Landward Limit of Cascadia Great Earthquake Rupture; a Summary of Constraints

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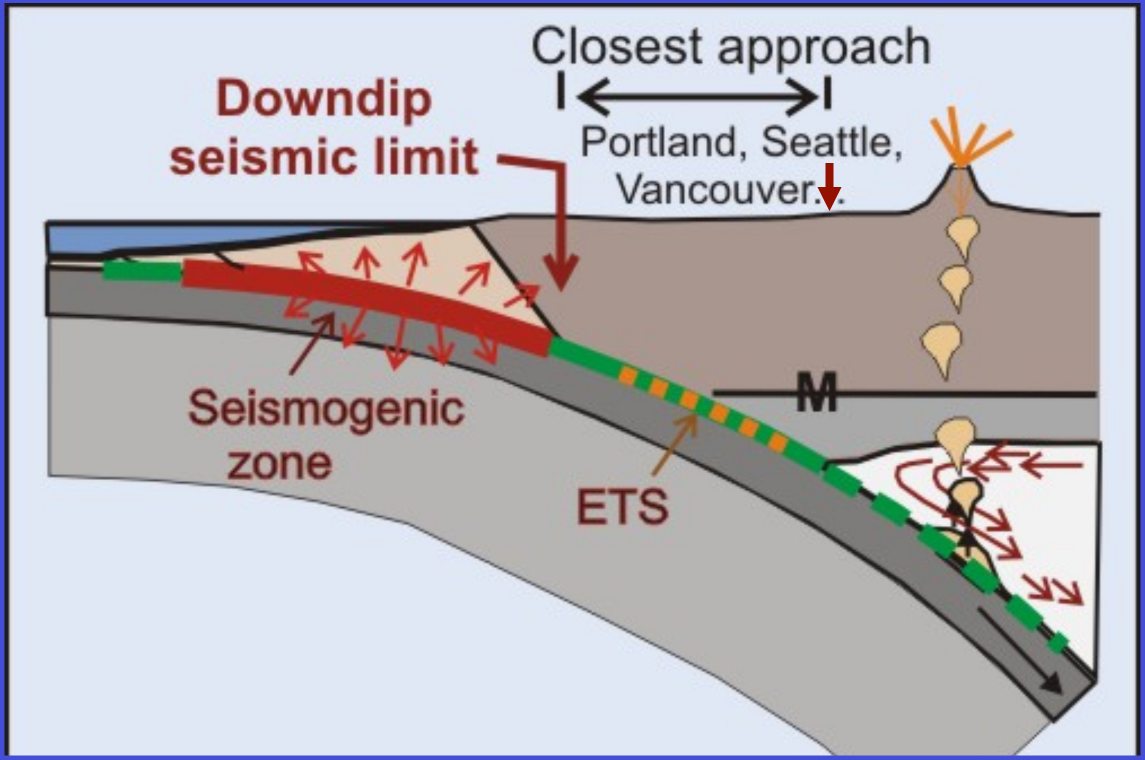
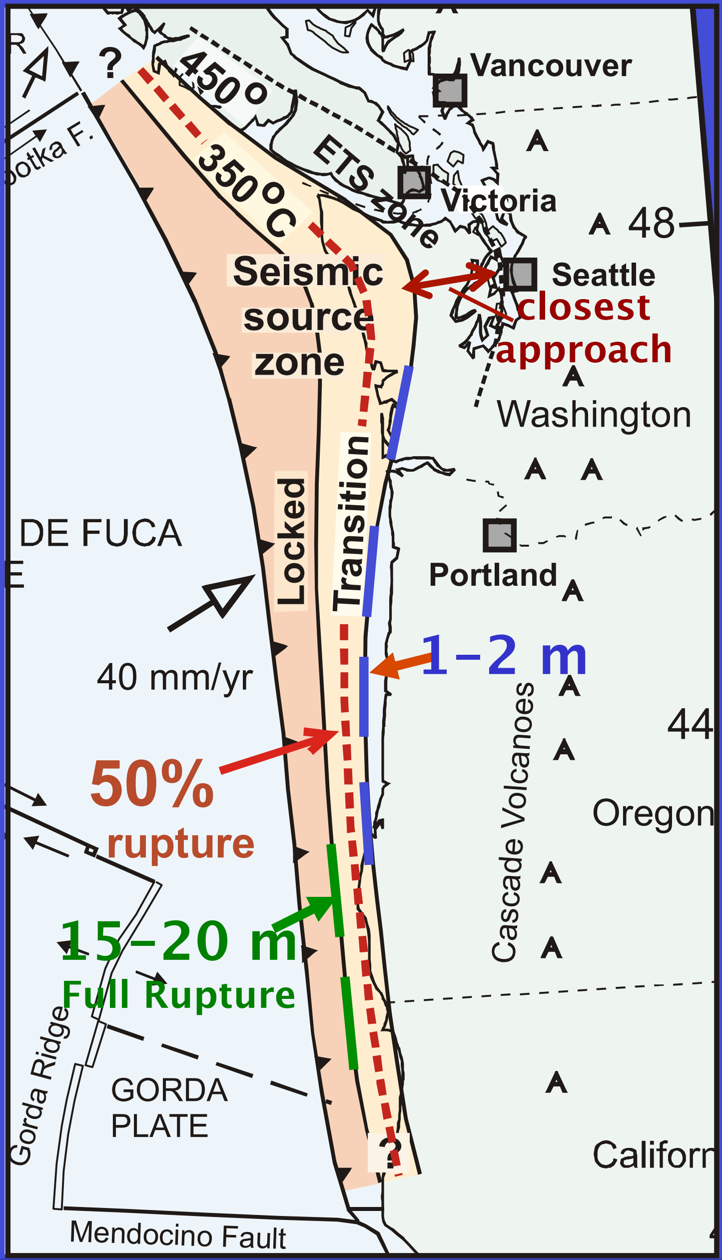


The Landward Limit of Cascadia Great Earthquake Rupture

–Most important control of shaking

(1) To allow comparisons, choose 50% of maximum rupture, ~10 m; i.e., mid-transition

(2) Smaller rupture, 1–2 m, near landward limit may be important for damaging shaking frequencies



Estimating downdip rupture extent

(a) Constraints to past rupture

(b) Constraints to 'locked zone'

(c) Physical process/state controls

*****None of the constraints are to the actual rupture zone; all require some assumptions***

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Estimating downdip rupture extent:

(1) Rupture zone from paleoseismic coastal marsh subsidence **(and 1700 tsunami);** 'paleo-geodesy'

(2) Locked/transition zones from geodetic deformation & dislocation models: GPS, repeated levelling, tide gauges, abs. grav., etc -

(3) Seismic-aseismic behaviour limits from downdip temperatures; "brittle-ductile transition"; 350^{o}C full rupture; 450^{o}C transition

(4) Change in thrust seismic reflection character from thin sharp (seismic) to thick shear zone (ductile)

(5) Forearc mantle corner (aseismic serpentinite & talc on thrust)

(6) ETS slow slip updip limit; slow slip accommodates most of plate convergence in ETS zone

(7) Geological associations with rupture, basins just offshore etc.

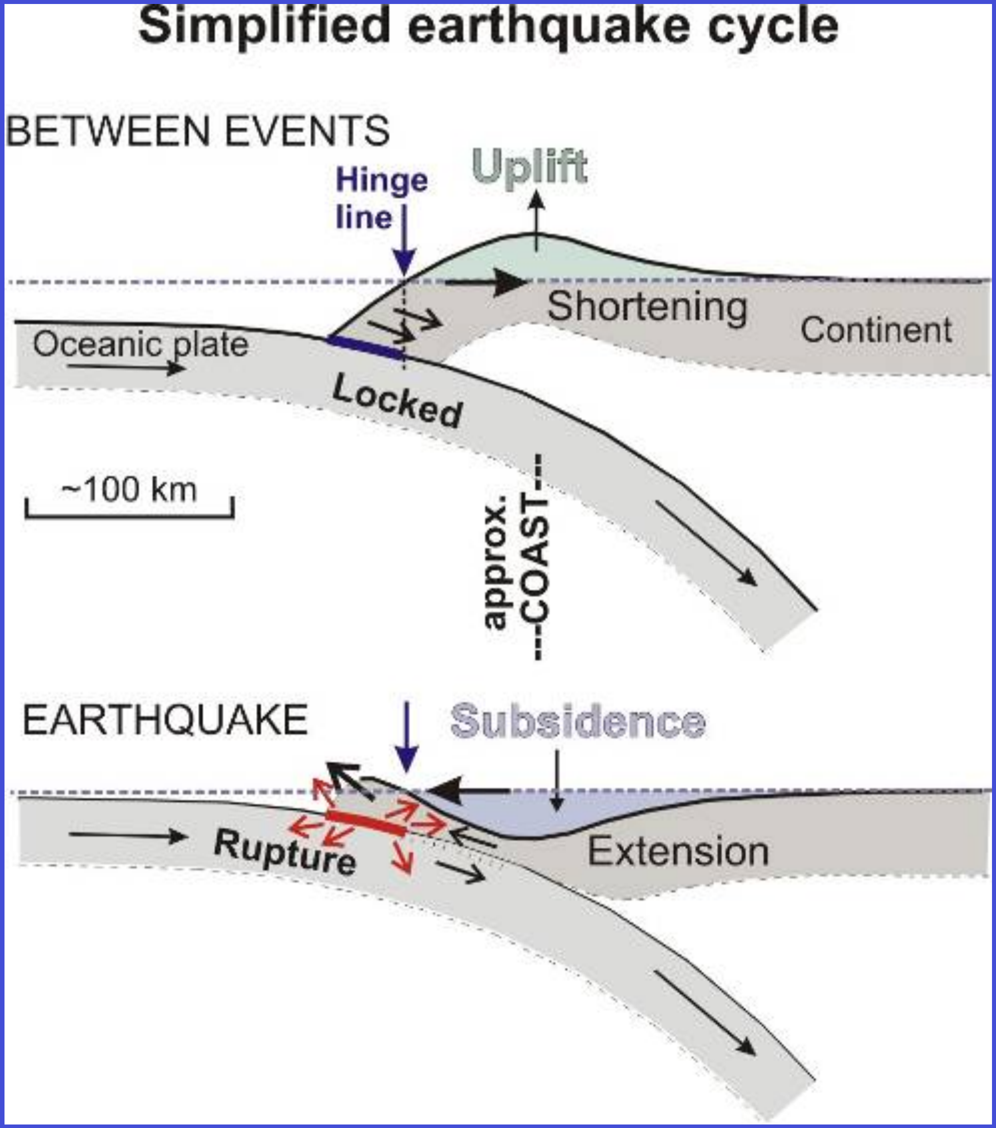
Also recent great earthquakes elsewhere- method calibration

Deformation through great earthquake cycle

Landward limit of significant rupture or locked zone is approx. over hinge line of uplift or subsidence

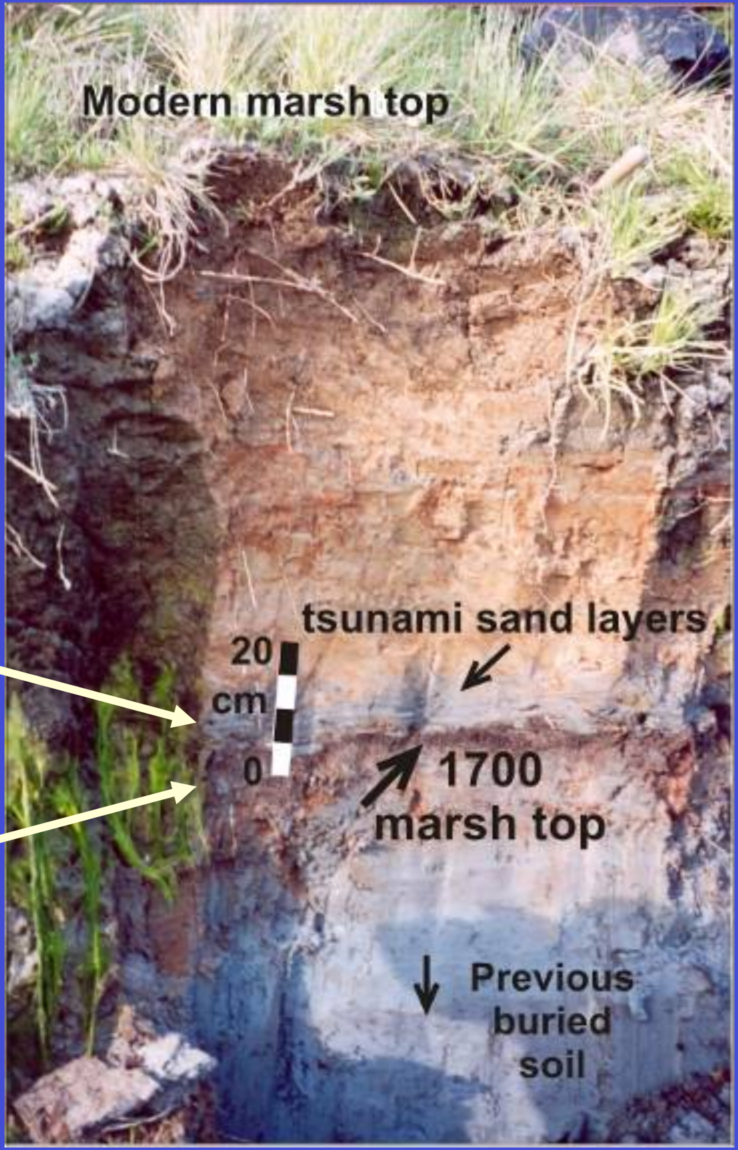
assumption:
rupture zone approx. equal to locked zone;
Especially complexity from post-seismic slip and relaxation

Note coastal coseismic subsidence requires most rupture to be seaward of coast (except near Mendocino)



1. Coastal marsh subsidence for 1700 and earlier events

"Paleoseismology-Paleogeodesy"
(e.g., Atwater, 1987)



Coseismic subsidence:

Sea-level marker organisms in sediment above and below old intertidal salt marsh top

includes some postseismic vertical motion, i.e., seismic rupture is somewhat seaward

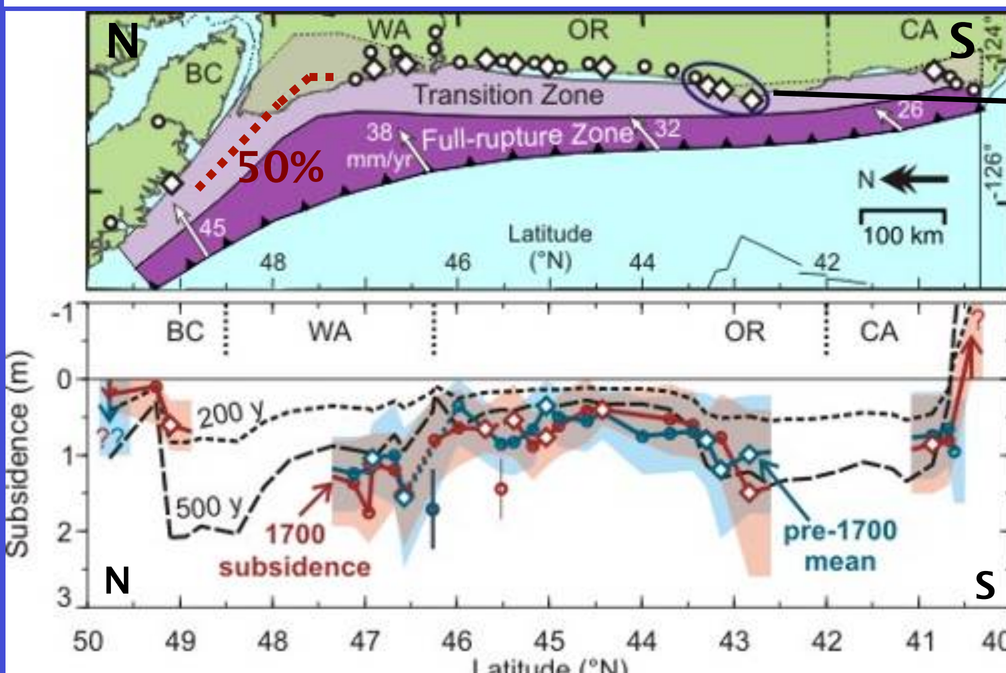
Many impressive coastal studies -many authors

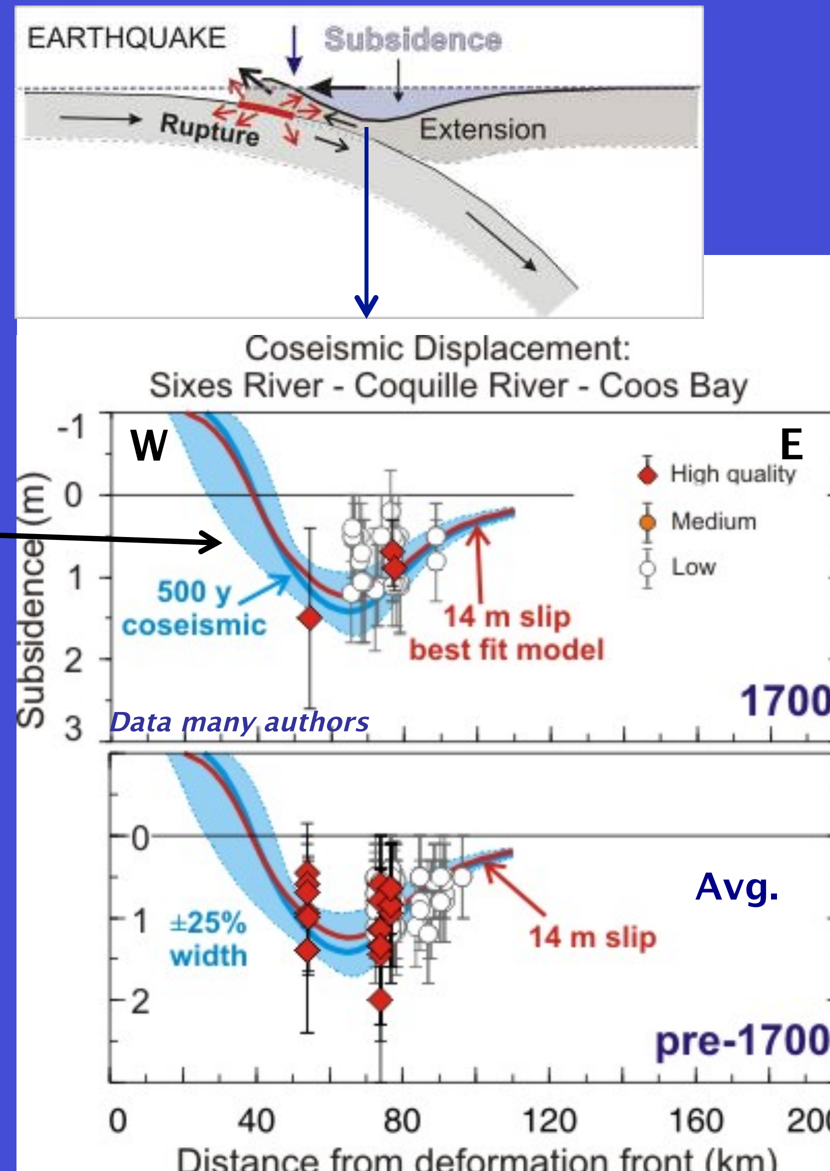
Photo L. Leonard B. Atwater

Coastal marsh subsidence for 1700 and earlier megathrust earthquakes *(Leonard et al., 2004; 2010)*

Poor resolution but coastal <u>subsidence</u> requires rupture mainly offshore. Some trade-off of landward limit and rupture displacement

Fluck et al. model **North-south transect**





see Hawkes et al., 2011 for new Oregon data

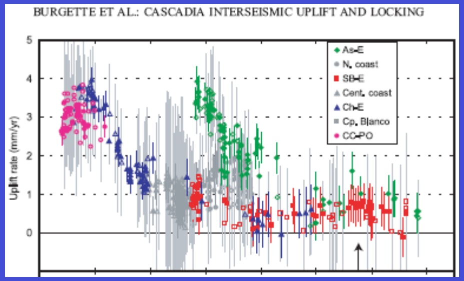
2. The "locked zone"

Current geodetic limit from fit of elastic dislocation model to vertical repeated levelling and tide gauge data

Coastal coseismic subsidence approx. equals uplift rate/yr x 500 yrs

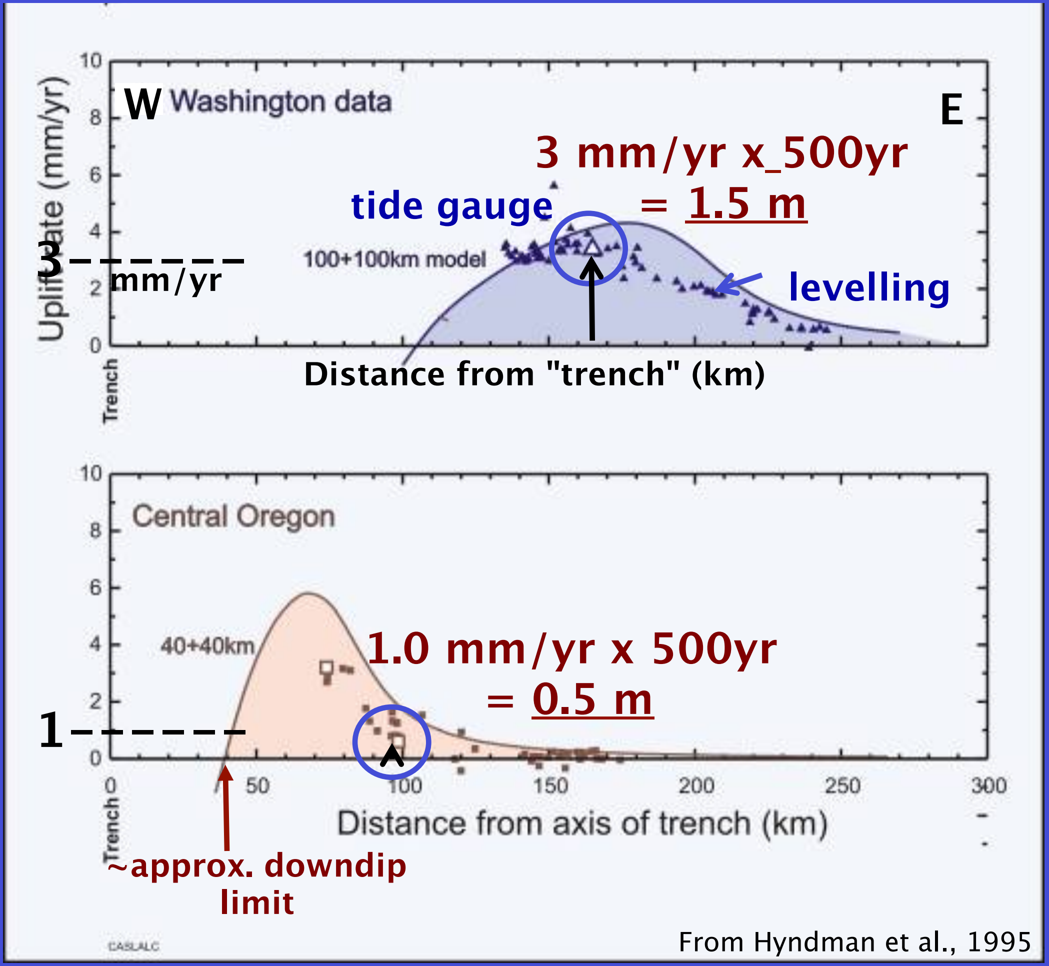
but post-seismic transients are important

Mitchell et al., 1994
Hyndman and Wang, 1995
Verdonck, 2005
Burgette et al., 2009



new Burgette et al. data for Oregon

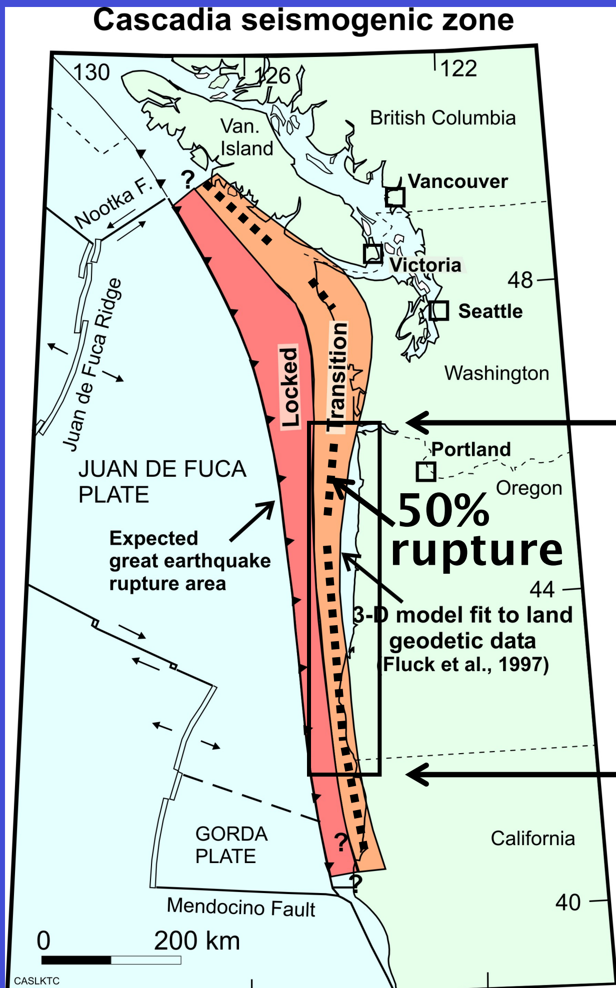
example of levelling and tide gauge data



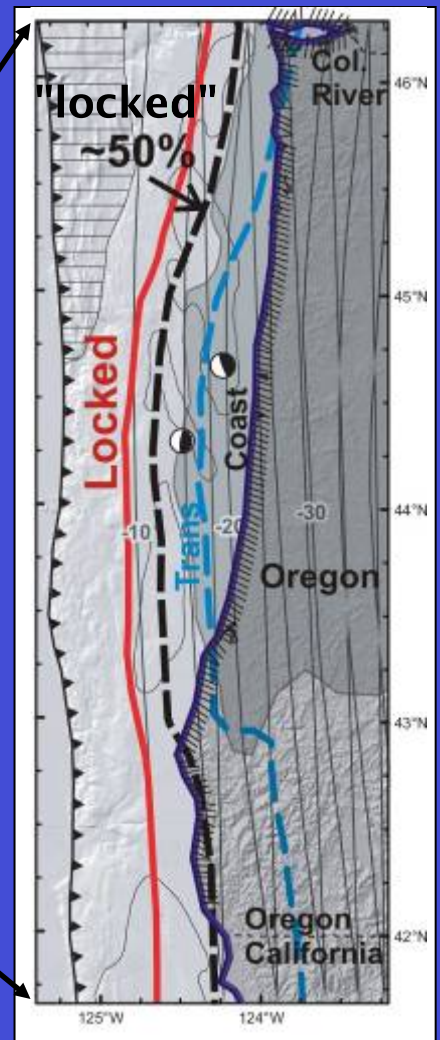
2a. Levelling & tide gauge data example models

both models ~50% "locked" is near coast for N. Wash. and ~50 km offshore for N. Oregon; 1-2 m displacement further landward

Fluck et al., 1997



Burdette et al., 2009

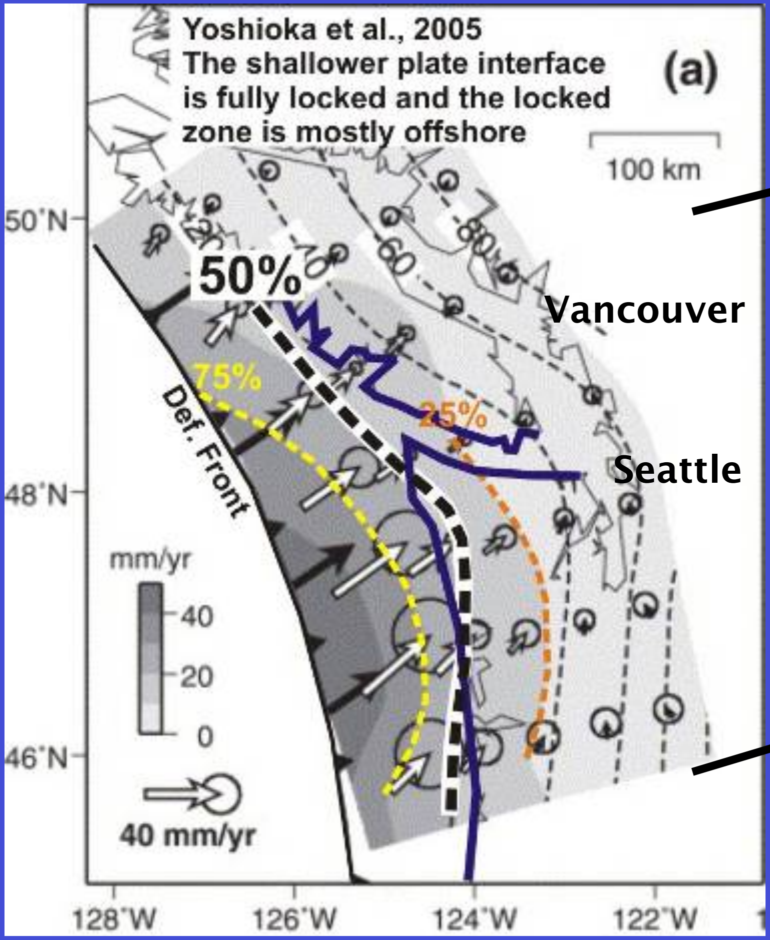


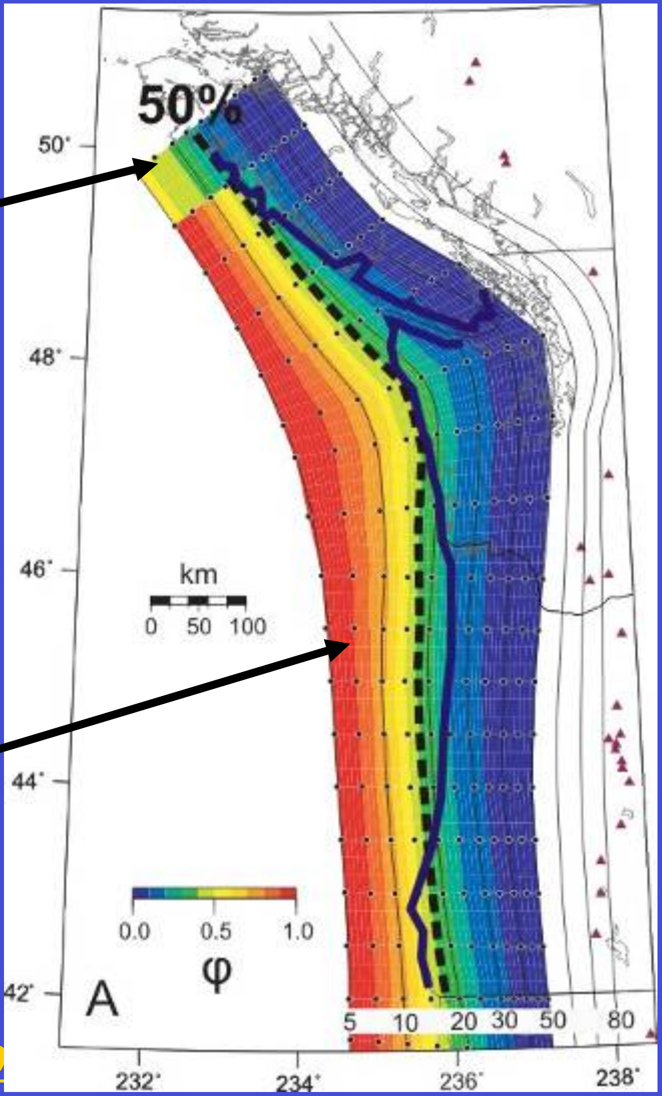
2b. Dislocation model inversions of Horizontal GPS data

Interseismic "backslip" 50% plate convergence near coast: 1-2 m rupture is further inland of coast because of slow taper transition in this type of inversion

Examples: Yoshioka et al., 2005

McCaffrey et al., 2007

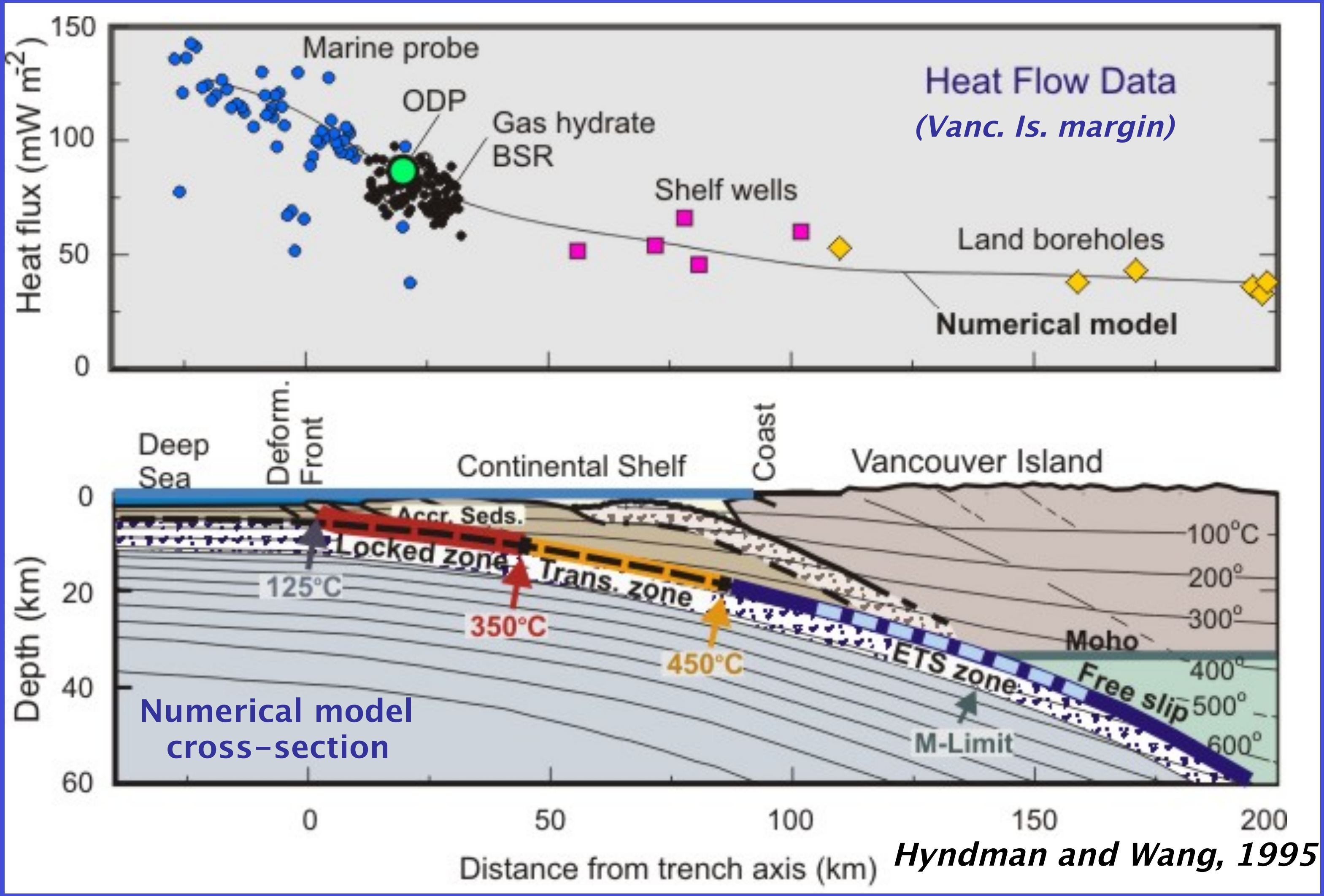




also Priest et al., 2009

3. Thermal limit for rupture extent:

Numerical thermal model seismogenic and transition zones, ~350 & 450ºC from lab data *(Hyndman & Wang, 1995).* No rupture possible above 450C?



Hyndman and Wang, 1995

Thermal limit for downdip rupture extent:

to 350º seismic; to 450º transition

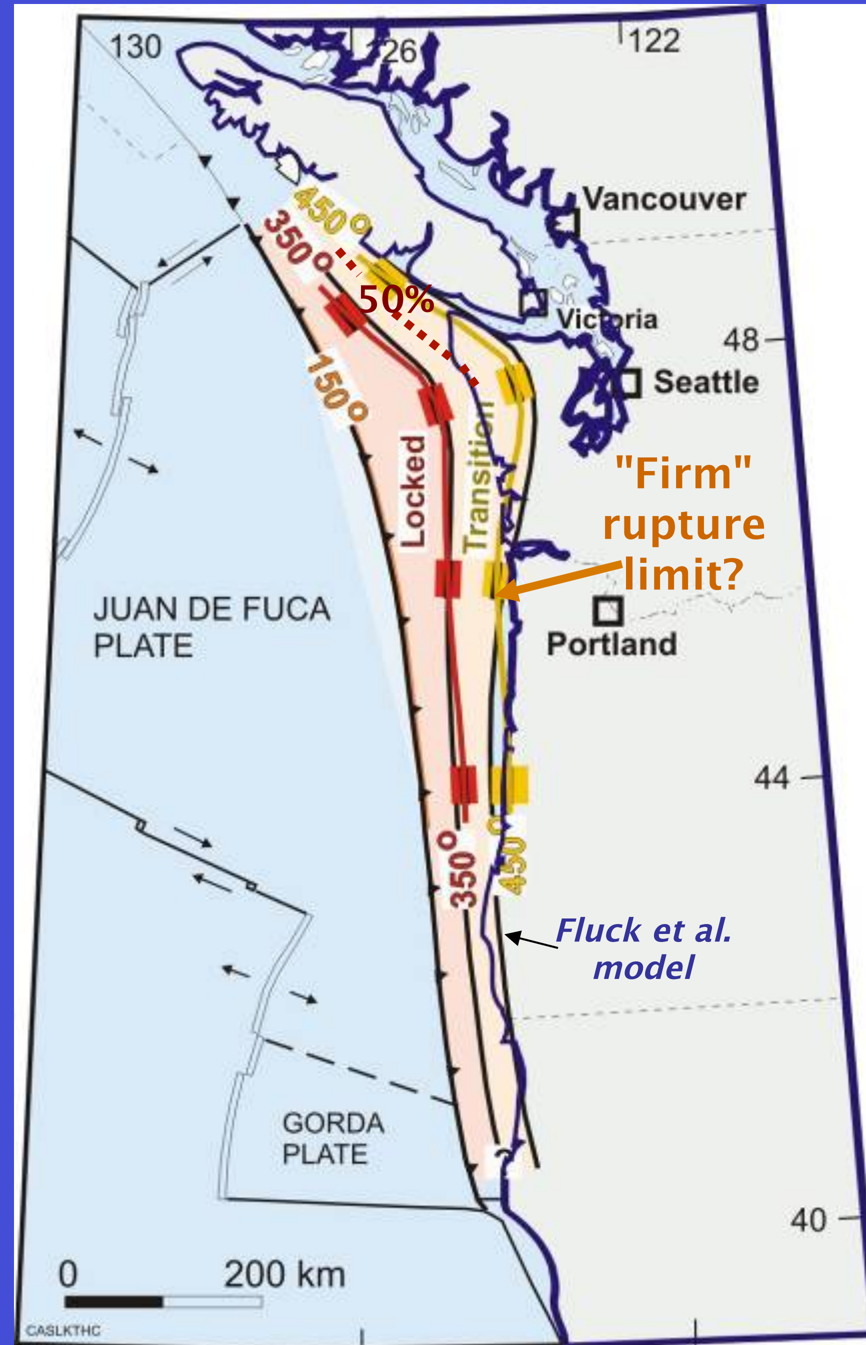
Estimates seismic behaviour to be mainly offshore

450C is a quite "firm" limit for 1-2 m rupture because of rapid increase in instantaneous shear stress at higher temperatures.

note: recent discussion of whether conductive thermal model is adequate

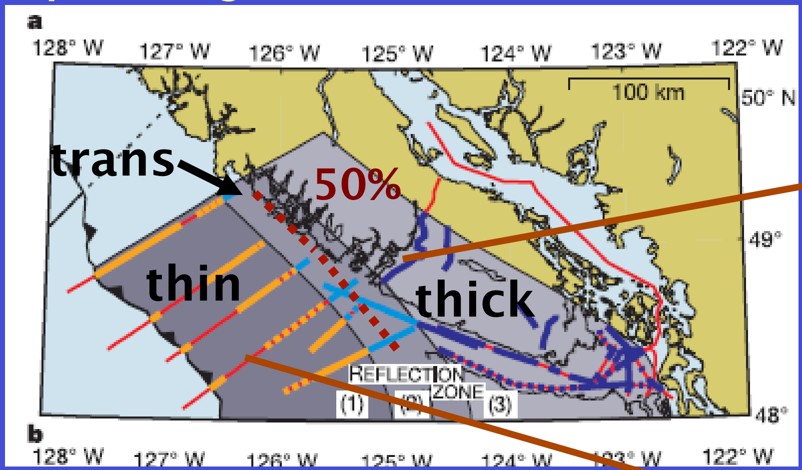
(I.e., Cozzens & Spinelli, 2010, hydrothermally cooled incoming crust)

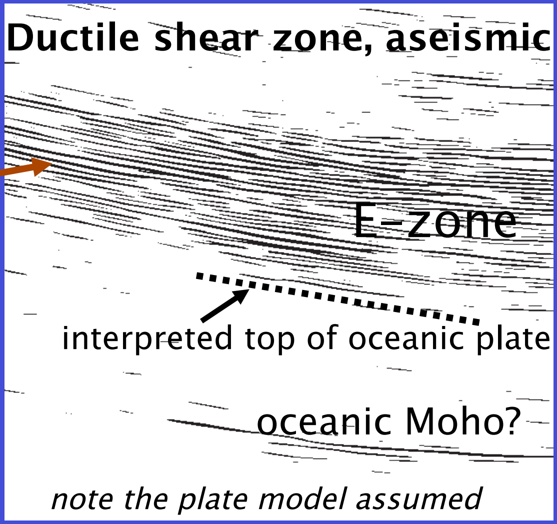
Hyndman &Wang, 1995
Oleskevich et al., 1997
McKenna & Blackwell, 2002
Currie et al., 2004
Cozzens & Spinelli, 2010

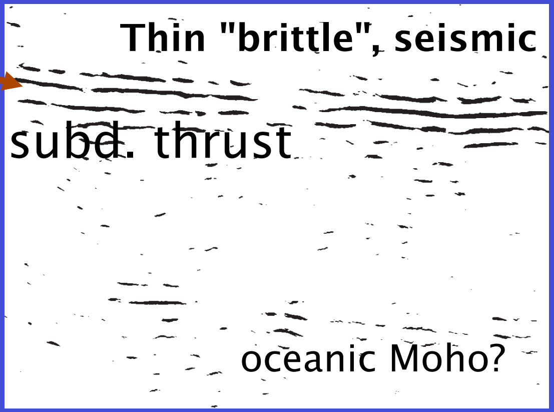


4. Downdip seismogenic extent: Thrust reflection character

-Change in thrust reflection from thin sharp (seismic) to thick shear zone (ductile)
(Nedimovic et al., 2003)
Mid-transition is just seaward of coast for Van. Island, i.e., ~50%
Not yet strong constraint.







(question of 'E' zone and top of plate)
(question of velocity weakening vs strain weakening and velocity strengthening vs strain hardening)

Nedimovic et al., 2003

5. Forearc mantle corner:

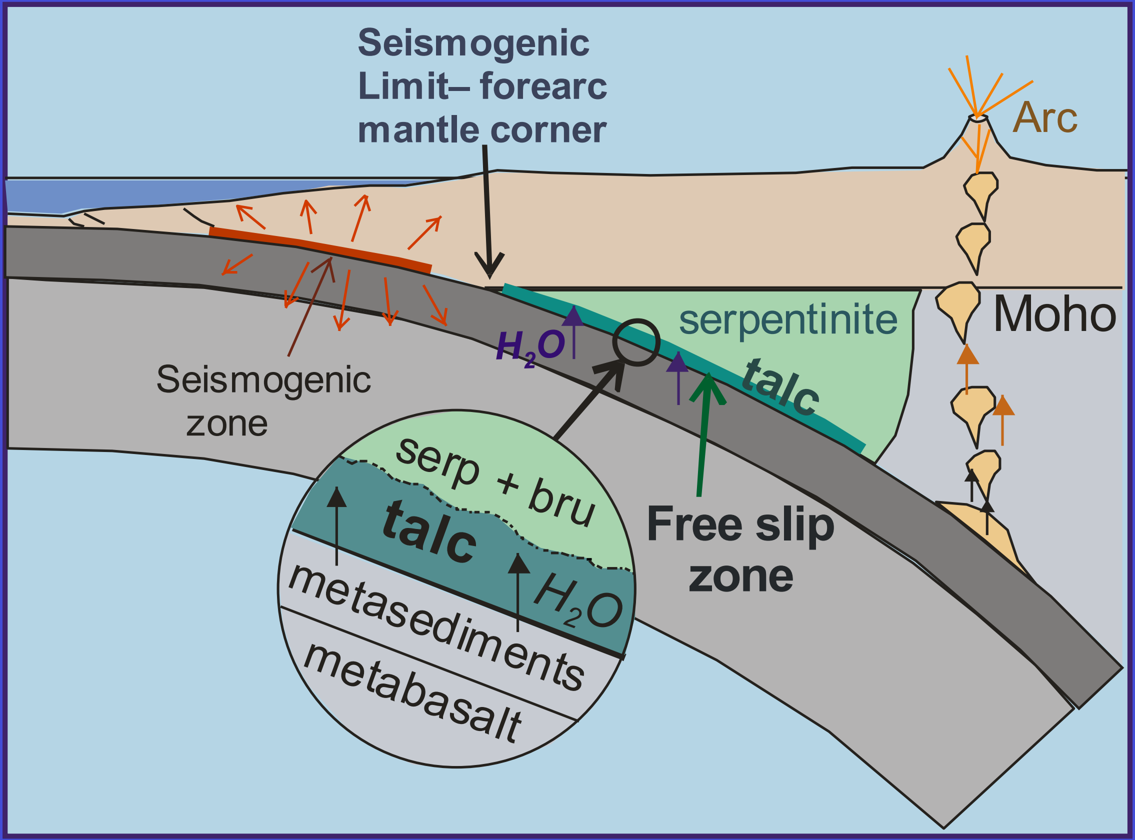
Hypothesis that downdip of forearc mantle corner, there is aseismic serpentinite and talc overlying the subducting crust. This limit fits many (cold) subduction zones ***(Hyndman et al., 1997).***

Cascadia limit is very likely thermal and further seaward.

This may be a firm limit for 1-2 m displacement because of fault properties

For most of margin forearc mantle corner is just landward of the coast

Moho corner not yet precisely defined (See McCrory plot)

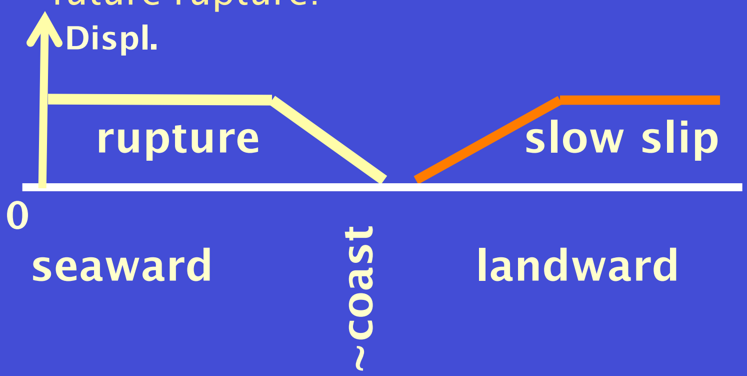


Peacock & Hyndman (1999)

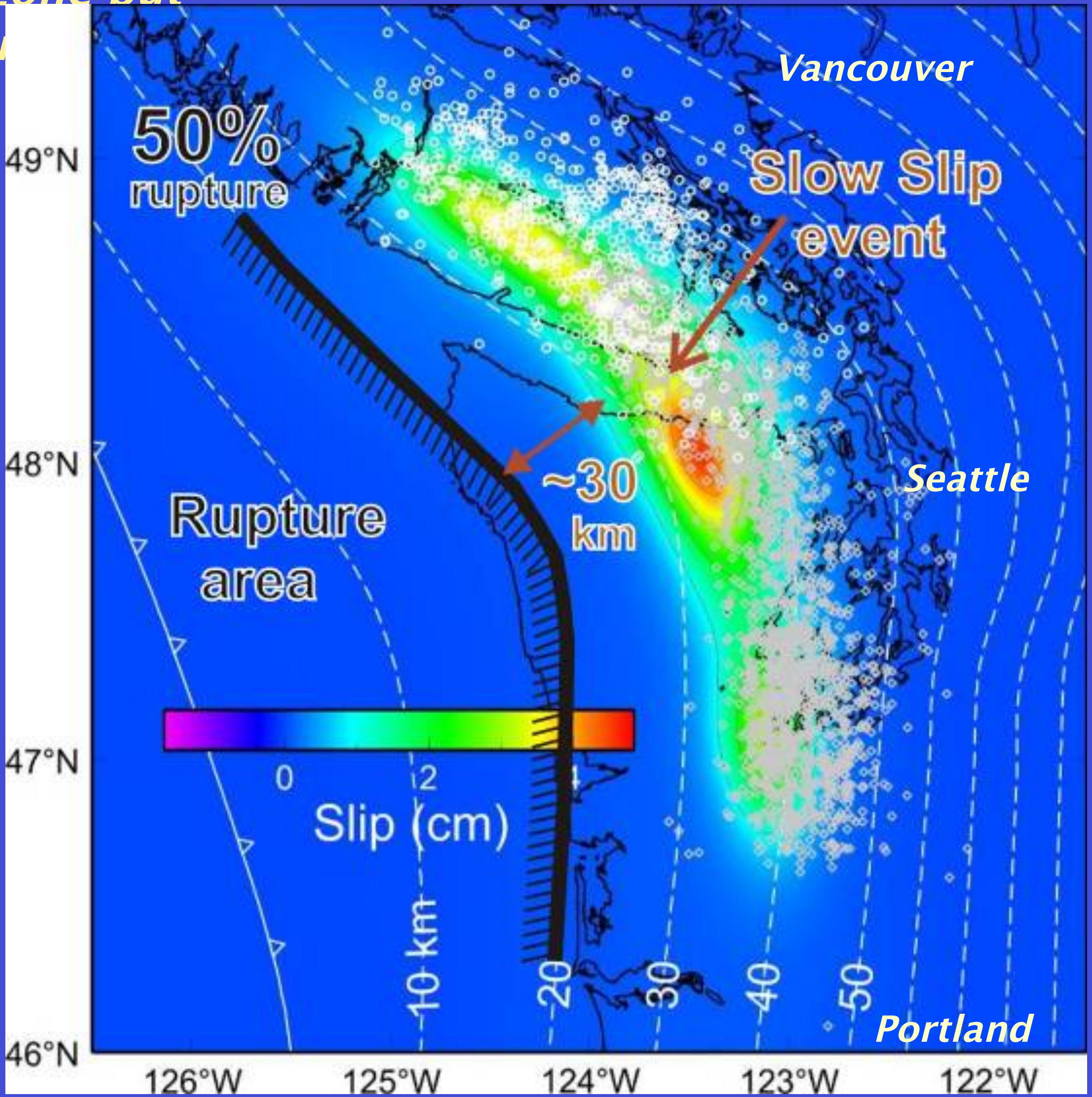
6. Updip limit of ETS slow slip

probably no rupture into ETS zone but rupture limit may be further u

–'most' of plate convergence accommodated by slow slip, so little elastic strain for future rupture?



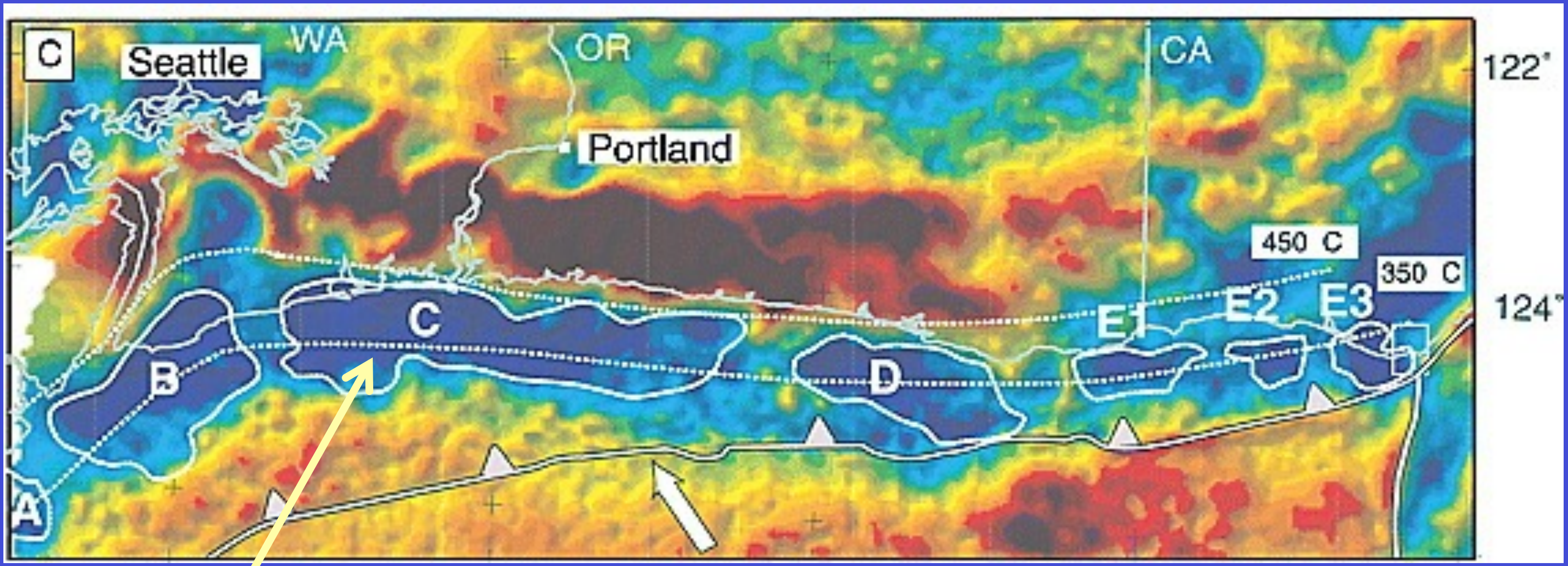
Note the gap between rupture and ETS for SW Japan 1944/46 events and vertically for San Andreas Fault



Slow slip contours (Wang)
Tremor (Kao and Wech)
(See also Wech et al., 2009; Chapman and Melbourne, 2009; McCaffery, 2009)

7. Rupture area may be defined by margin basins

as defined by gravity etc.; also may define segmentation (e.g., Wells et al., 2003; Fuller et al., 2008; Morgan et al., 2008...)



gravity defined basins

Wells et al., 2003

Summary Downdip rupture limit

50% (~10 m), 50-100 km seaward of major coastal cities; reasonably defined.

10% (~1.5 m) poorly defined, 10's km further landward

General Agreement

(1) Paleoseismic coastal subsidence: 50% is a few 10's km seaward of coast (except south and north Cascadia); 10% further landward but excludes significant rupture into ETS zone.

(2) Locked/transition zones from geodetic deformation, GPS: 50% is a few 10's km seaward of coast (near coast N. Wash. and landward N. Calif.). 1-2 m rupture extends further landward but requires very long tail to reach ETS zone or mantle corner.

(3) Thermal limit (350C full rupture 450C transition): 50%: mainly just seaward of coast. 1-2 m may be limited by 450C; increase in instantaneous shear strength.

(4) Change in thrust seismic reflection character: just seaward of coast for S. Vancouver Island but still needs calibration.

(7) Margin basins: just seaward of coast may define rupture area as for other subd. zones

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Further landward (but do not exclude shallower limit)

(5) Forearc mantle corner limit: mostly just landward of coast, but actual limit may be thermal further seaward. This corner may be a firm 1-2 m limit because of thrust properties.

(6) ETS slow slip limit: mainly just landward of the coast, but evidence that actual limit is further seaward with a gap between ETS and rupture (as in SW Japan and San Andreas).

Some other factors and issues

(1) How are ground motion vs distance from fault relations determined? aftershock distribution? Rupture models? must match landward limit defined in our models

(2) Appropriate landward limit for estimating significant ground motion? What is "significant rupture displacement" for ground motion? 10%, 20%, 1-2 m?
Are thermal (~450C) and the forearc Moho firm zero-rupture limits to any rupture?

(3) Coastal subsidence- (a) What is the relation between the marsh subsidence i.e., months to years, (including afterslip and relaxation) and fault coseismic displacement, (b) is variability of co-seismic subsidence mainly related to interseismic strain buildup time, not to variability in landward limit?

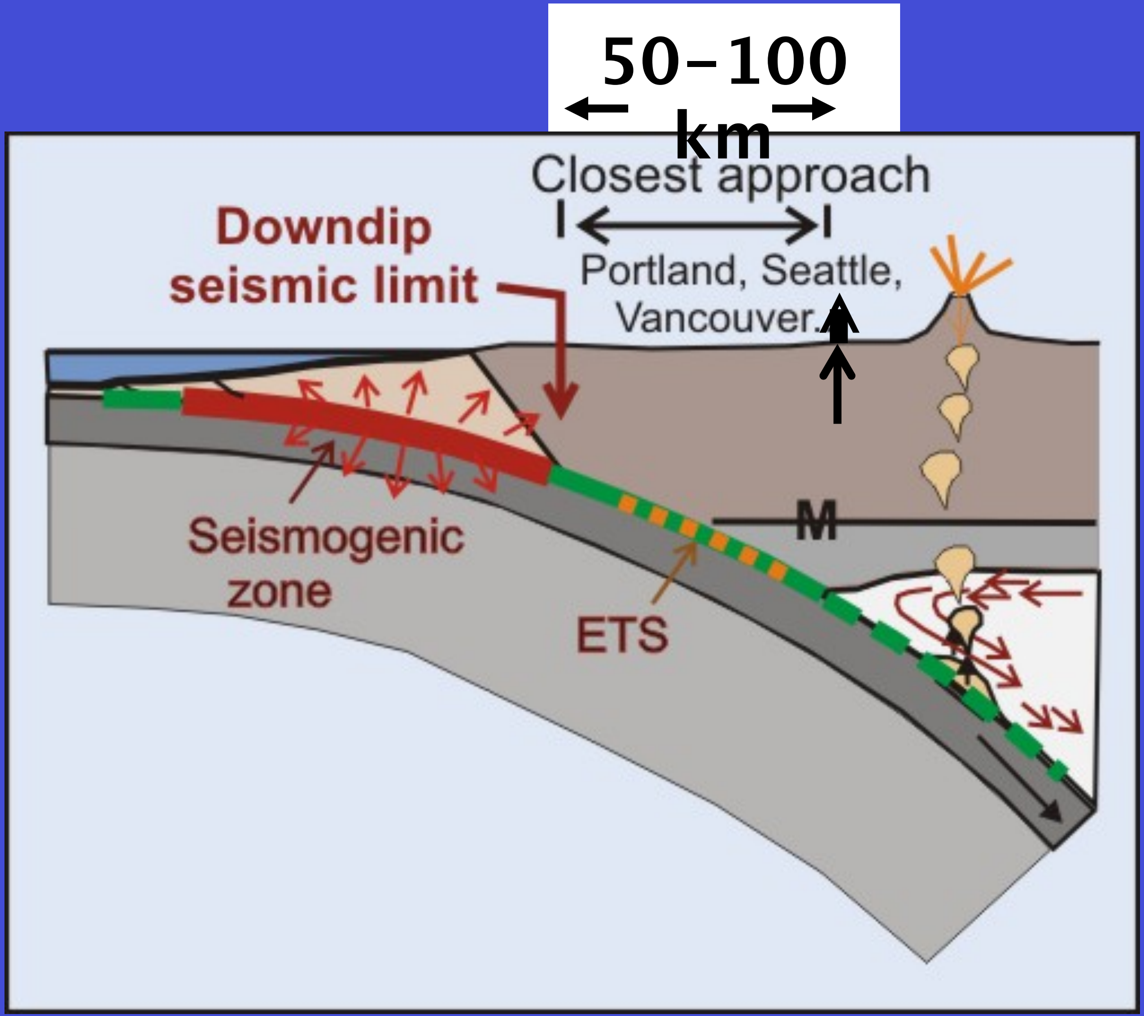
(4) Question of relation between geodetically estimated "locked/transition" zones and co-seismic rupture area (that produces significant ground motion)?

(5) Relation between updip limit of ETS slow slip (and tremor) and downdip limit of important coseismic displacement? Is there a gap or offset? as indicated for SW Japan and San Andreas. How is plate convergence accommodated in the gap?

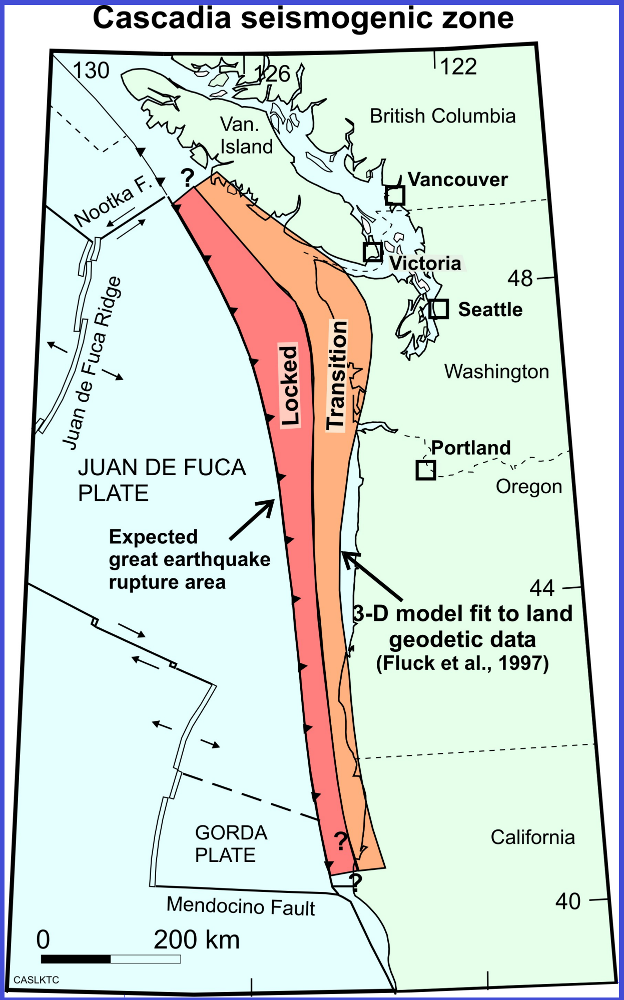
(6) How are geological features, margin basins etc. related to rupture area? Why?

(7) Comparisons with recent great earthquakes elsewhere; testing of methods

Thank you



50–100
km
Closest approach
Portland, Seattle,
Vancouver
Downdip
seismic limit
Seismogenic
zone
ETS
M



Cascadia seismogenic zone
130
126
122
British Columbia
Van.
Island
Vancouver
Victoria
Seattle
48
Nootka F.
Juan de Fuca Ridge
Locked
Transition
Washington
Portland
Oregon
JUAN DE FUCA
PLATE
Expected
great earthquake
rupture area
44
3-D model fit to land
geodetic data
(Fluck et al., 1997)
GORDA
PLATE
California
Mendocino Fault
40
0
200 km
CASLKTC