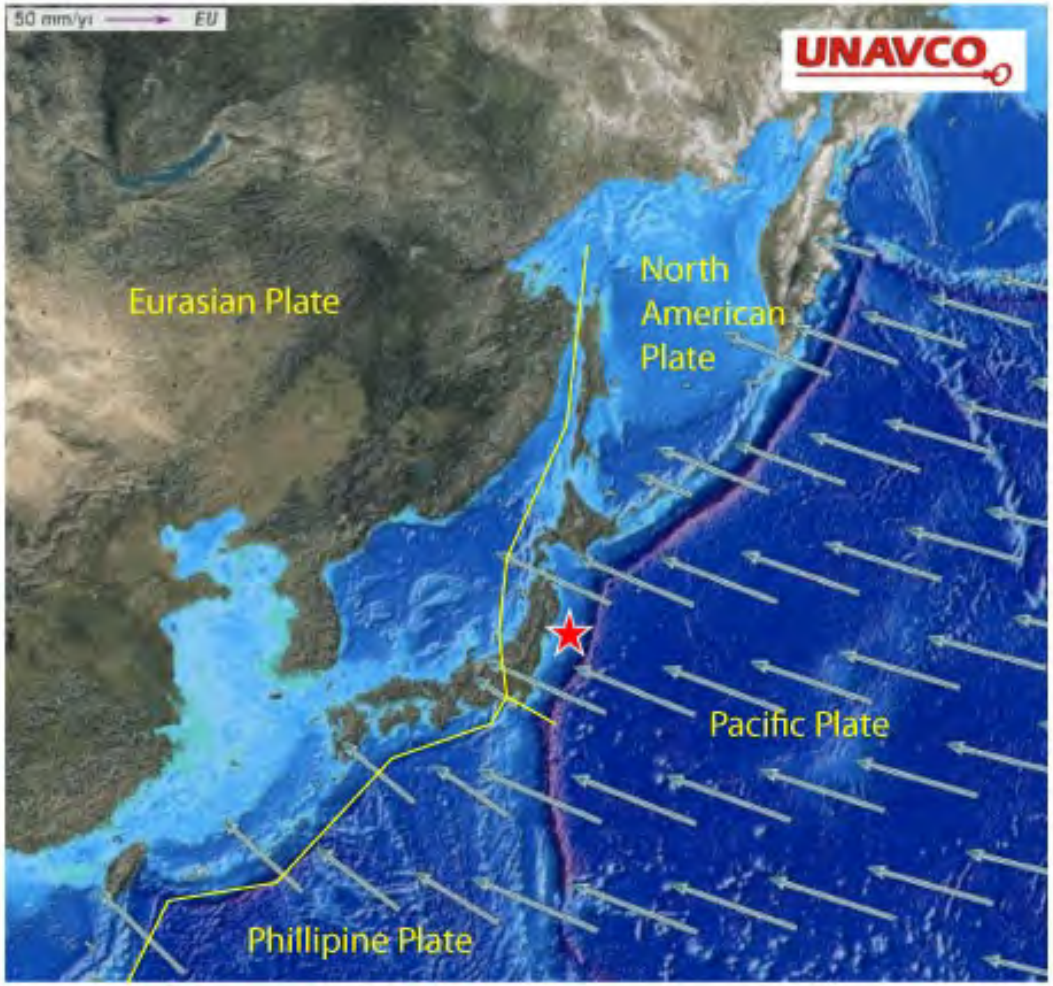




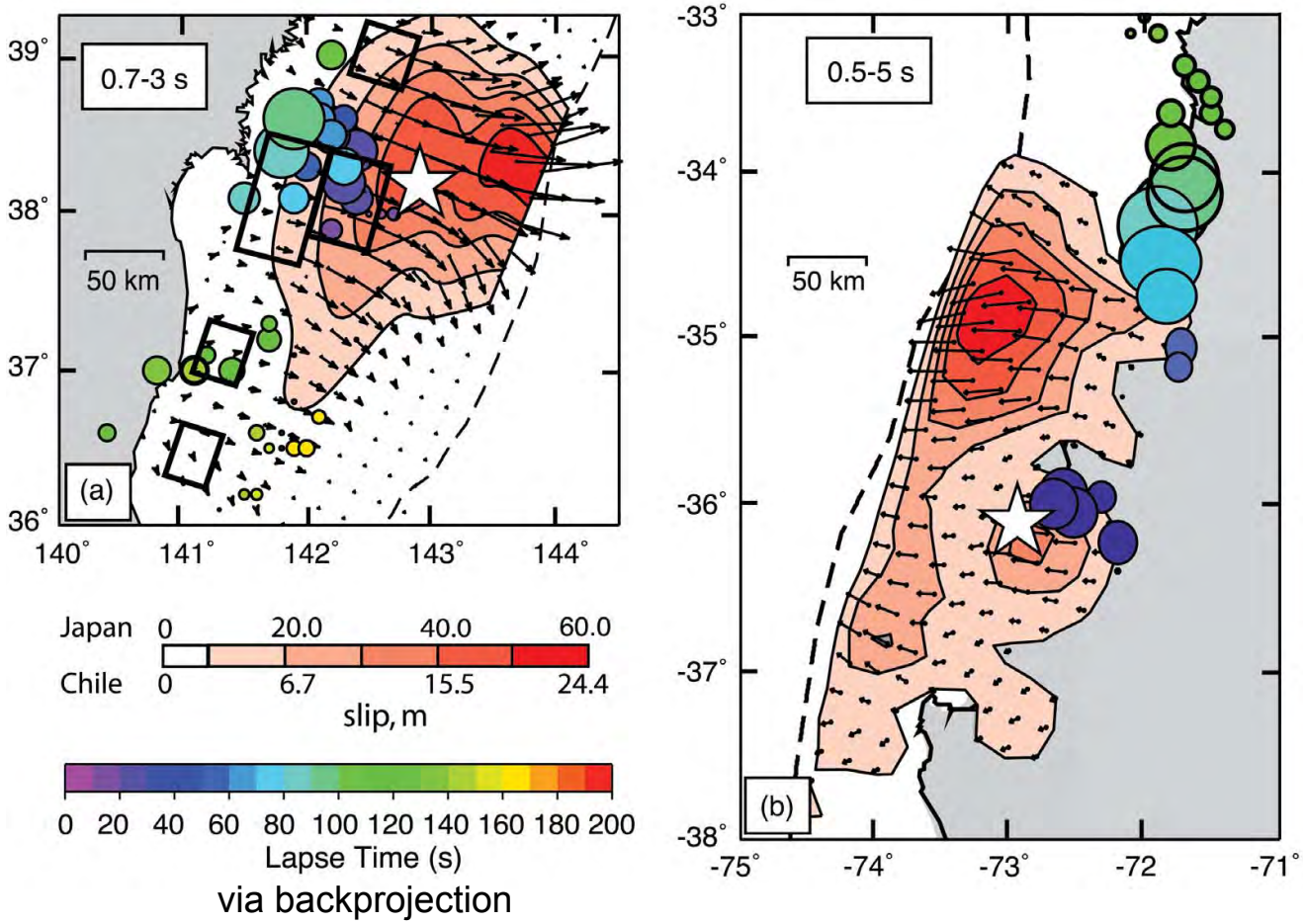


Moreno et al., 2010

2011 M_W 9.0 Tohoku-oki, Japan, earthquake



Slip in the 2010 Chile and 2011 Japan events



Maximum slip is ~50 m in the Japan earthquake!

Lay et al., 2012

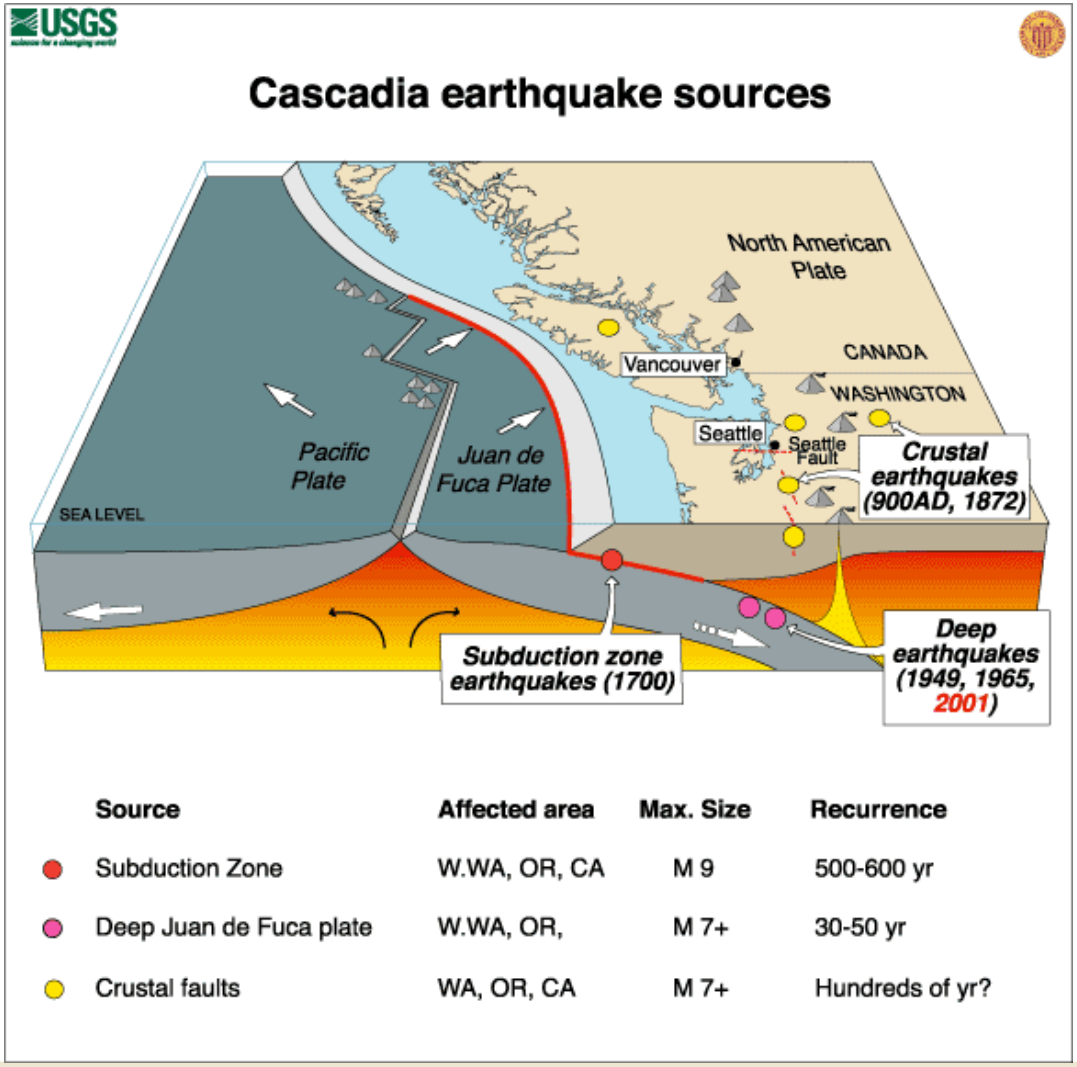
IRIS
Teachable Moments

Part of houses swallowed by tsunami burn in Sendai, Miyagi Prefecture (state) after Japan was struck by a strong earthquake off its northeastern coast Friday, March 11, 2011.

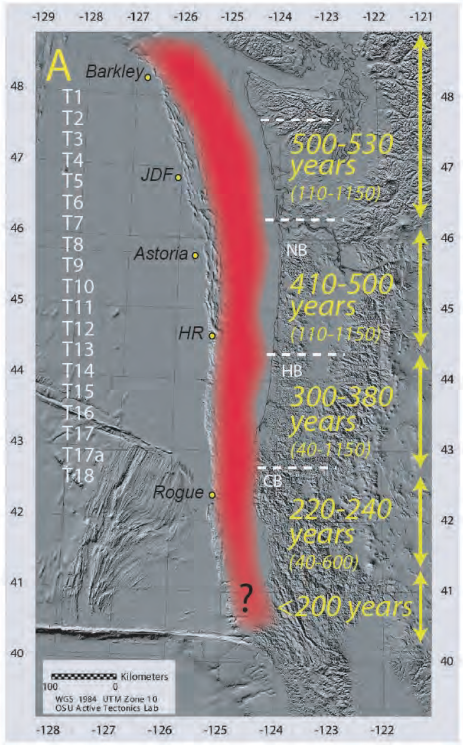
New York Times

The tsunami waves traveled far inland, the wave of debris racing across the farmland, carrying boats and houses with it.

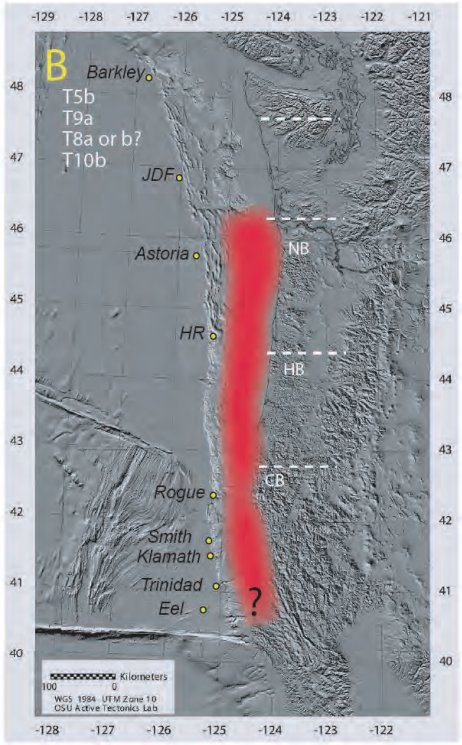
The Future: Cascadia



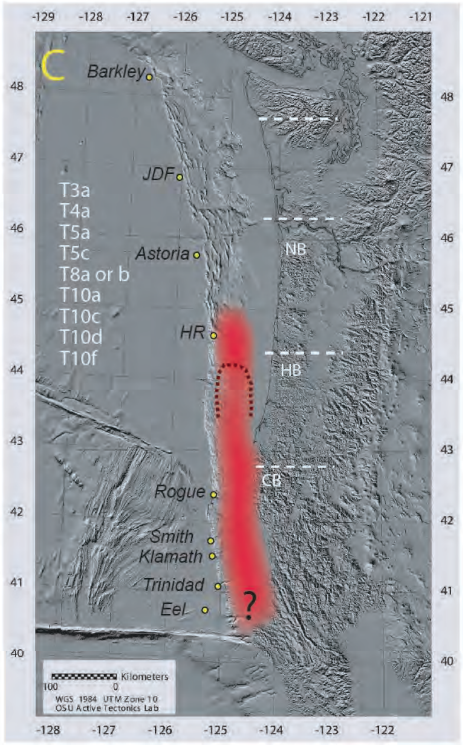
History of earthquakes: the turbidite record



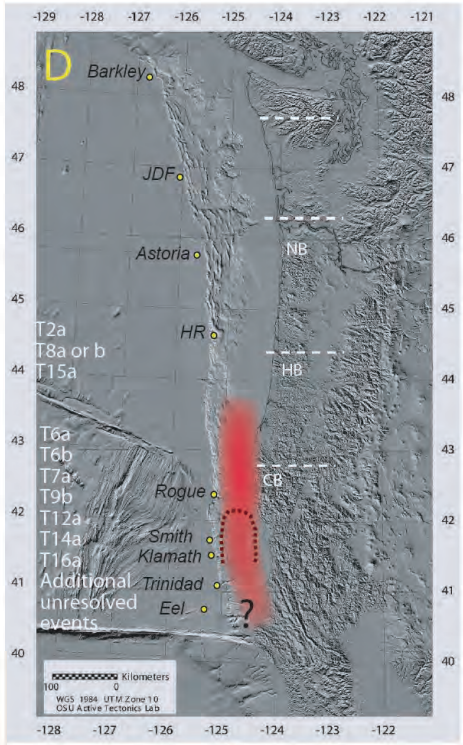
A. Full or nearly full rupture, 19 events



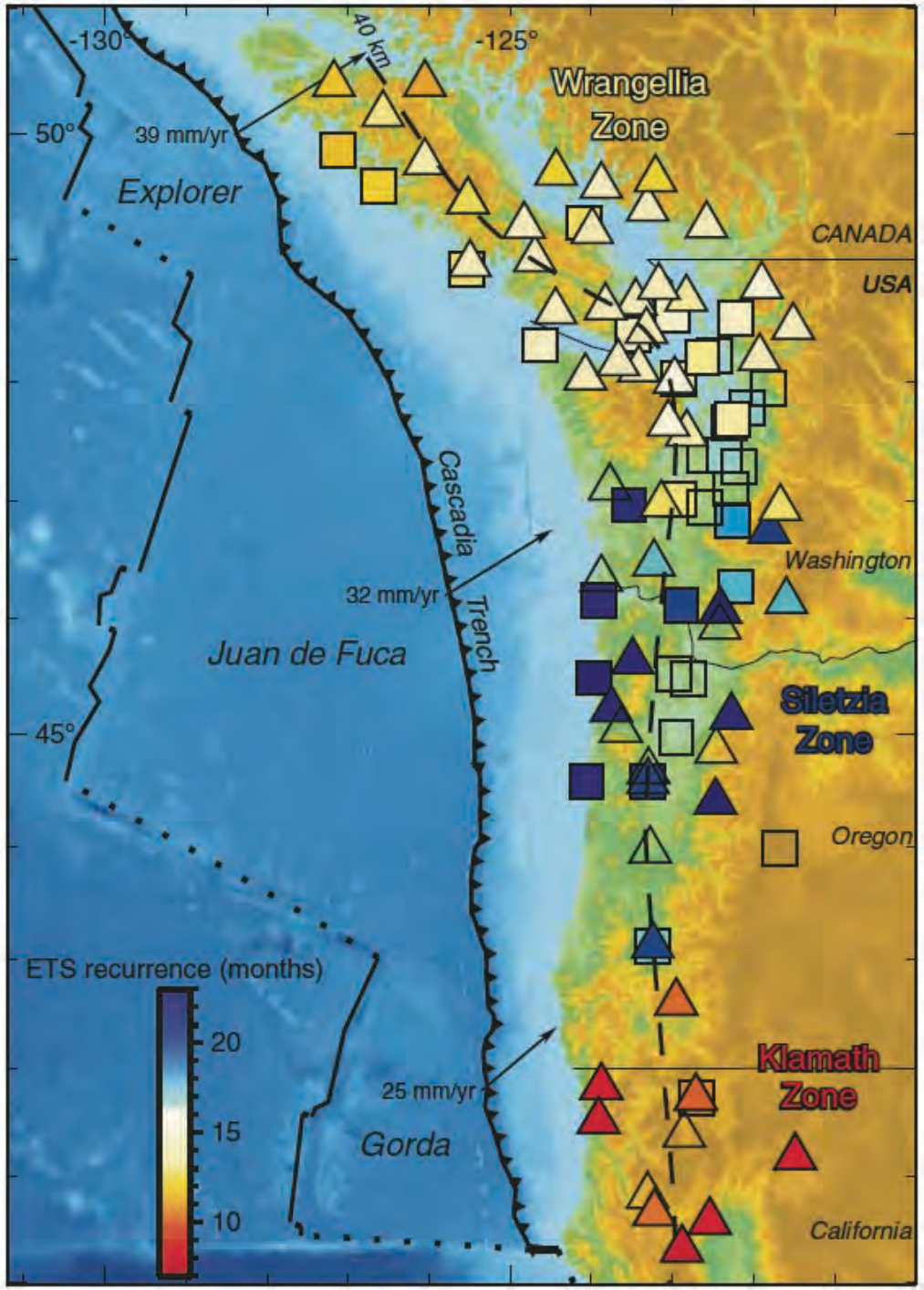
B. Mid-Southern rupture, 3-4 events.



C. Rupture from central Oregon southward, 10-12 events.



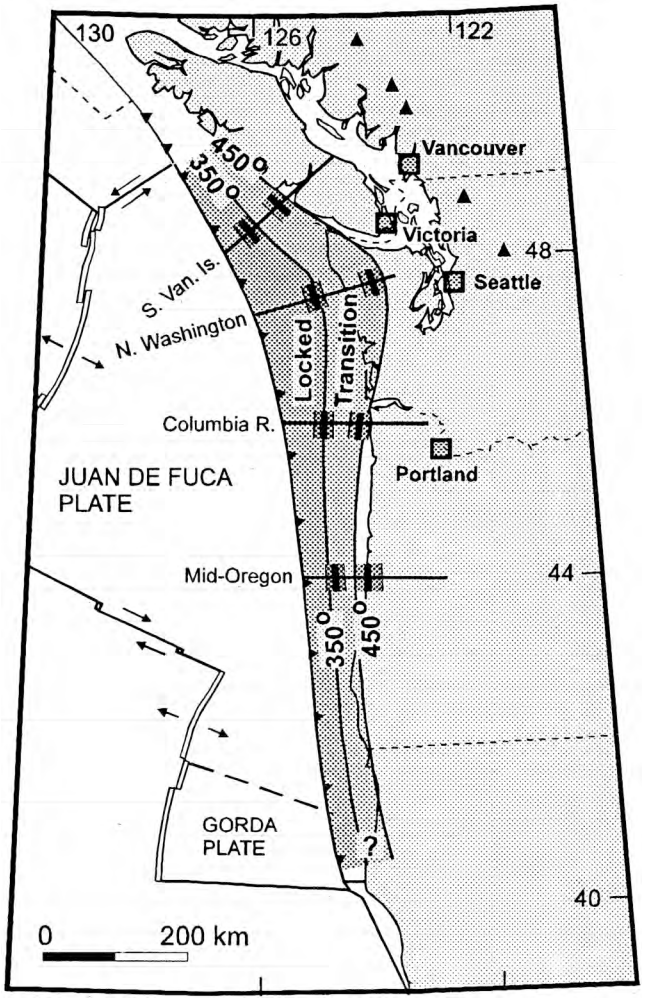
D. S Oregon/N California events, minimum of 7-8 events.

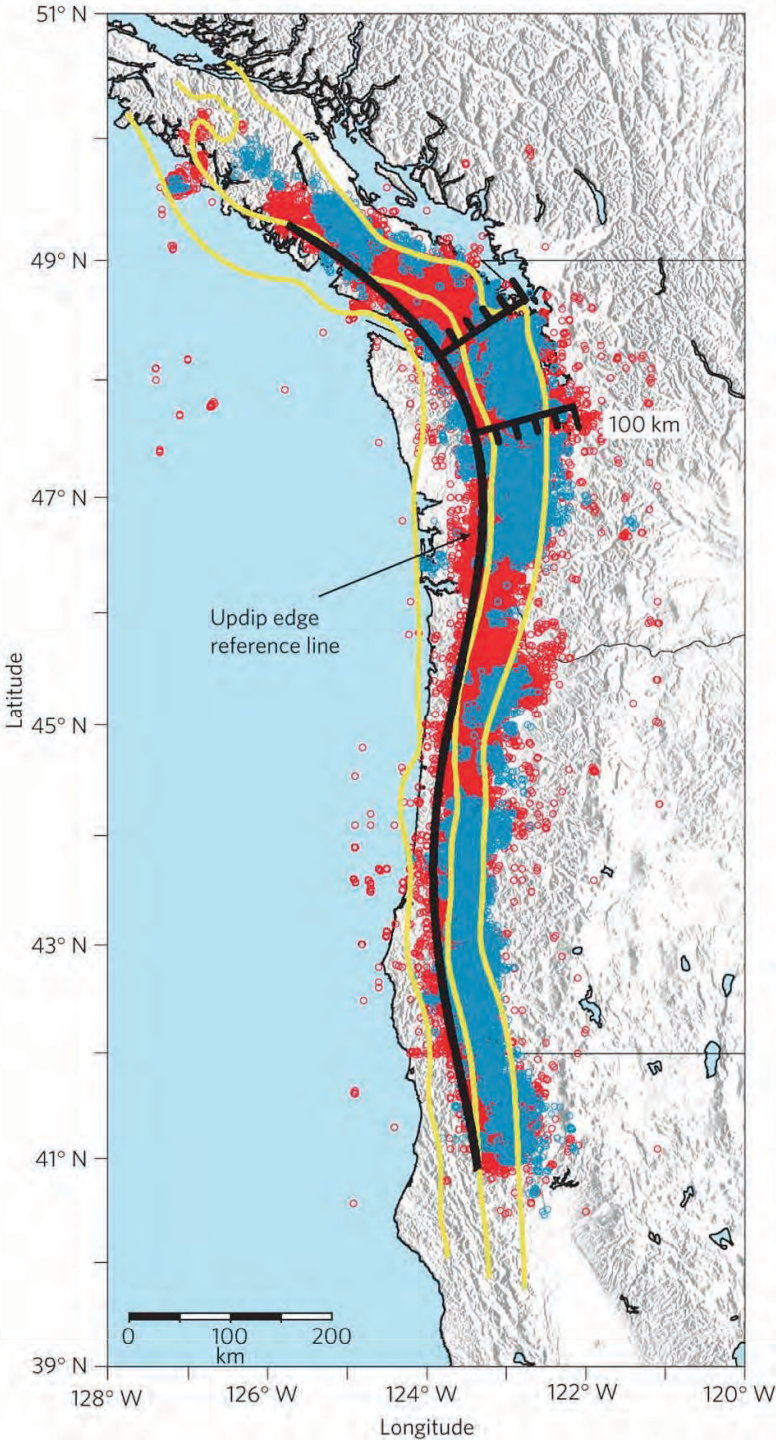


Tremor recurrence varies along Cascadia

Brudzinski and Allen, 2007

Tremor lies downdip of the seismogenic zone

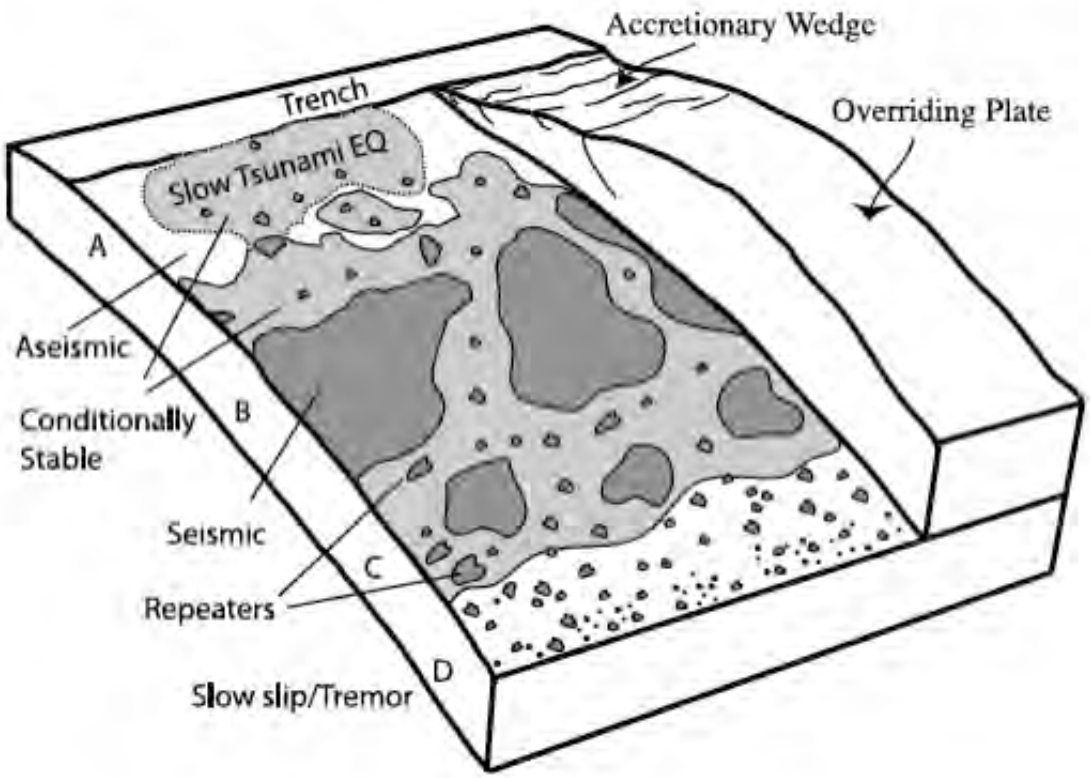




Hyndman et al., 1995; Wech and Creager, 2011

Summary

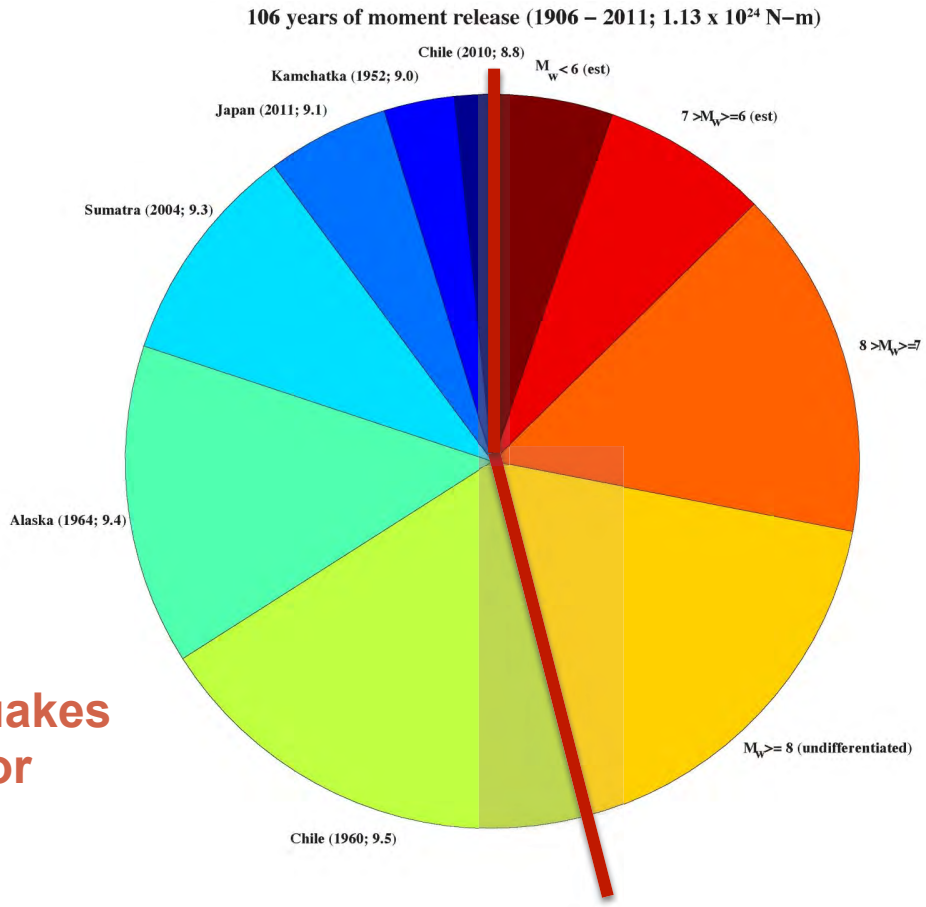
- Each new earthquake brings further insight into the seismogenic zone
- Fault complexity may be related to variable frictional stability conditions along the fault
- Fault behavior may vary from seismic cycle to seismic cycle



Lay et al., 2012

Acknowledgements

- NSF GeoPRISMS and Margins program
- Collaborators: Susan Bilek, Susan Schwartz, Cliff Thurber, Bob Engdahl, Jeremy Pesicek, Haijiang Zhang, Sri Widiyantaro, Wolfgang Rabbel, Melissa Driskell, Shishay Bisrat



6 subduction megathrust earthquakes over the last 106 years account for over half of the energy released during that time.