Cascadia Subduction Zone Creep

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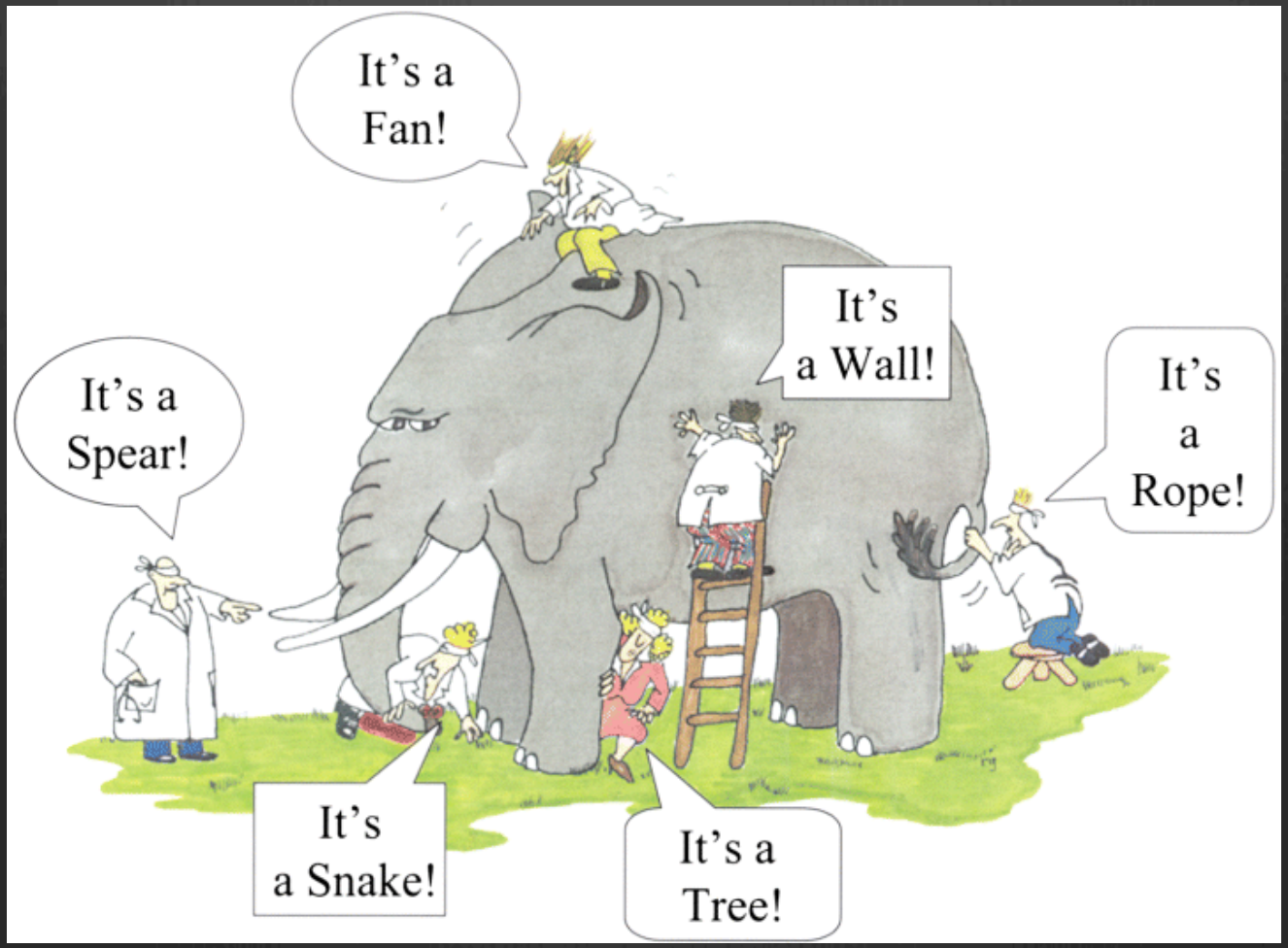
Rob McCaffrey and Ken Creager



G. Renee Guzlas, artist, source: http://www.nature.com/ki/journal/v62/n5/fig_tab/4493262f1.html

What the heck is a subduction zone???

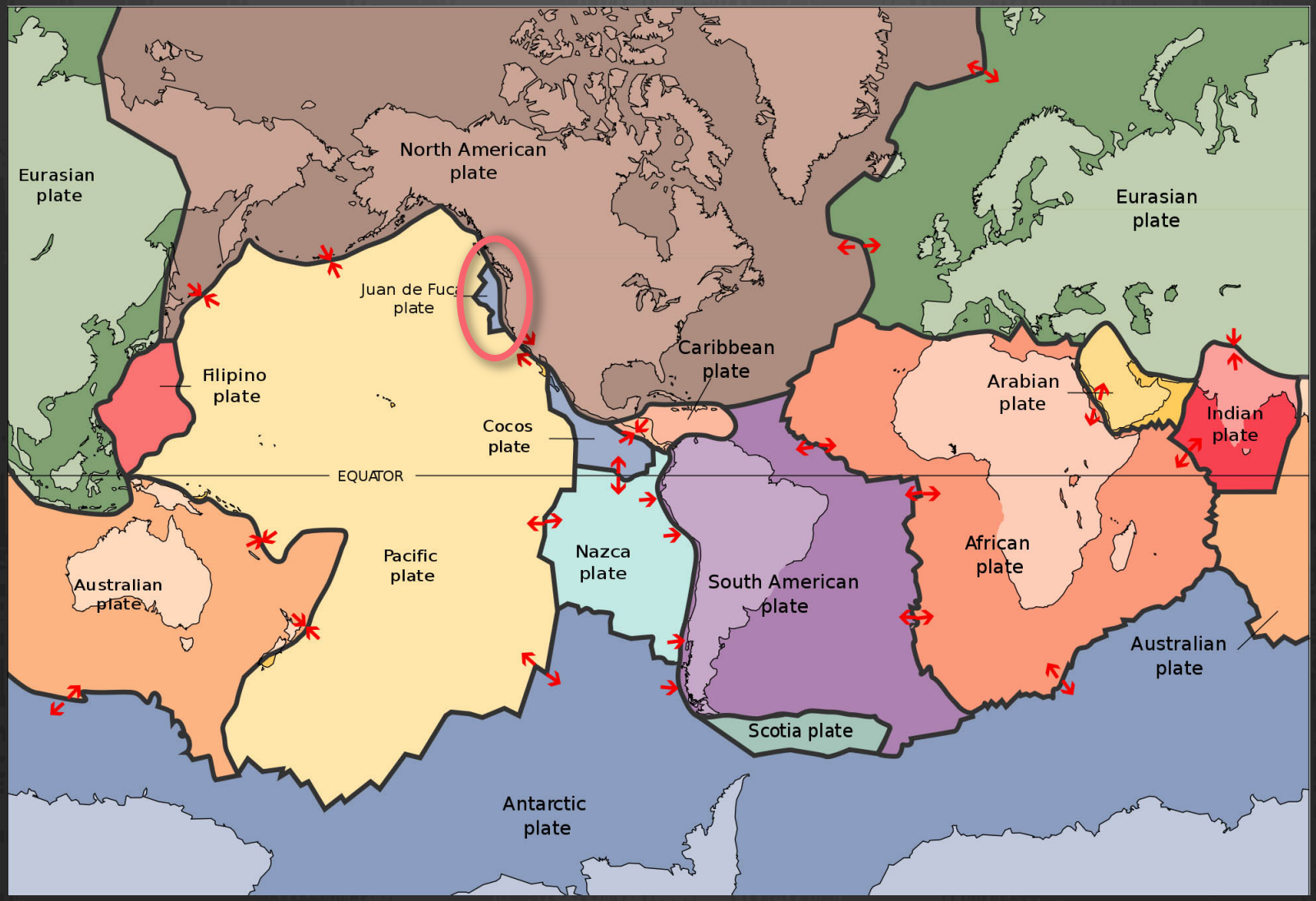
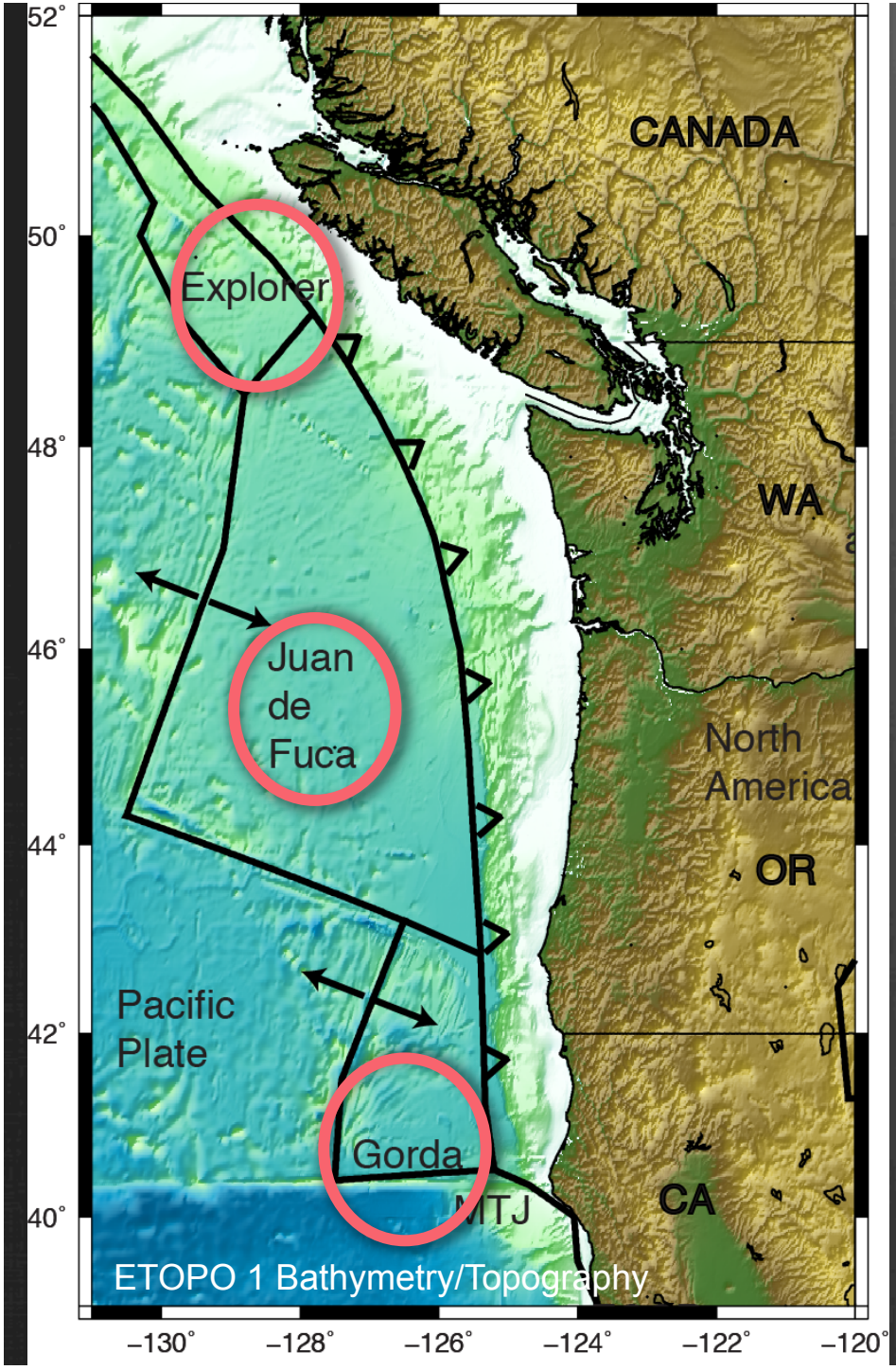


Image from http://www.sanandreasfault.org/Tectonics.html

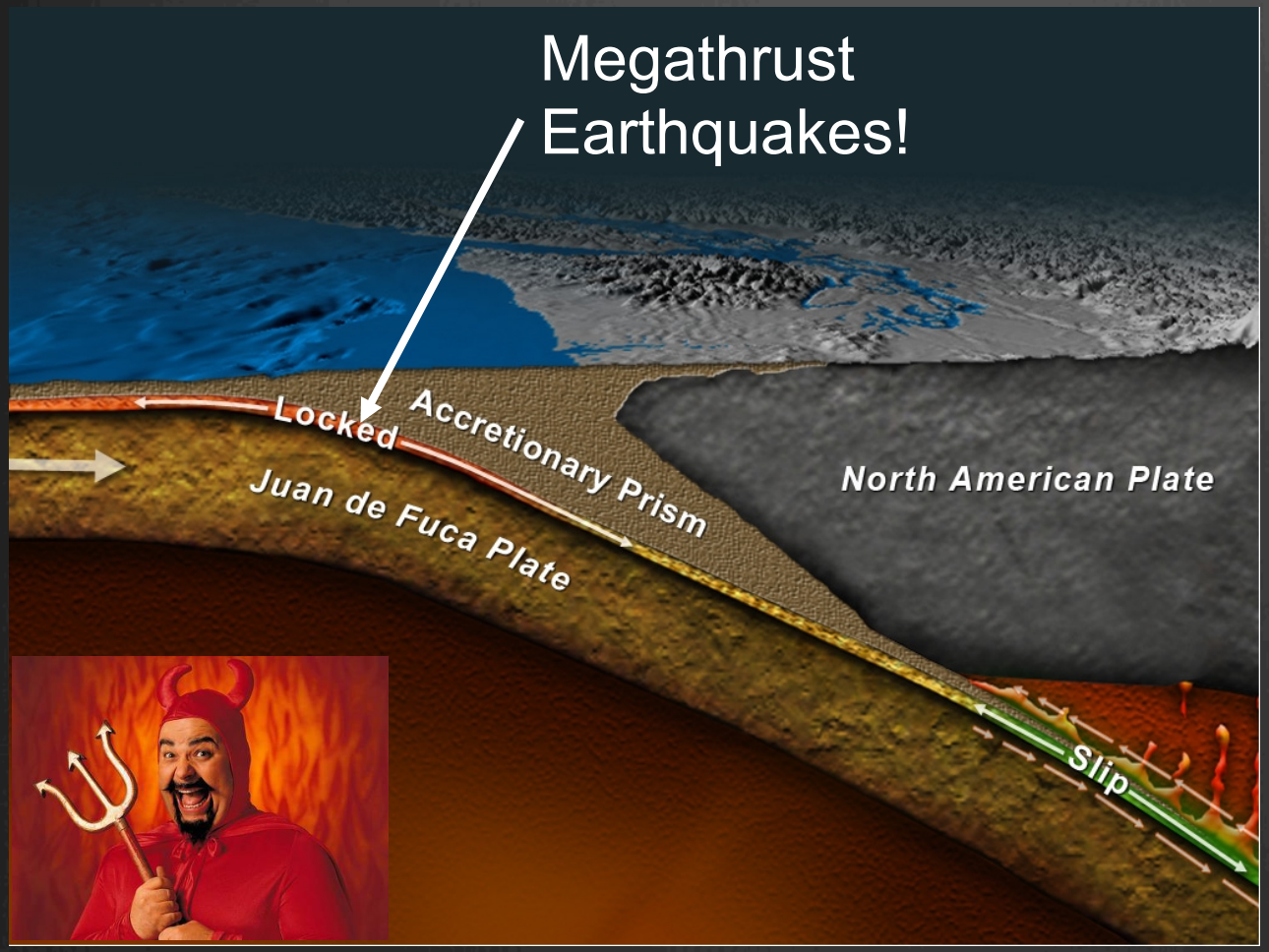


Cascadia Subduction Zone

- Last Major Earthquake: ~9pm on January 26, 1700
- We know precisely the time and date because of Tsunami records in Japan (Atwater et al., 2005)!
- Rupture length: 1000 km
- Plates slipped ~20 m!
- Magnitude ~8.7-9.2

Figure made with General Mapping Tools

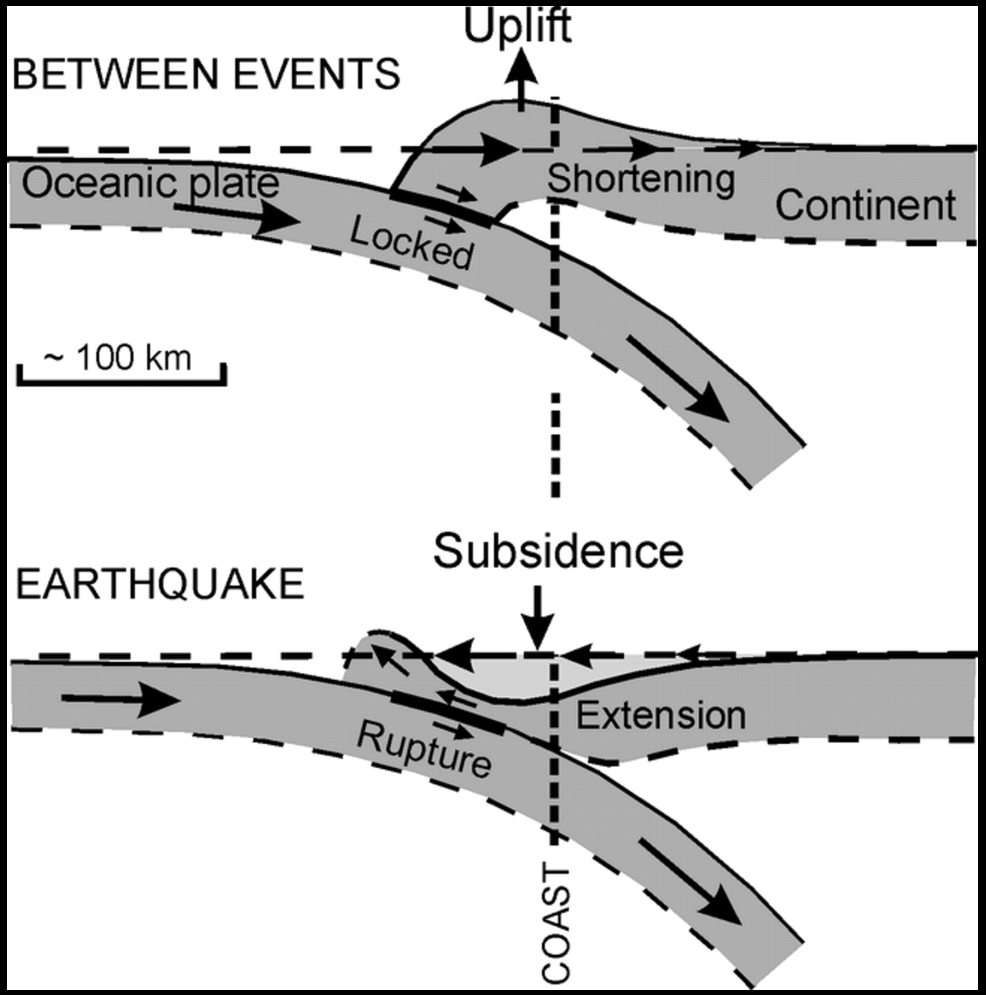
Cascadia Subduction Zone



- **"Locking"** describes how much plates are stuck.
- **"Creep"** describes how much plates slip between major earthquakes
- Between major Earthquakes, Plate interface stuck and building stress

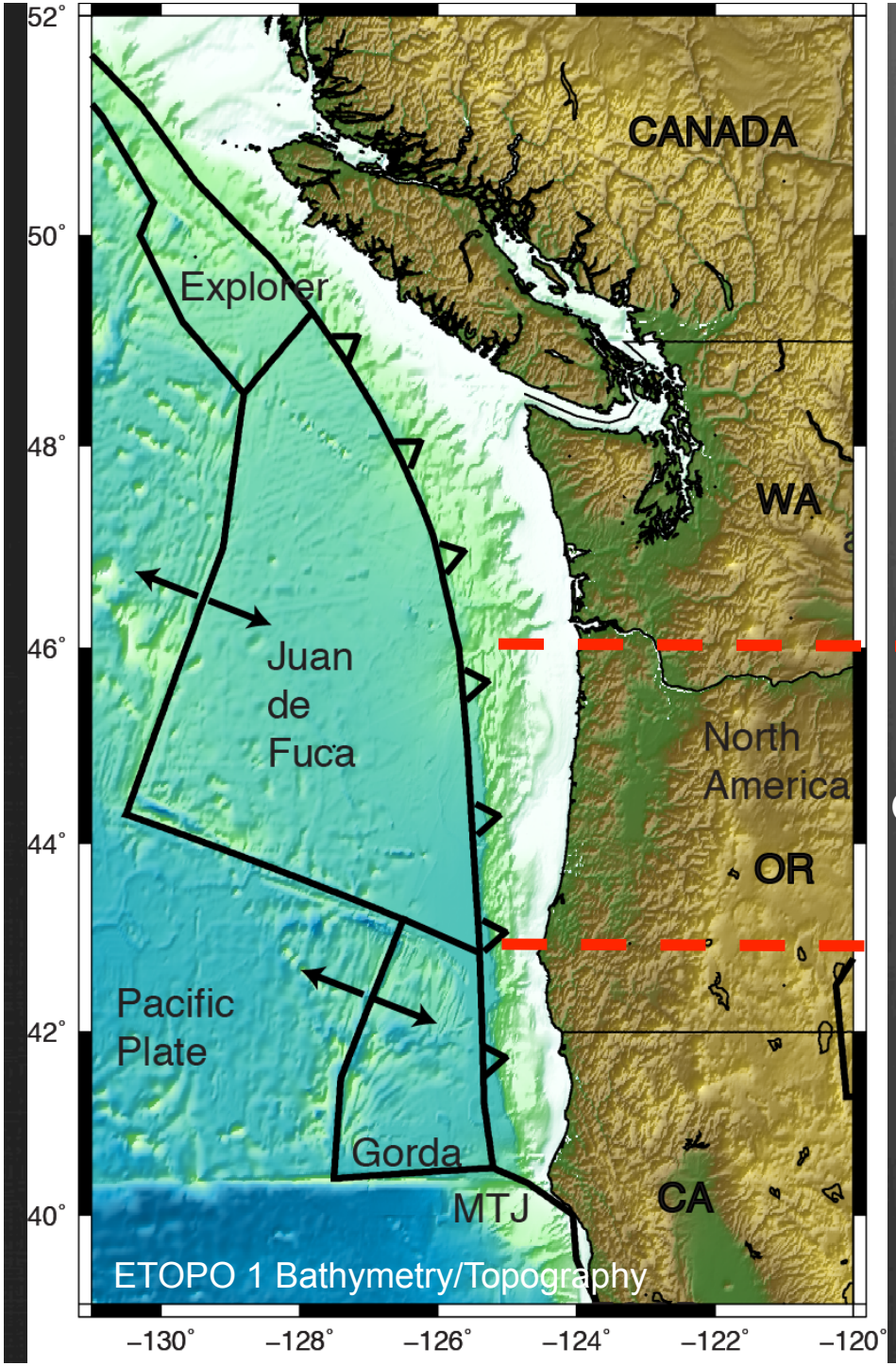
Figure from John Delaney, picture taken from a website I may regret being on…

What happens when plates are stuck?

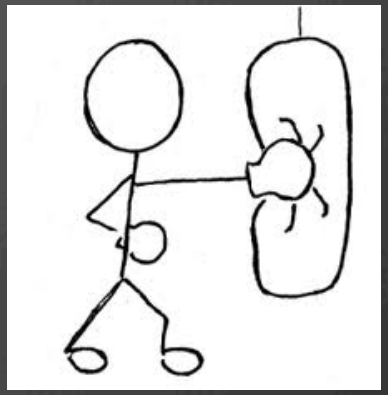


Japan experienced about a meter of subsidence at the coast. The tsunami was a whopping 10m high (33 ft)!

Image from Leonard et al. [2003]



The Punch Line



Creep!

- Persistent inter-megathrust earthquake fault creep in central Cascadia
- Margin wide distributions of inter-megathrust uplift (and estimated locking) and subsidence from past earthquakes

The Tusk: Global Positioning Systems (GPS)

- GPS Satellite emit signals with known wavelengths (~19 and 24 cm).
- Pseudorange: difference in time between satellite emission and detection on the ground and multiplying it by the speed of light.
- At least 4 satellites needed for 3D positioning
- Curently 32 healthy GPS satellites in orbit

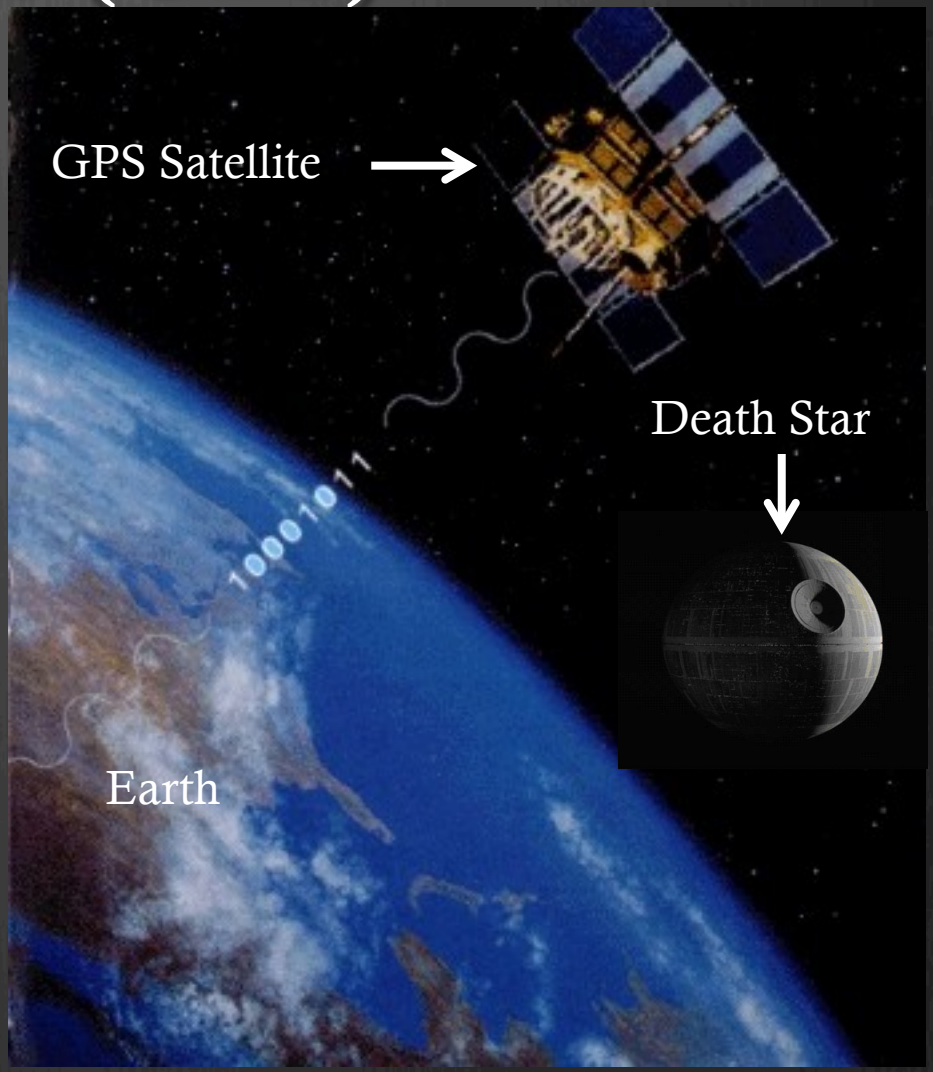


Image from http://www.geosoft-gps.de/english/gps_infos/info_2_e.html

The Tusk: Global Positioning Systems (GPS)

http://en.wikipedia.org/wiki/Survey_marker

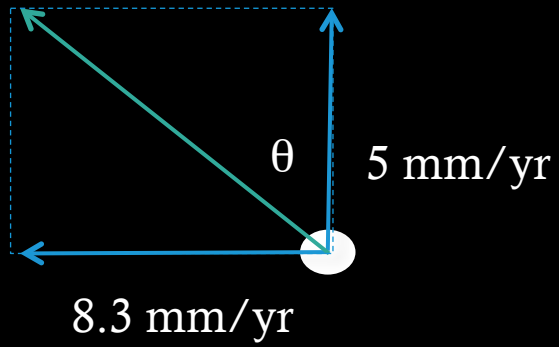
http://facility.unavco.org/

https://earthdata.nasa.gov/featured-stories/featured-research/looking-mud

GPS

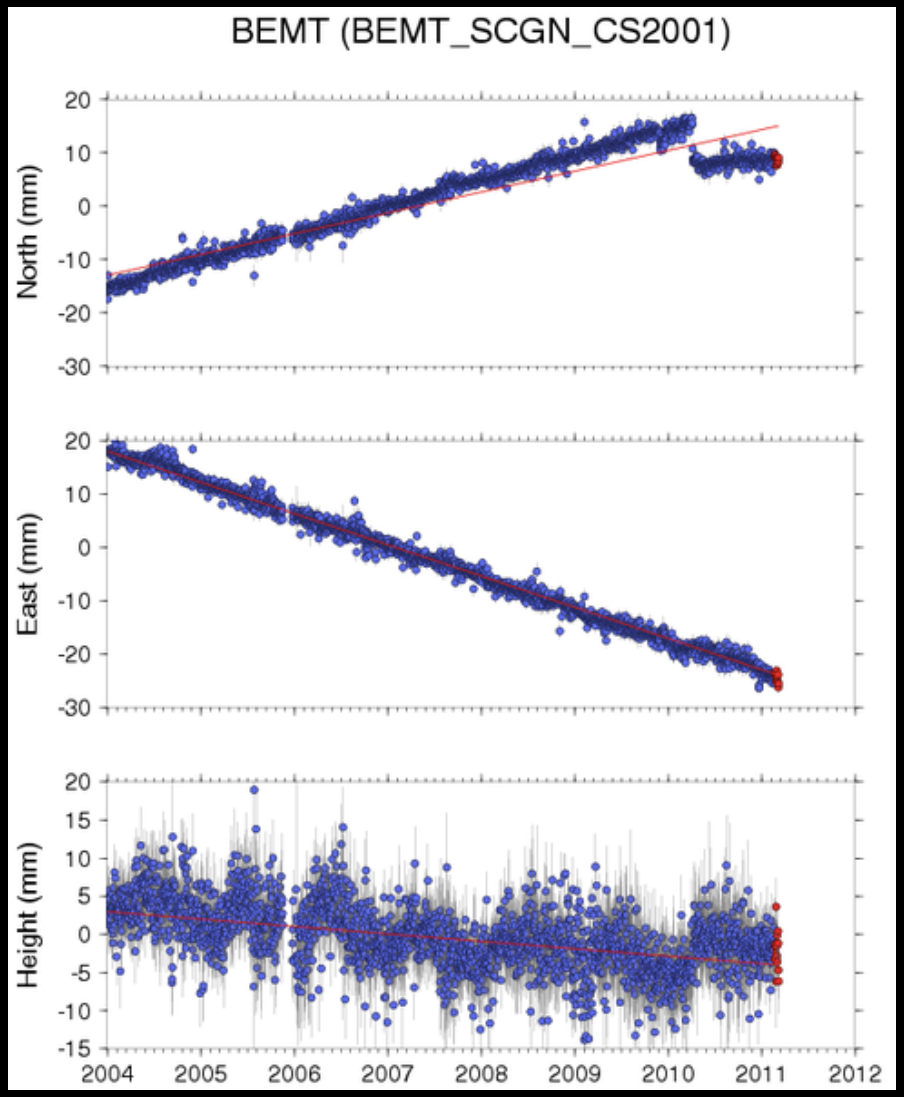
Blue dots – daily position estimates in North, East and Vertical directions for one site

Horizontal Velocity by eye:



GPS Rate = sqrt(5^2+8.3^2) = 9.69 mm/yr

θ = atan (8.3/5) = 59 degrees



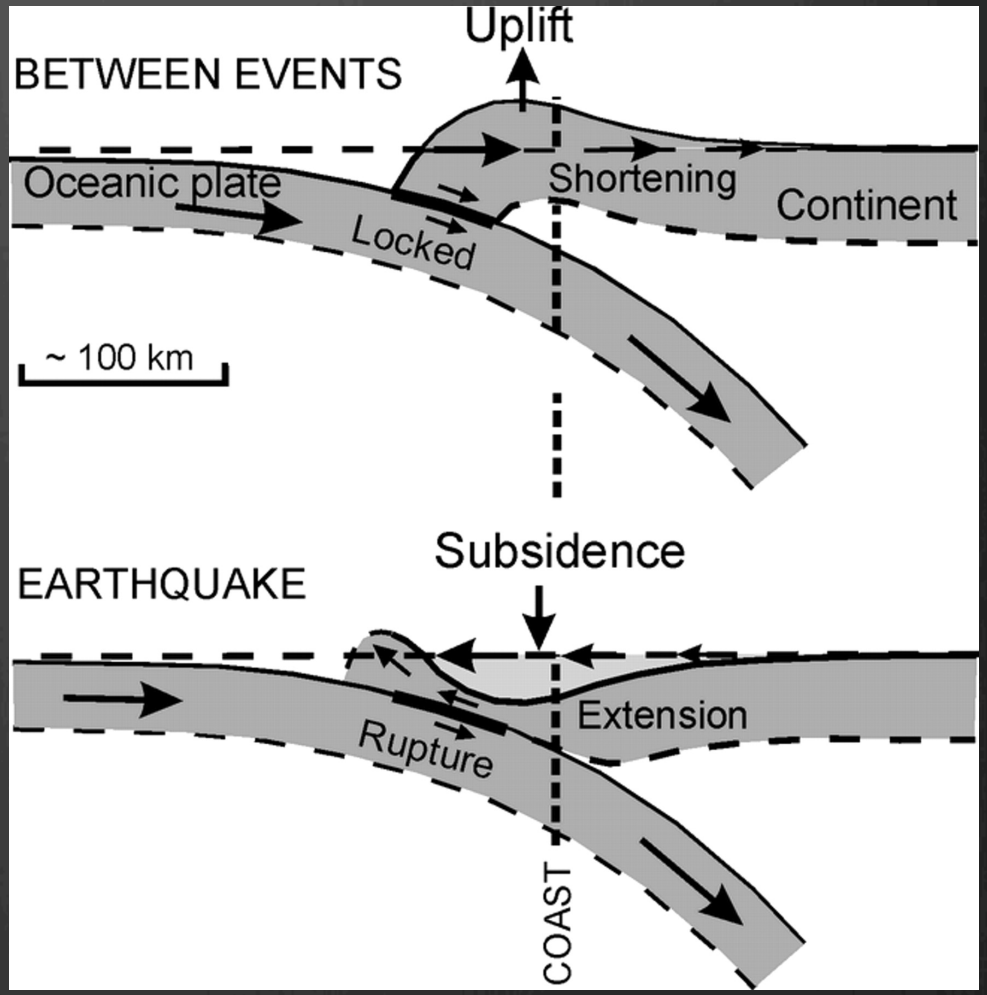
For you math nerds…

Velocities are calculated by fitting the time series (least-squares) with the linear equation:

$$p(t_i) = p_o + v * t_i + \sum_{j=1}^{N} \boldsymbol{A}_j \boldsymbol{H}(t_i - t_j) + U_1 \sin(2\pi t_i) + U_2 \cos(2\pi t_i) + U_3 \sin(4\pi t_i) + U_4 \cos(4\pi t_i)$$

p = position
p_o = initial position
v = velocity
t = time
H = Heaviside function (step function) for earthquakes or equipment changes
A = amplitude of offset
$U_{1\text{-}4}$ = constants for seasonal variations

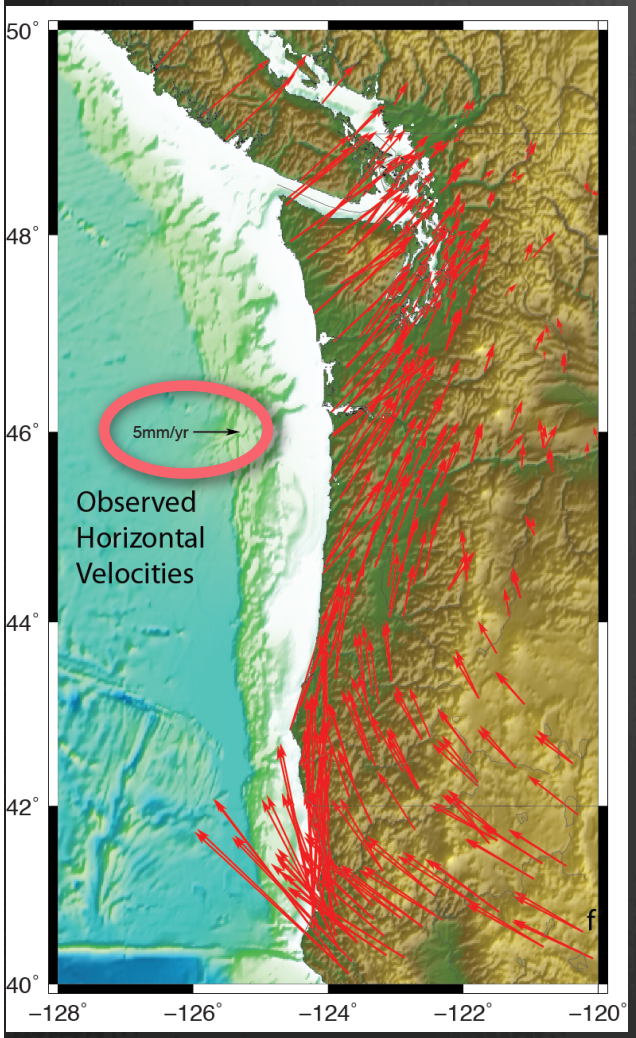
The Leg: Tide Gauge and Leveling Uplift Rates



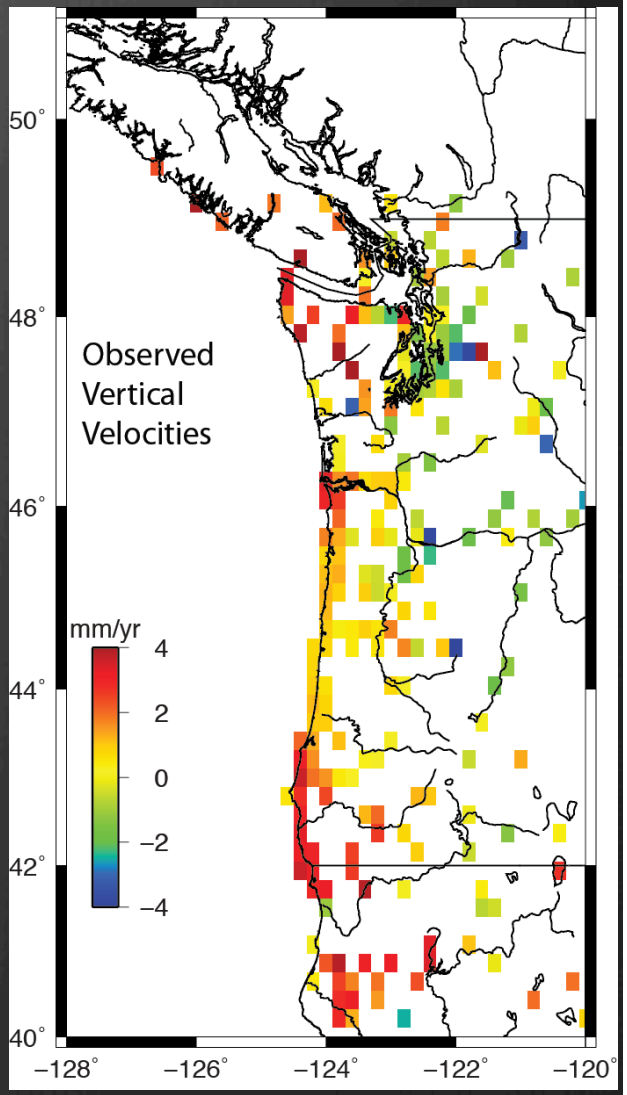
www.oco.noaa.gov

Uplift rates from Burgette et al [2009], observations from 1925-2006

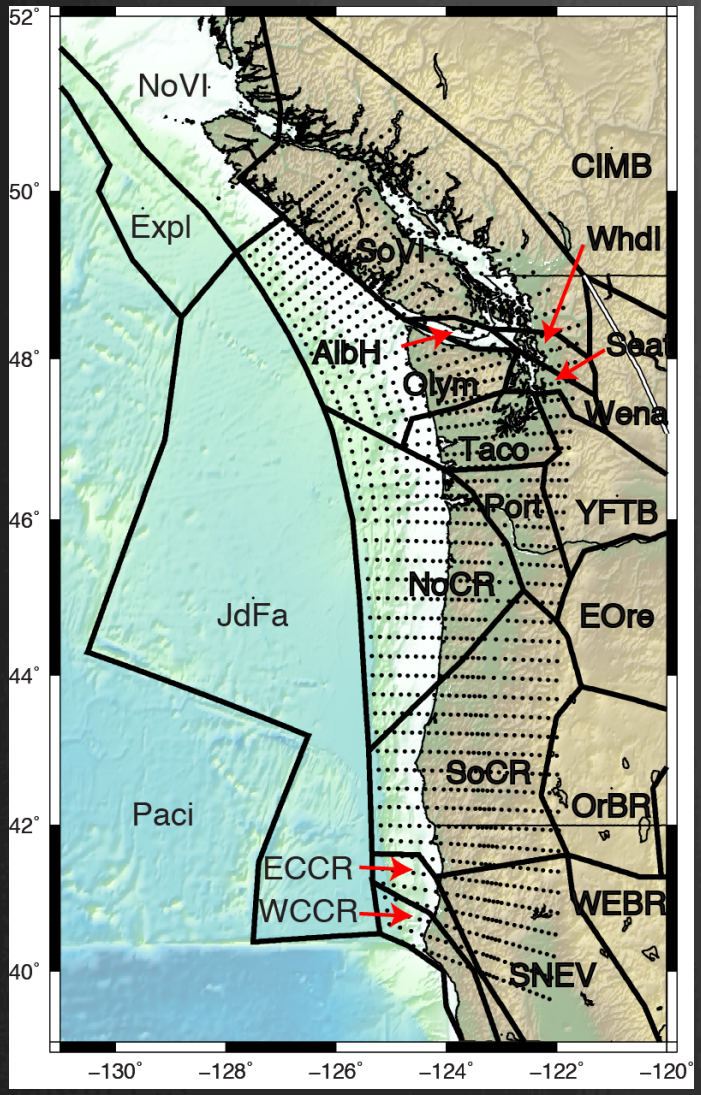
Inter-Megathrust Earthquake Velocities



- PANGA and PBO GPS 3 component time series from 1997- 2013 used to derive velocities
- Earthquakes and equipment changes removed
- Tide and Leveling uplift rates from *Burgette et. al.* [2009]
- Reduced coastal interseismic uplift from ~43-46°N

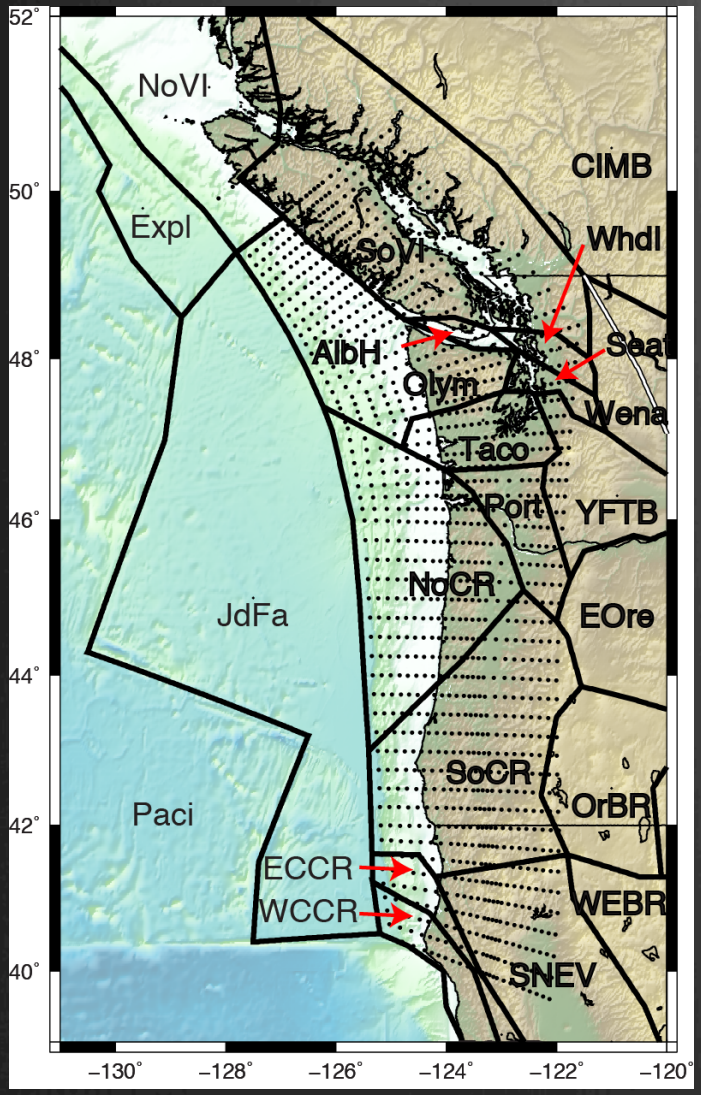


Mechanical Block Models



- Mechanical models simulate how we think the earth works. Model contains parameters (fault rate, locking…).
- TDEFNODE, block modeling software – Written in **Fortran!**
- Block models divide the region into tectonic blocks
- Fault defined by nodes; geometry based on *McCrory et al.* [2004]
- Free Parameters: block rotations, deformation due to fault motion, fault locking
- Velocity data applied to model, low misfit model parameters are solved
- **Problem:** Locking non-unique – limited observations offshore

Mechanical Block Models

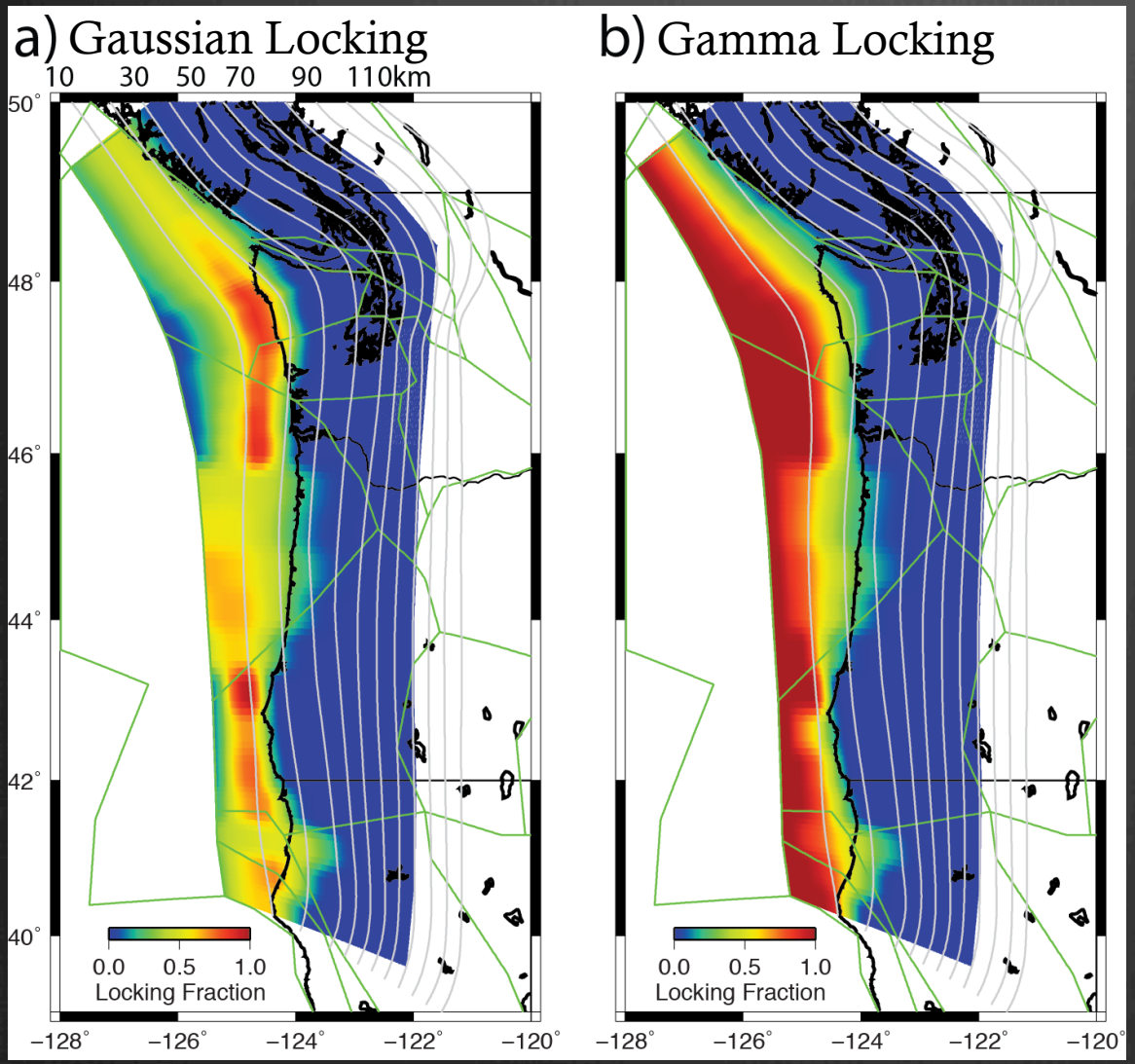


- Locking described in 2 ways:

1. **Gaussian model** –Gaussian locking distribution. Mean depth, width and amplitude are solved (e.g., *McCaffrey et al.* [2013])

2. **Gamma Model** – Fully locked near trench, transitioning by a function gamma to fully slipping down-dip (e.g., *Wang et al.* [2003]). Upper and lower depths of the transition zone and gamma are solved

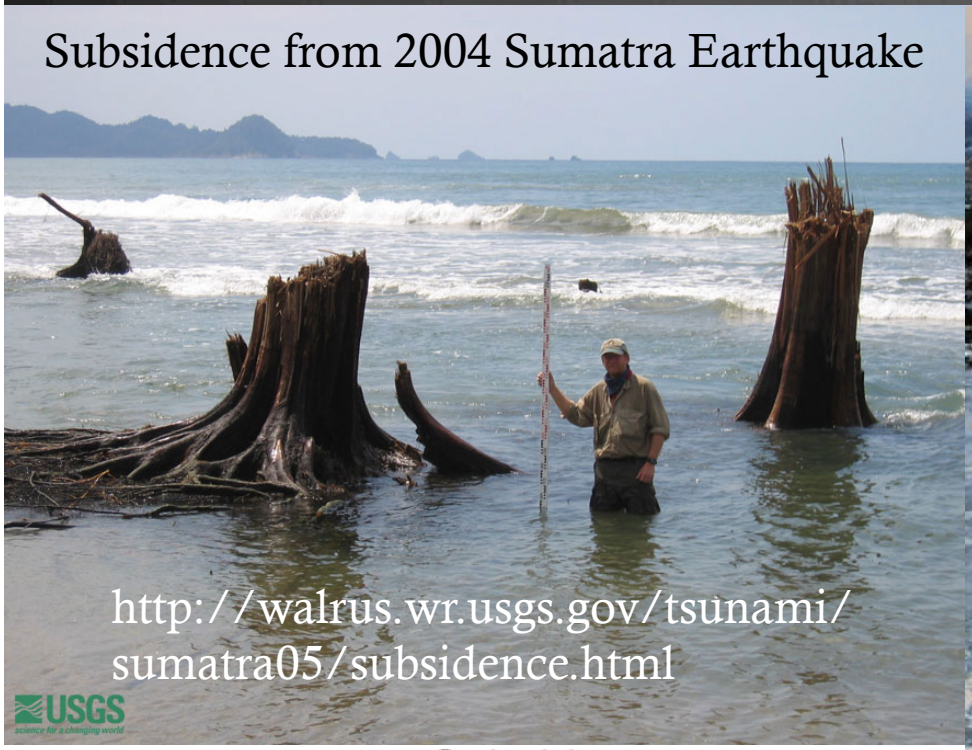
1. Locking Fraction

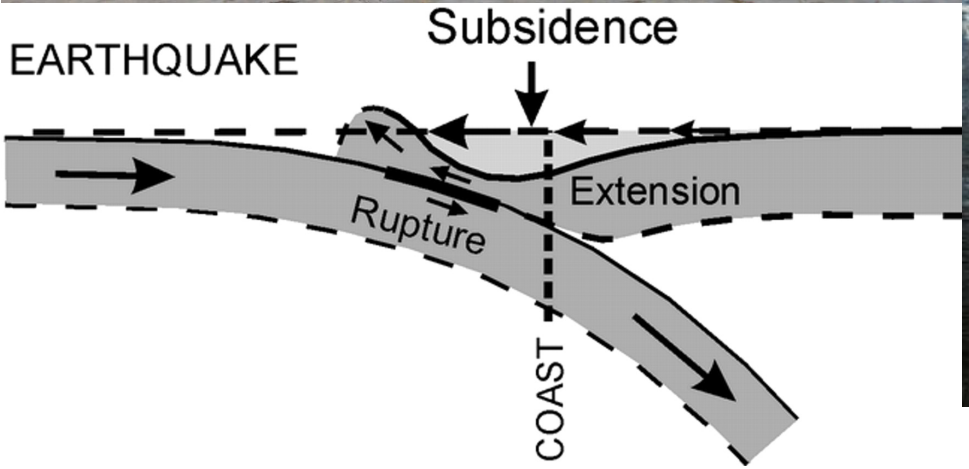


- Residuals nearly identical: reduced χ^2 = 1.6 for each
- Locking distribution offshore dependent on model assumptions
- Near the coast similar locking emerges
- Wide transition zone between ~43-46°N

The Tail: Paleoseismic Data

Subsidence from 2004 Sumatra Earthquake





2011 Japan Tsunami

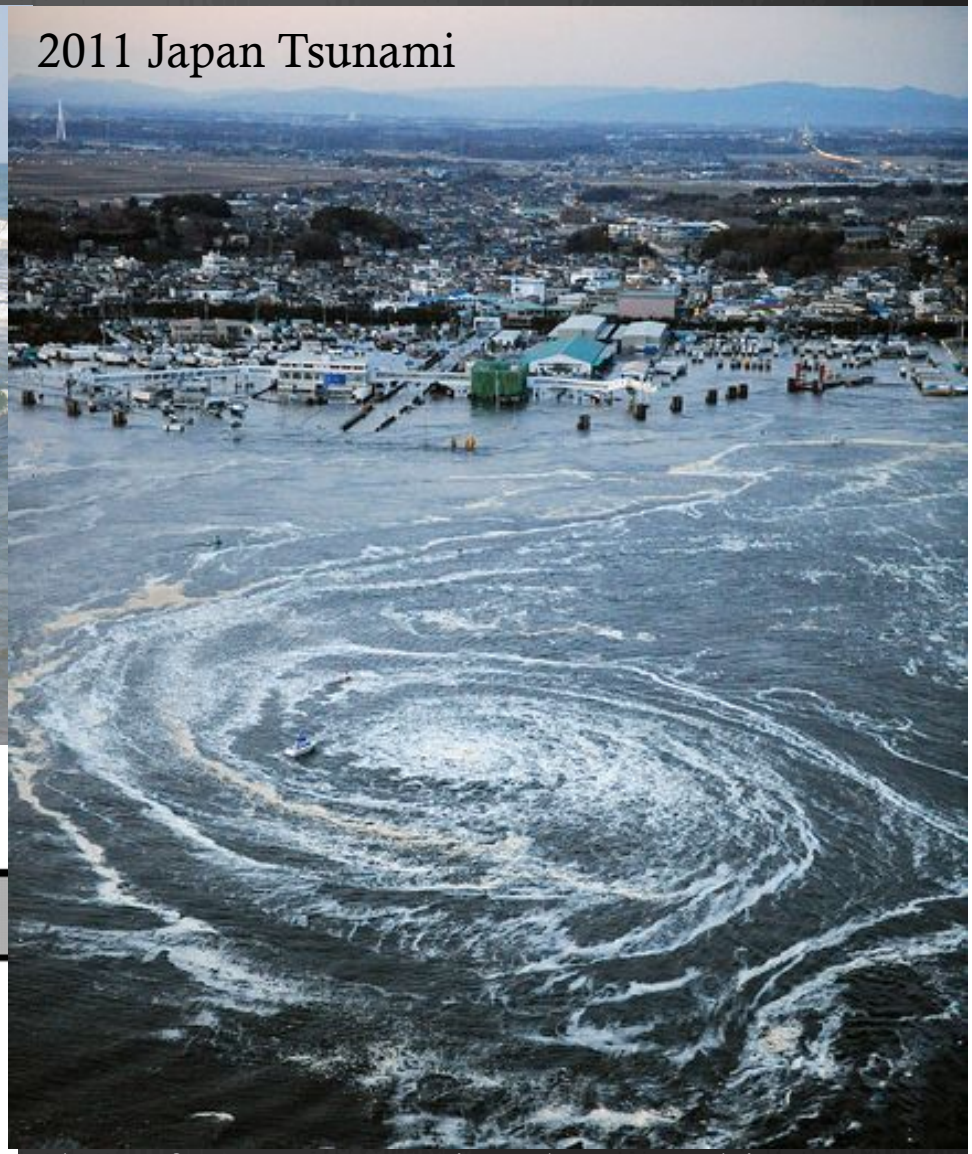
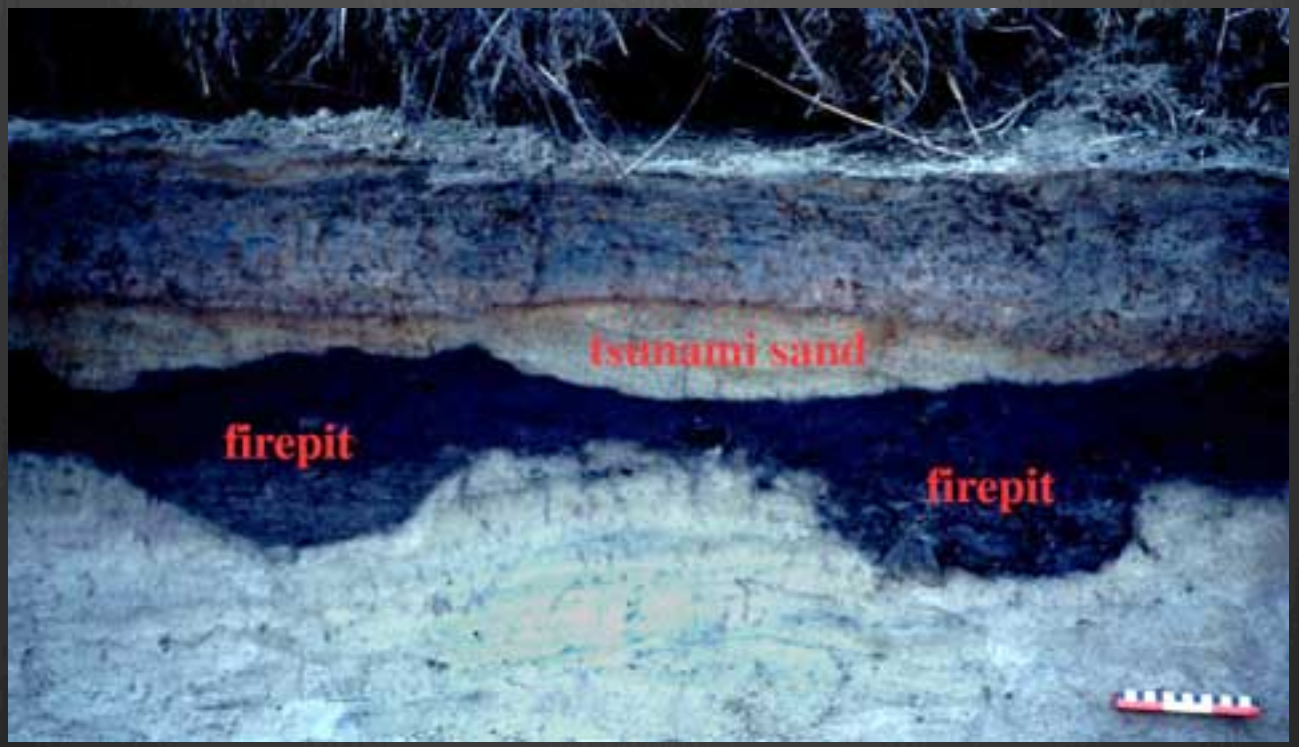


Photo from news.nationalgeographic.com

The Tail: Paleoseismic Data

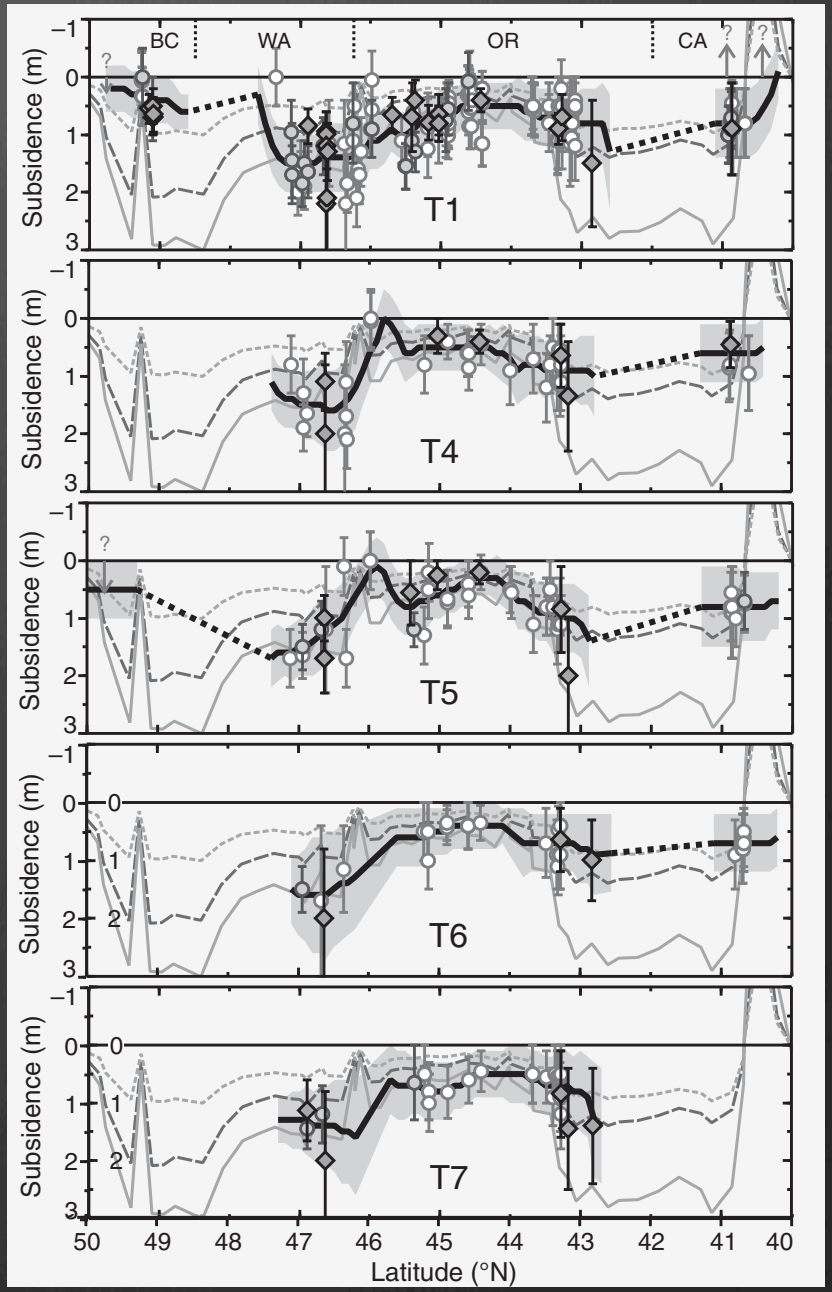


http://en.wikipedia.org/wiki/File:Pcascadia.jpg

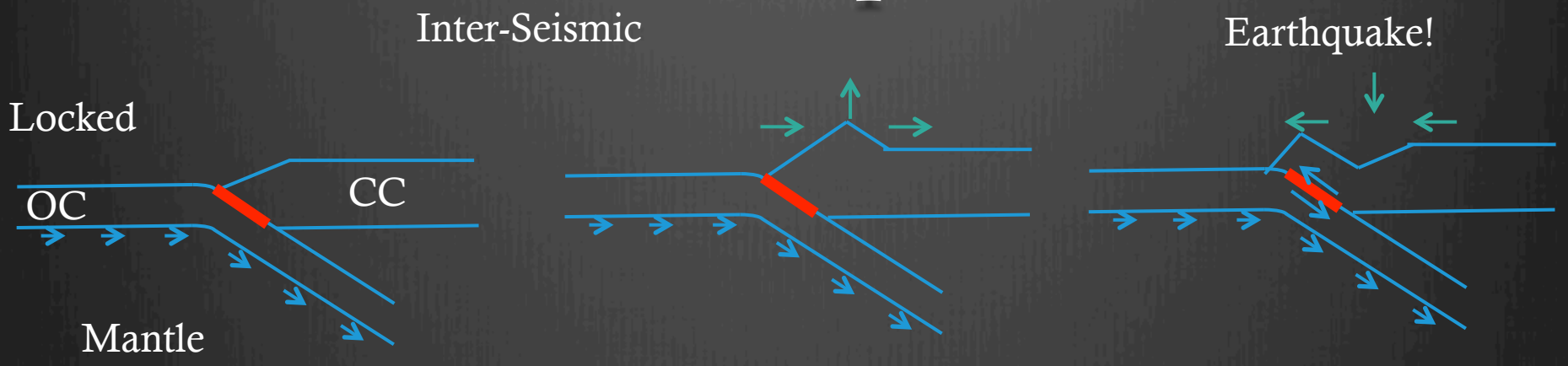
Paleoseismic data can tell you when and by how much coastal areas subsided due to an earthquake.

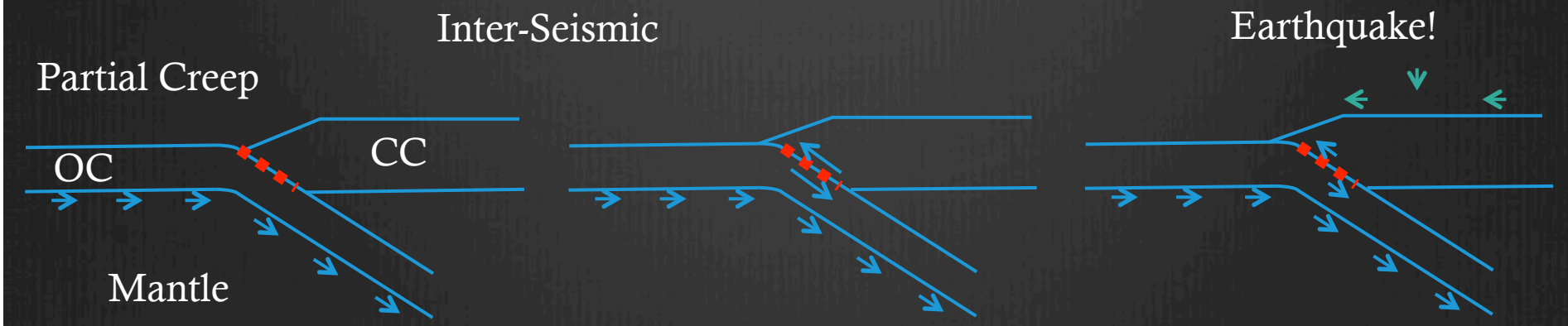
Earthquake Subsidence from Paleoelevation Studies

- Leonard et al., 2010 compile subsidence measurements from previous studies that includes events from the past 6500 years
- Less subsidence from ~43.5-46N is a persistent feature of Cascadia great earthquakes
- Central Cascadia has reduced
  - Inter-megathrust earthquake uplift
  - Subsidence due to earthquakes

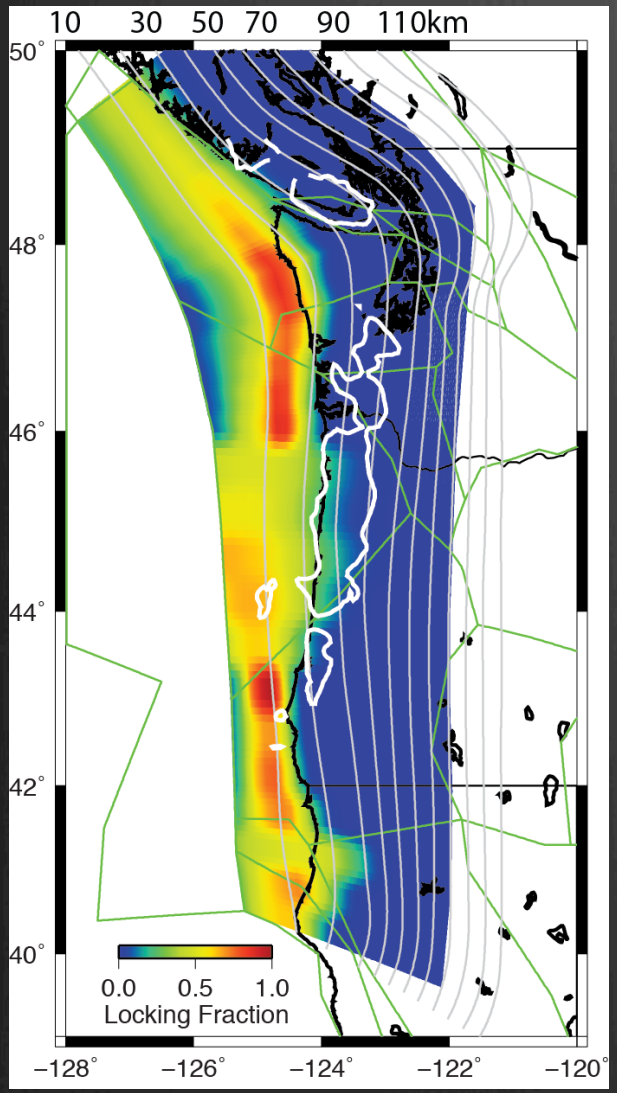


My Elephant: Central Cascadia Creep





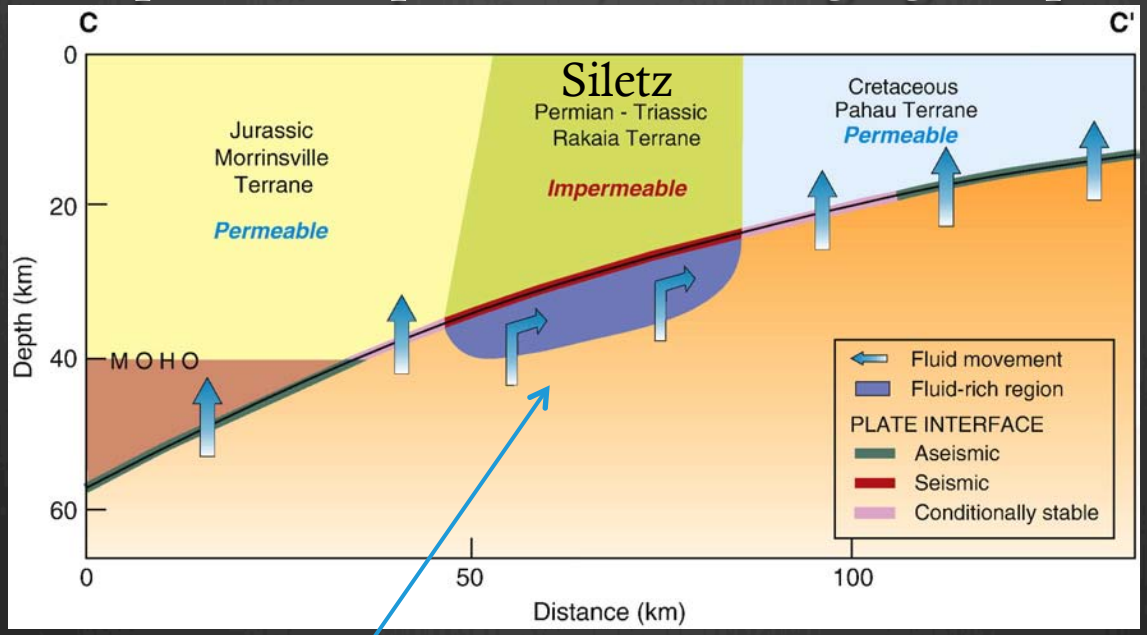
Why Creep in Central Cascadia?



- Eocene (~50 Ma) age accreted basalt -- Siletz terrane influences locking [*Burgette et al.*, 2009]
- Rigid – few earthquakes and Impermeable (?)
- Dense – Large gravity anomalies (white line, 10 mgal contour, *Blakely et al.*, 2005)
- Seismic surveys show it is thickest near coastal central OR; extends ~35km offshore in central OR [*Trehu et al.* 1994] and east of Olympic in WA (*Parsons et al.*, 2005)

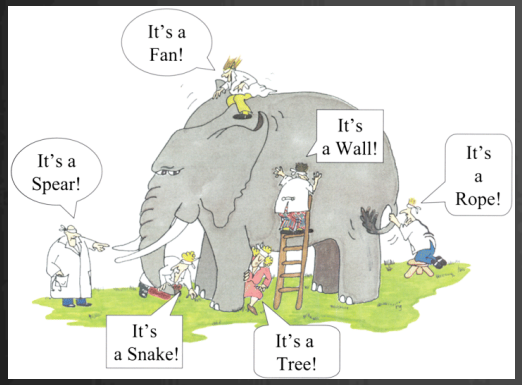
Siletz Terrane – Creepy?

- Geochemical reactions from high T and P release water
- Impermeable terrane in overriding crust traps water and increases pore fluid pressure, encouraging creep



Modified conceptual model of Reyners and Eberhart-Phillips, 2009

Trapped water from Basalt-Eclogite transition



The Punch Line

- Reduced inter-megathrust uplift rates (and inferred locking) and earthquake subsidence suggest persistent fault creep in central Oregon
- We suggest the presence of an (impermeable?) 50Ma accreted basalt (Siletz) promotes creep
- Regardless of why it is creeping, these results suggest central Cascadia will slip less during future great earthquakes, impacting the seismic hazard of the region.
- Schmalzle, G.M., McCaffrey, R. Creager, K. Central Cascadia Subduction Zone Creep, *Geochemistry, Geophysics, Geosystems,* doi: 10.1002/2013GC005172, 2014

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