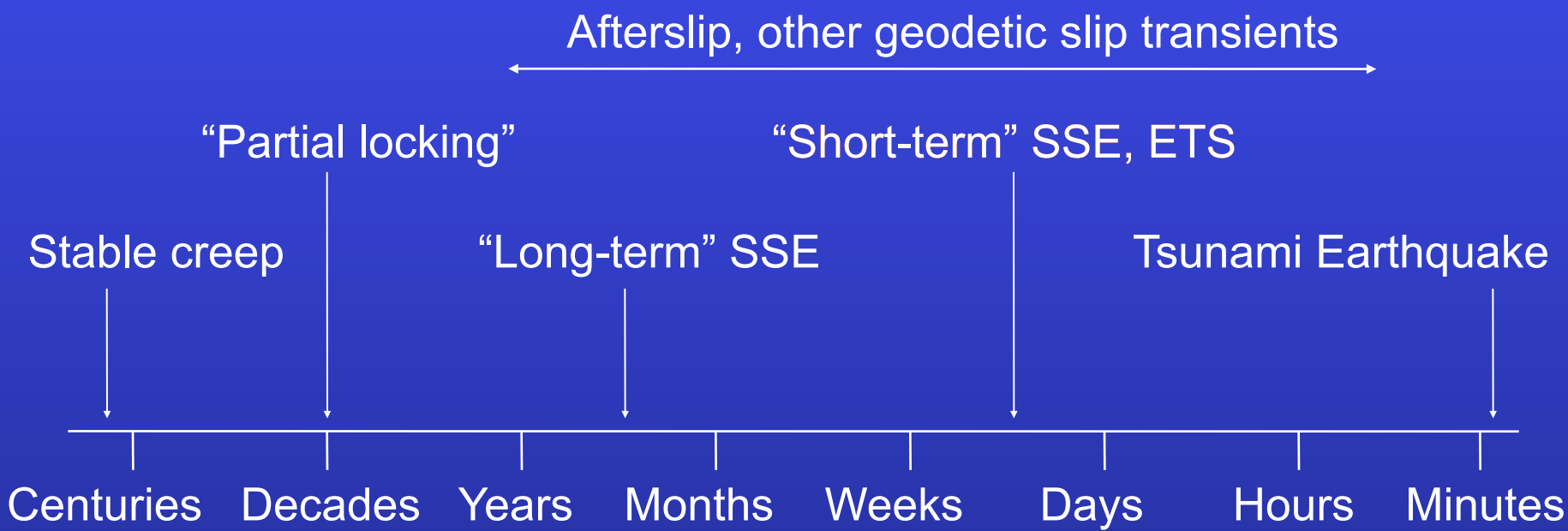
Investigating Thermo-Tectonic Conditions for ETS and Similar Events

Kelin Wang and Herb Dragert

Pacific Geoscience Centre, Geological Survey of Canada

Spectrum of Fault Slip Behaviours



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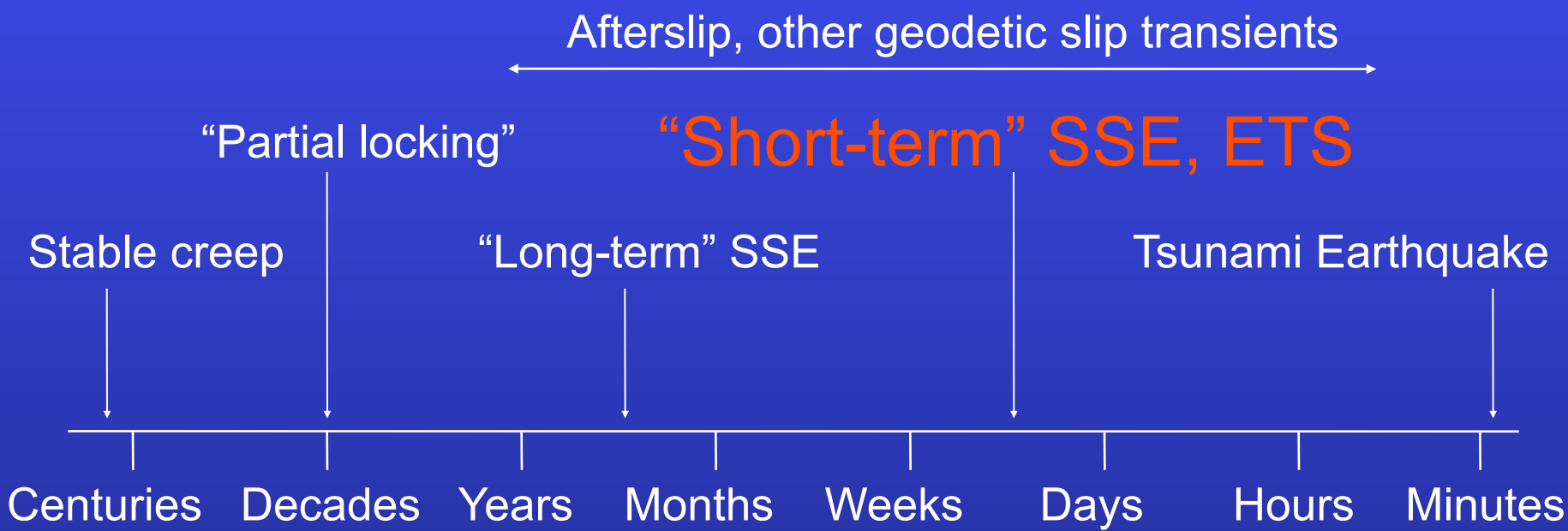
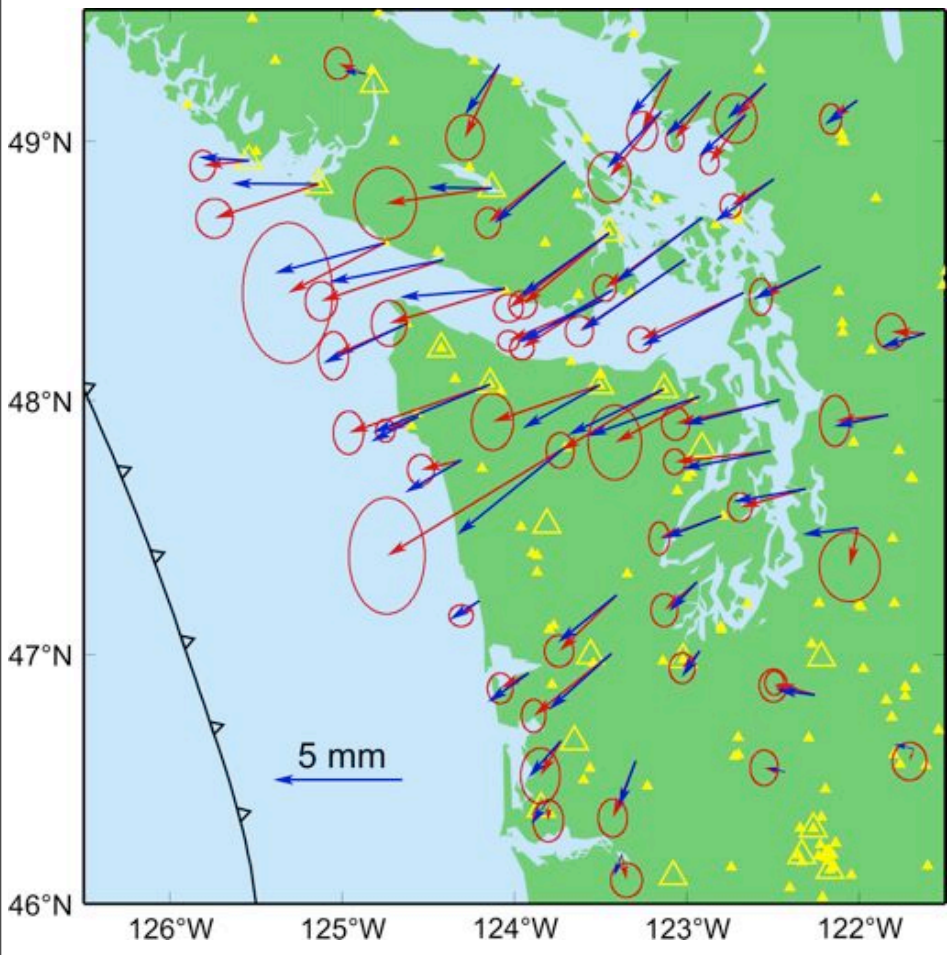
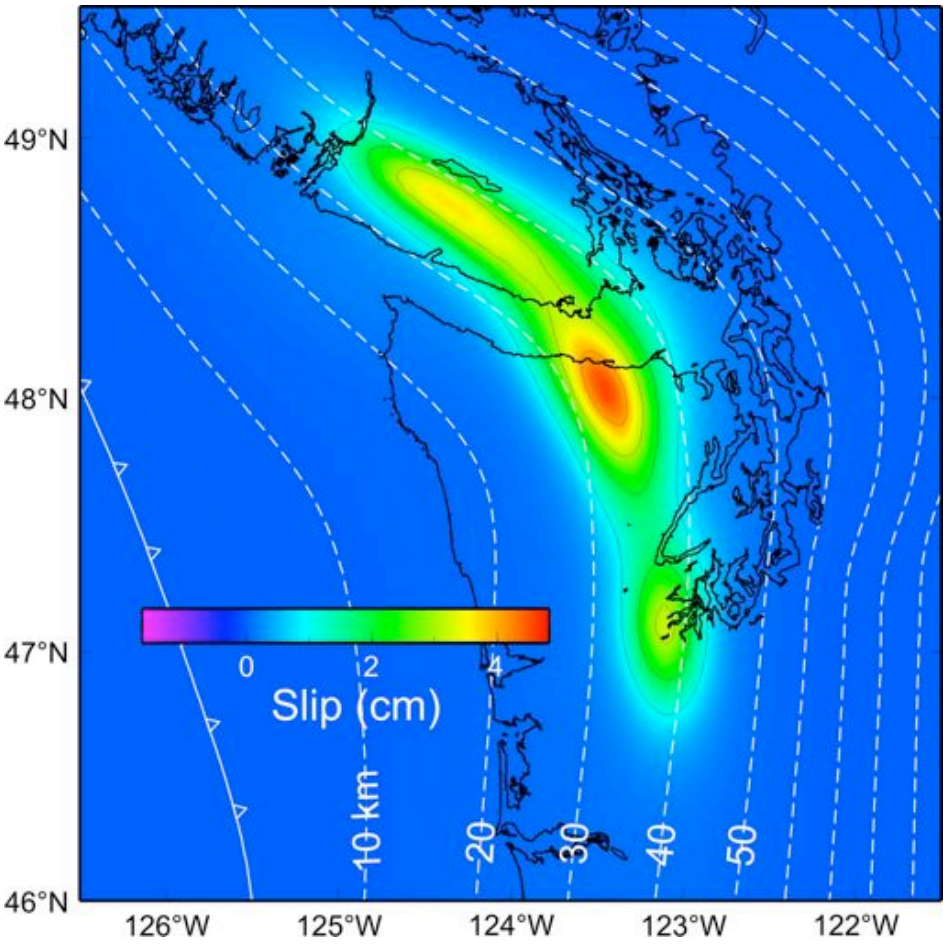


Northern Cascadia ETS event of May 2008





Nonlinear inversion of three GPS components; slip distribution assigned Gaussian auto-correlation with correlation scales 50 km in strike and 25 in dip.

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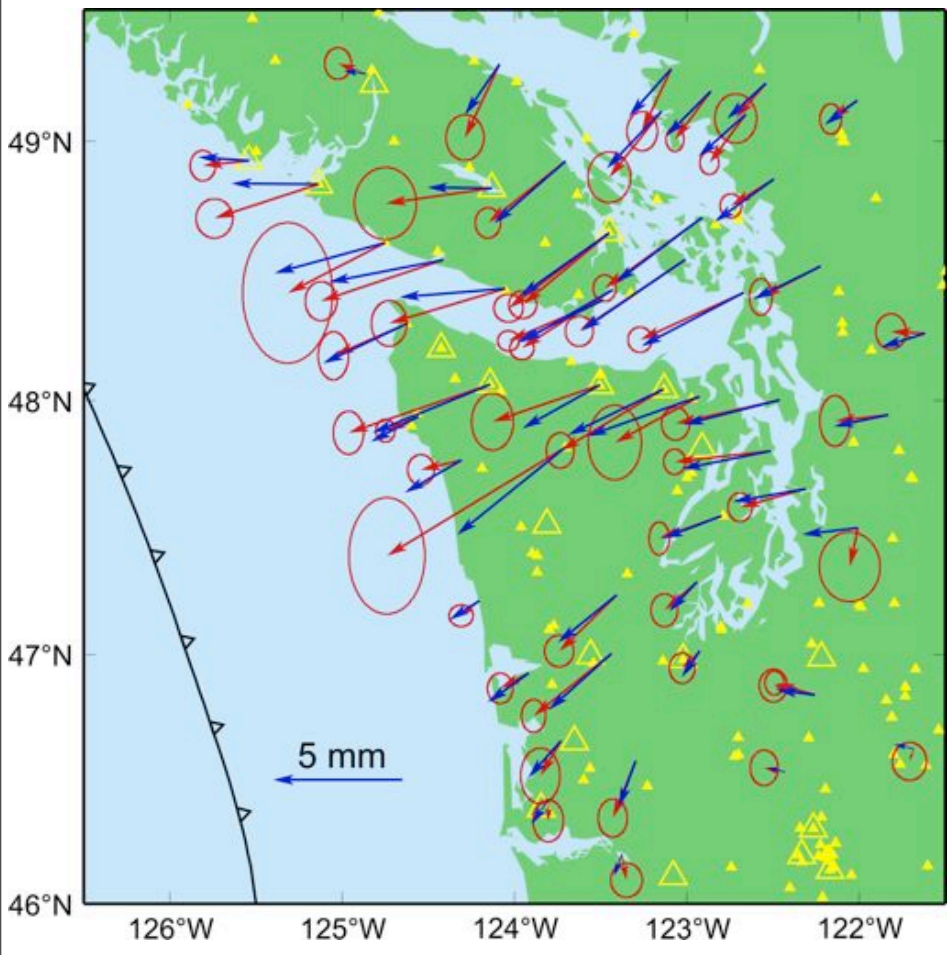

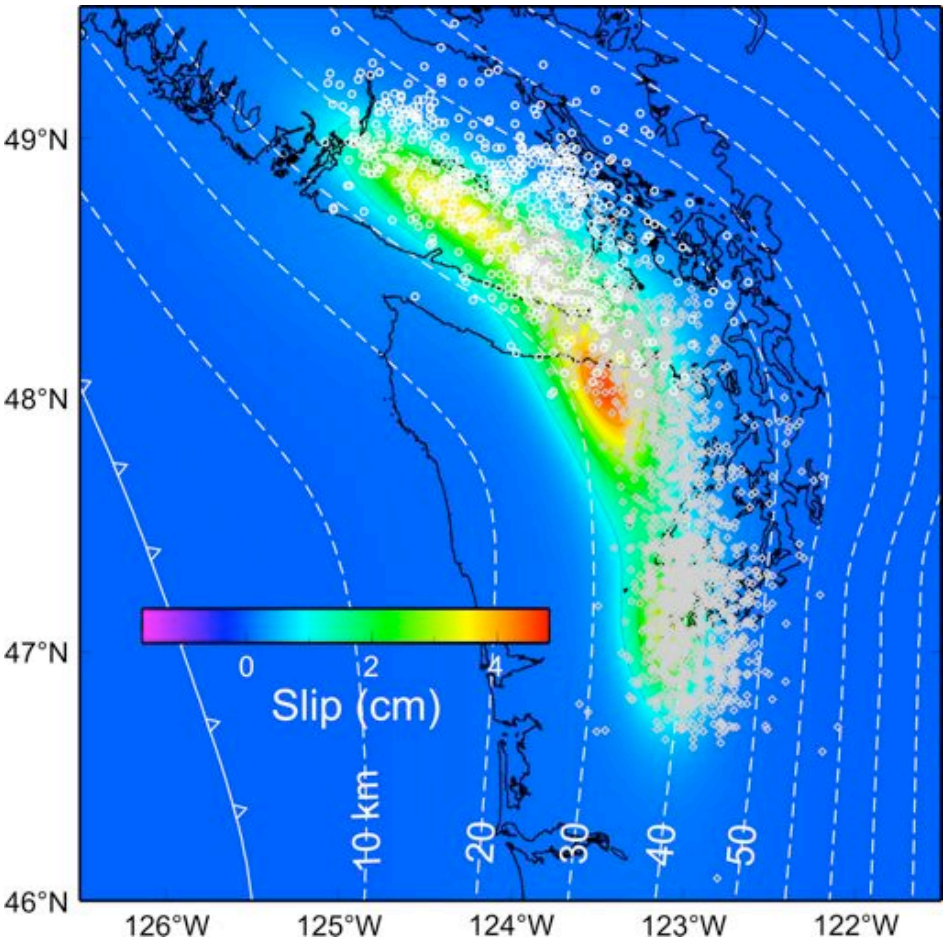

Tremor located by Kao (white) and Wech (gray)

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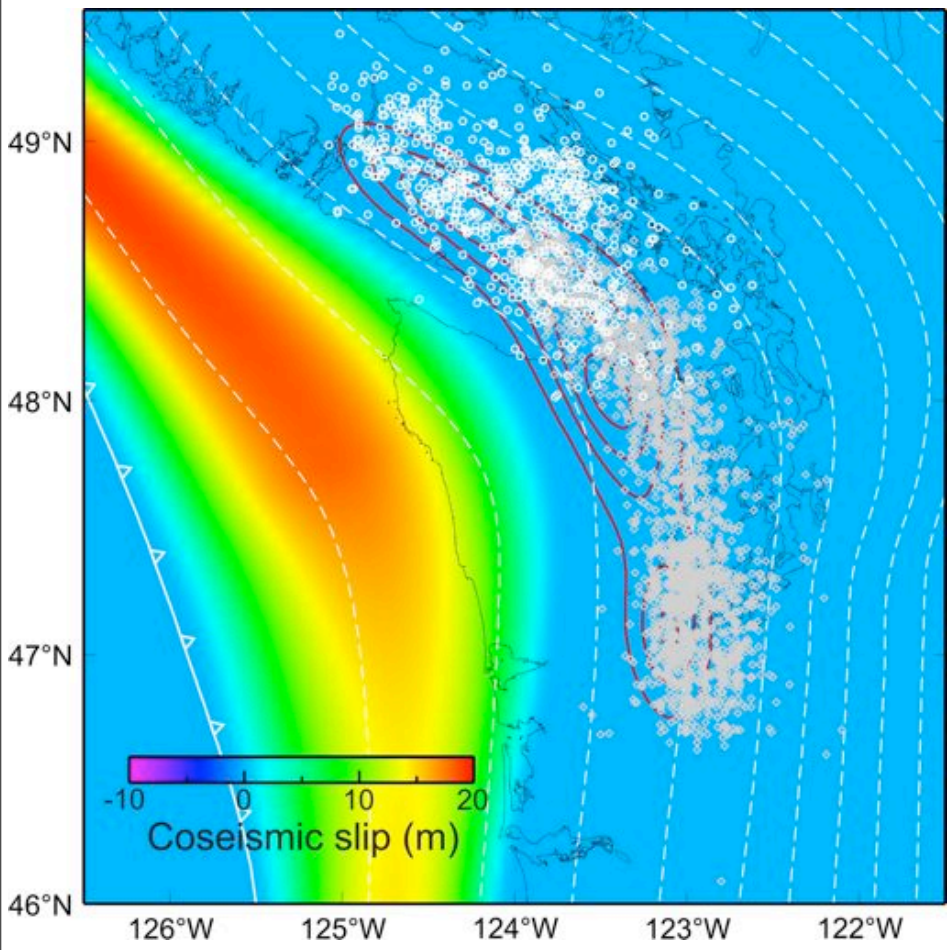
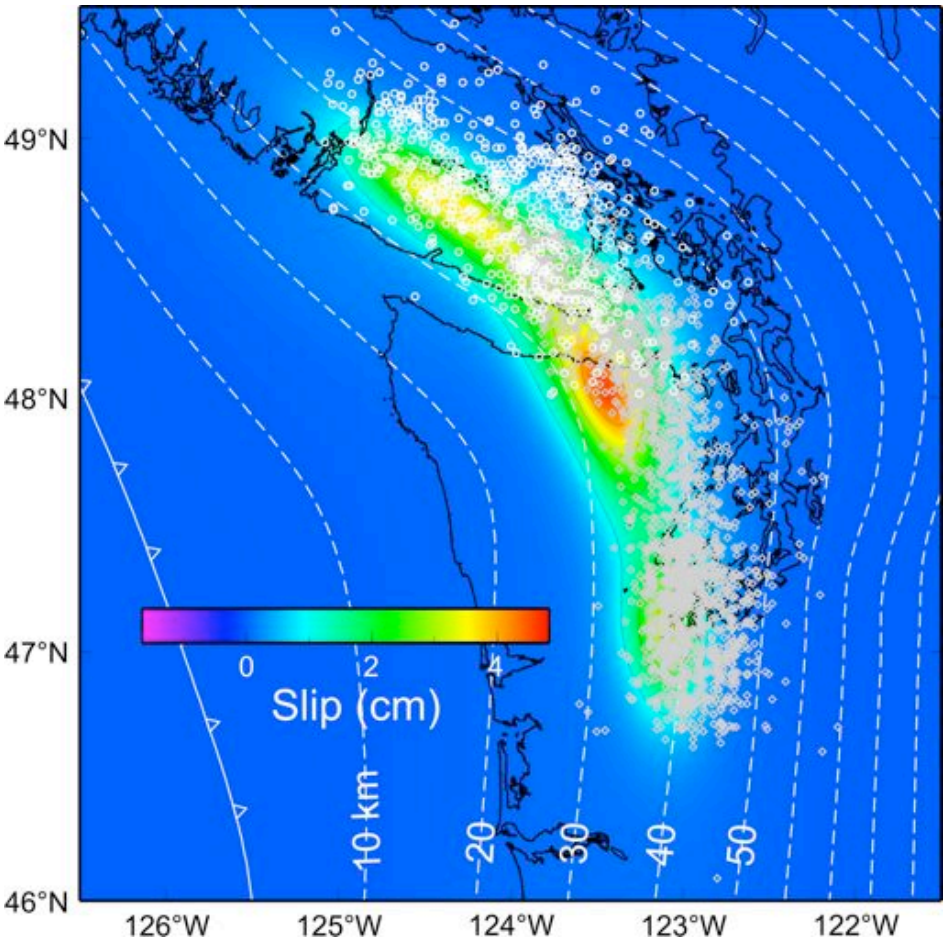


Comparison with a worst-case scenario of megathrust rupture



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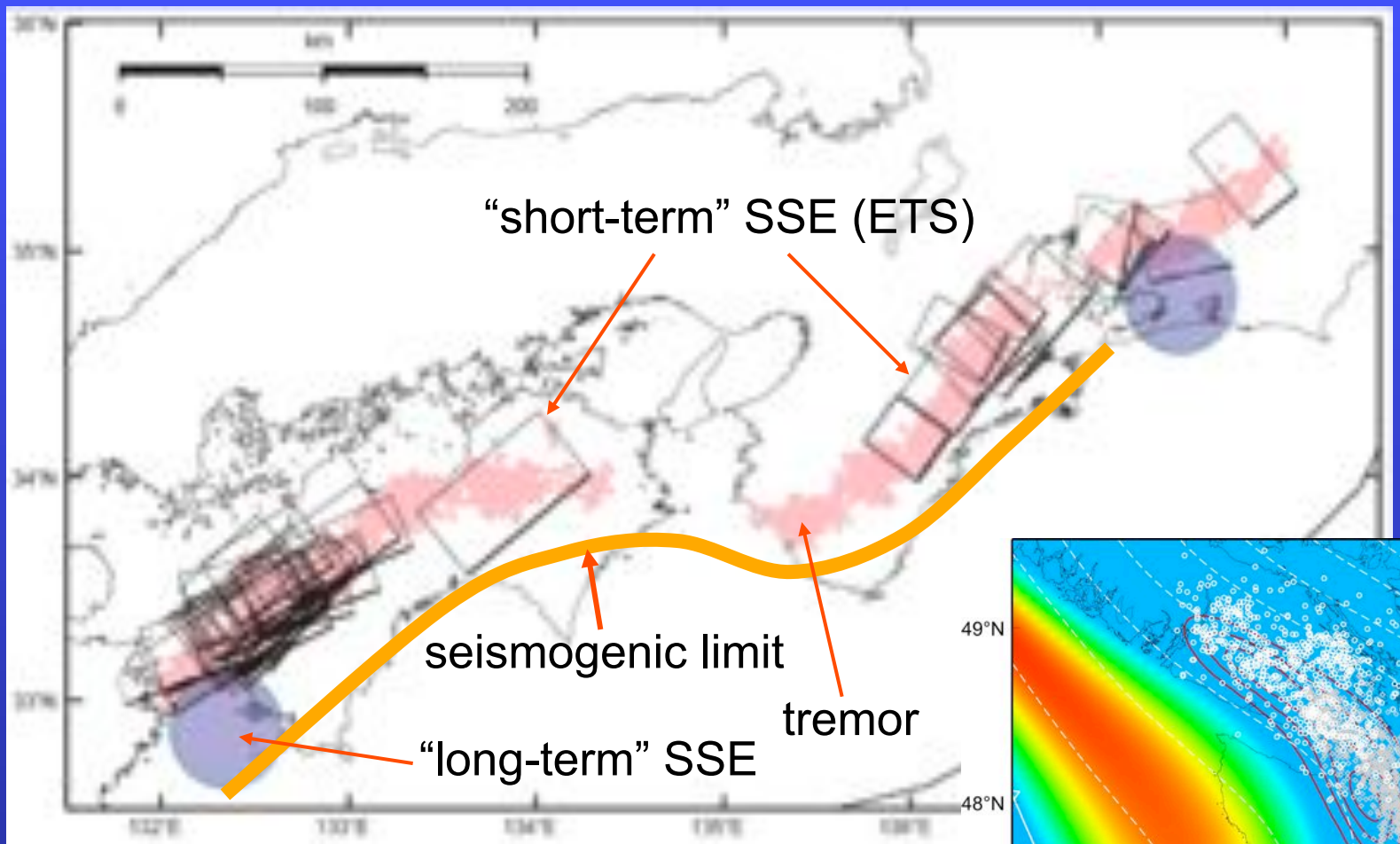
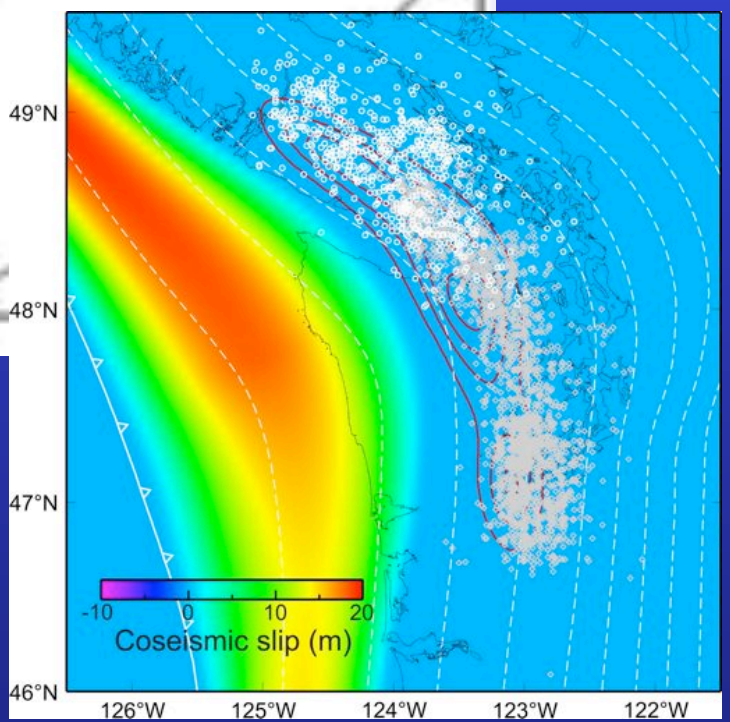
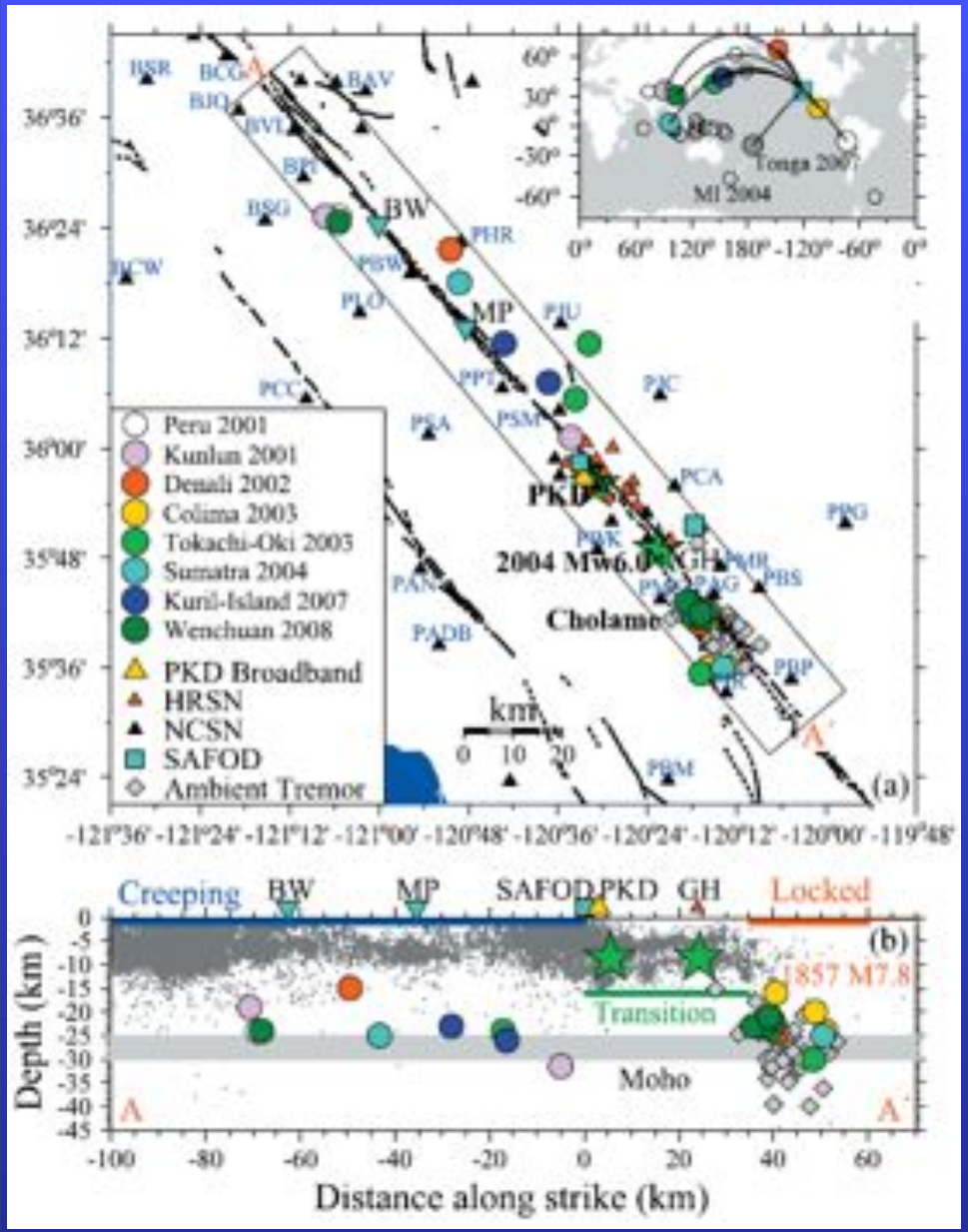
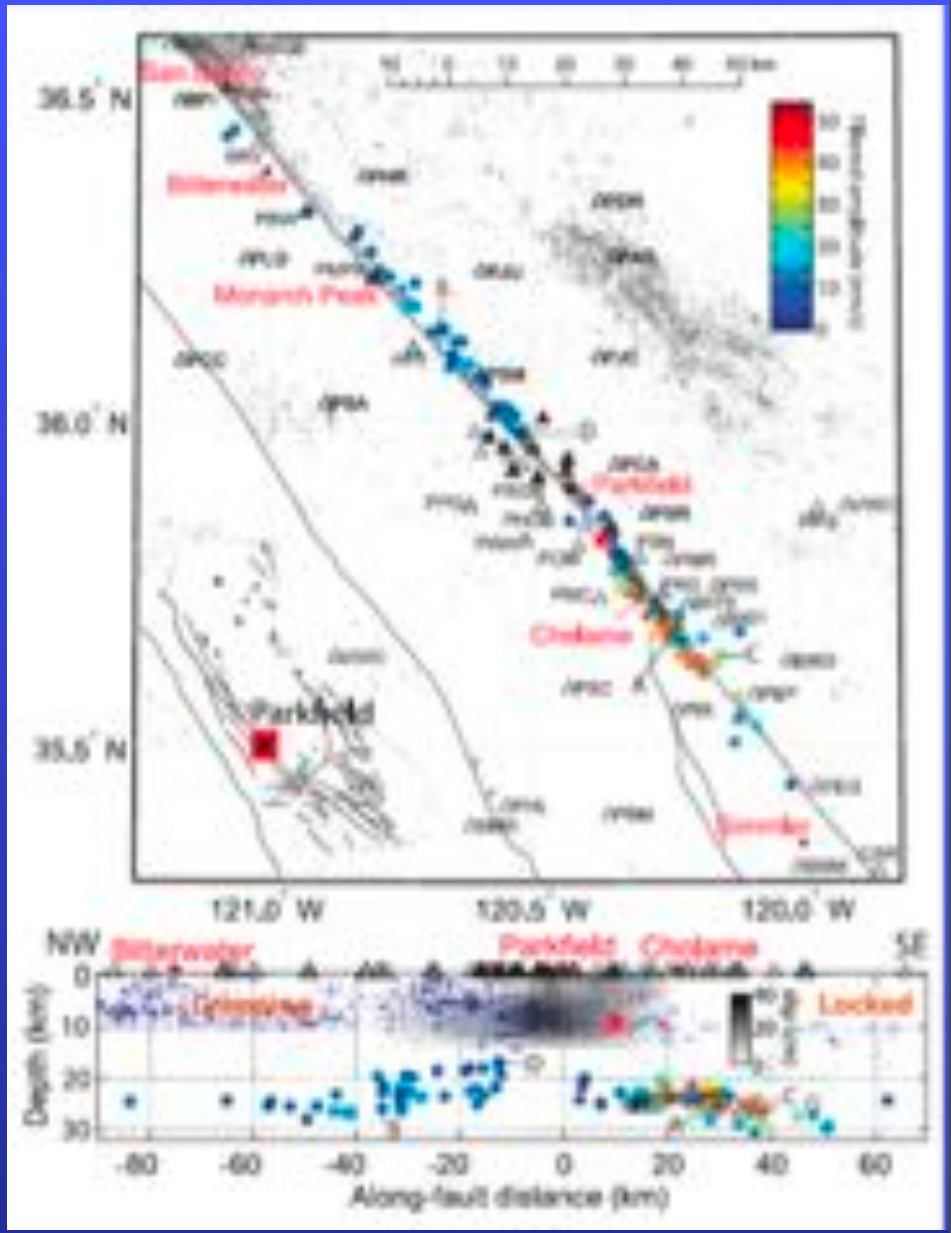




Modified from Sekine et al., 2010

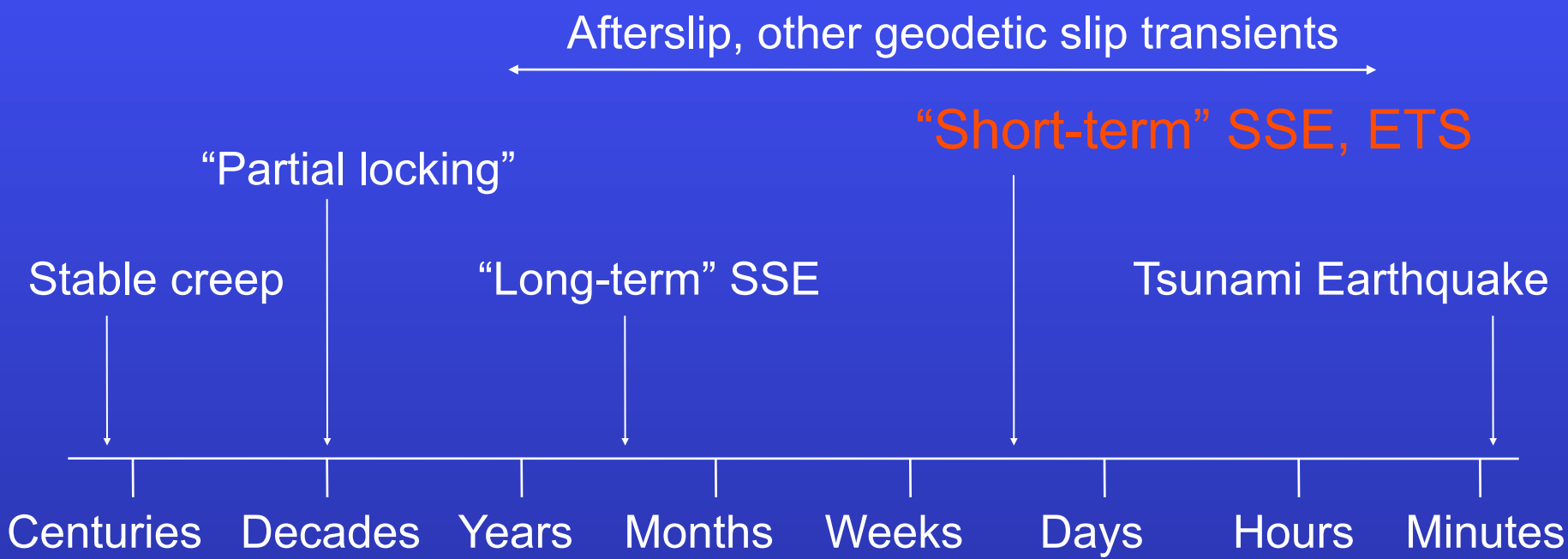


Peng et al., 2010



Shelly and Hardebeck, 2010

Spectrum of Fault Slip Behaviours



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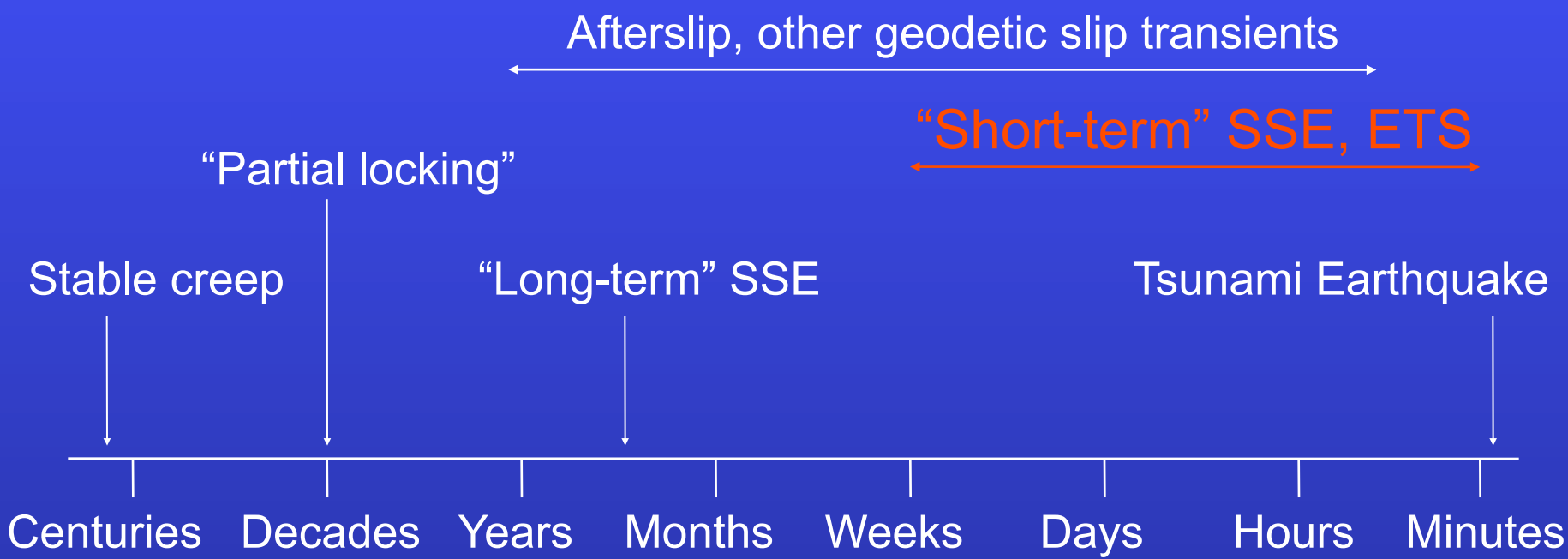

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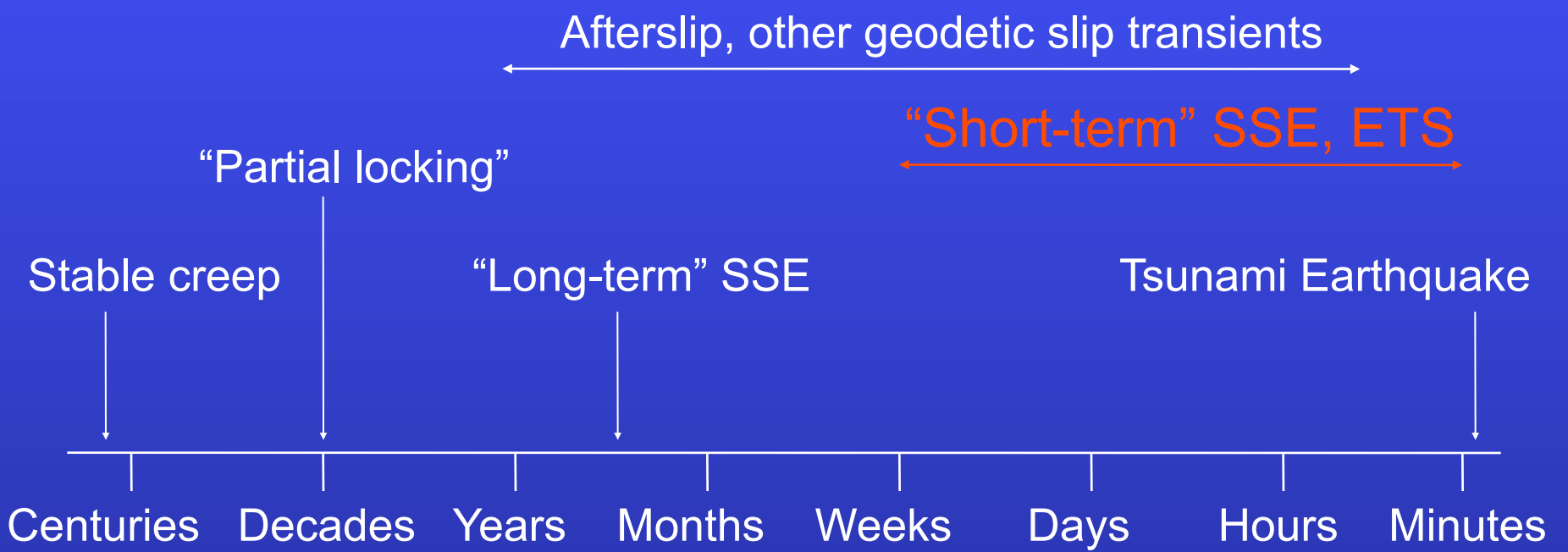
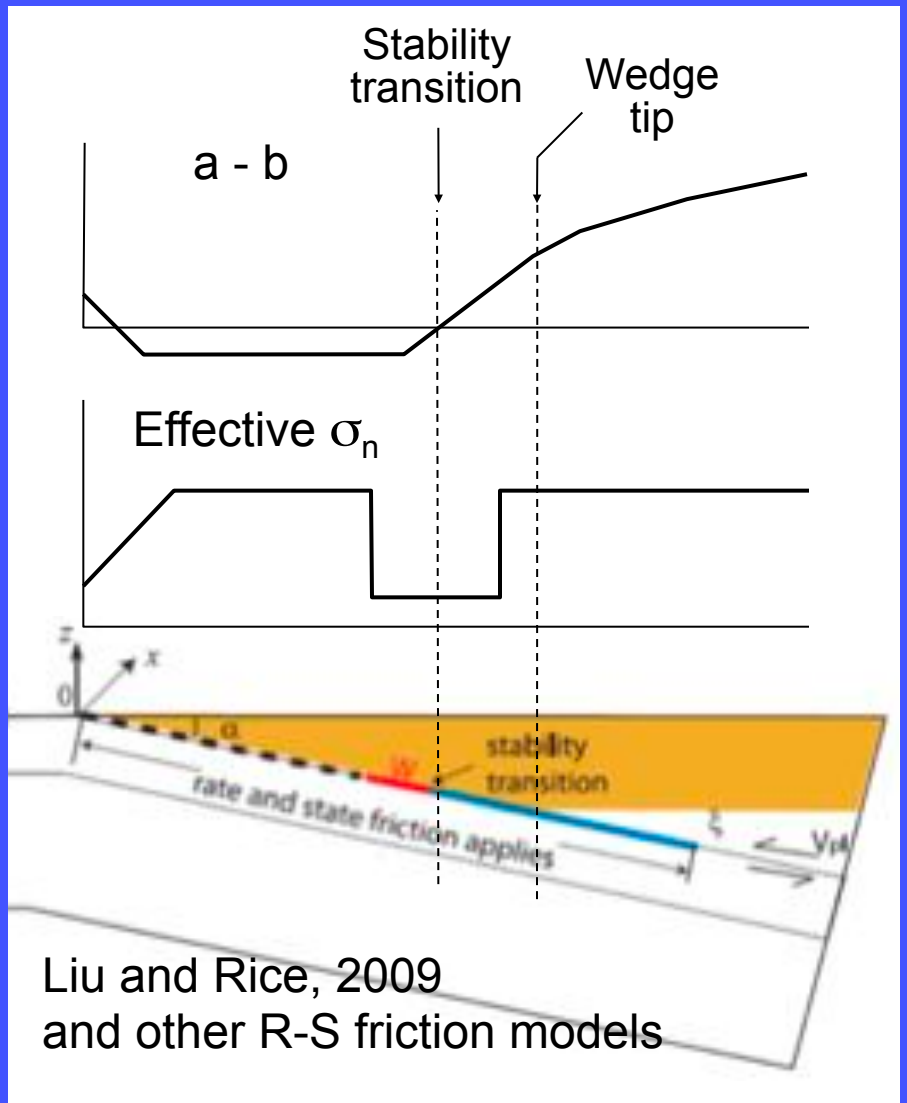


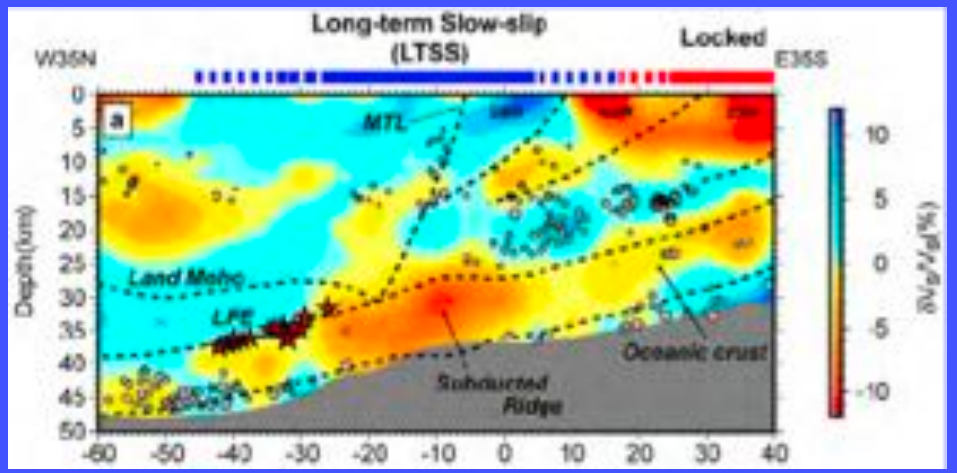
- Slip accompanied by tremor (ETS) is a subset of SSEs and requires specific conditions.
- Most ETS appears to be associated more with the continental Moho than with the seismogenic limit.

No relation with wedge tip



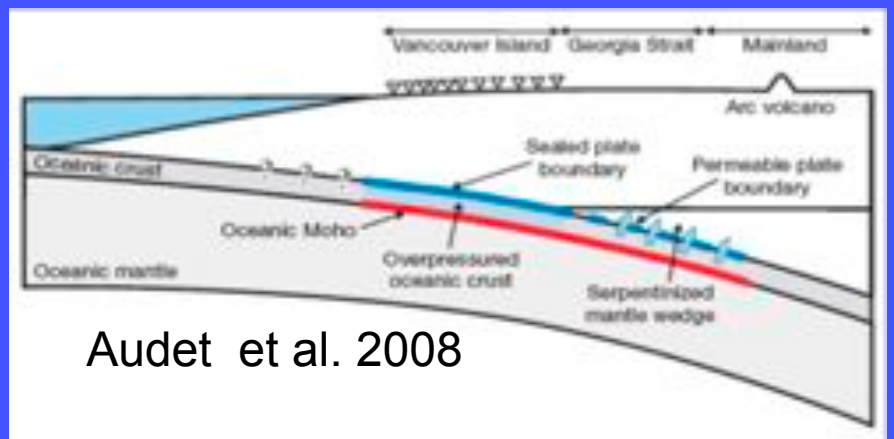
Liu and Rice, 2009
and other R-S friction models

Landward of wedge tip



Kato et al., 2010

Seaward of wedge tip



Audet et al. 2008

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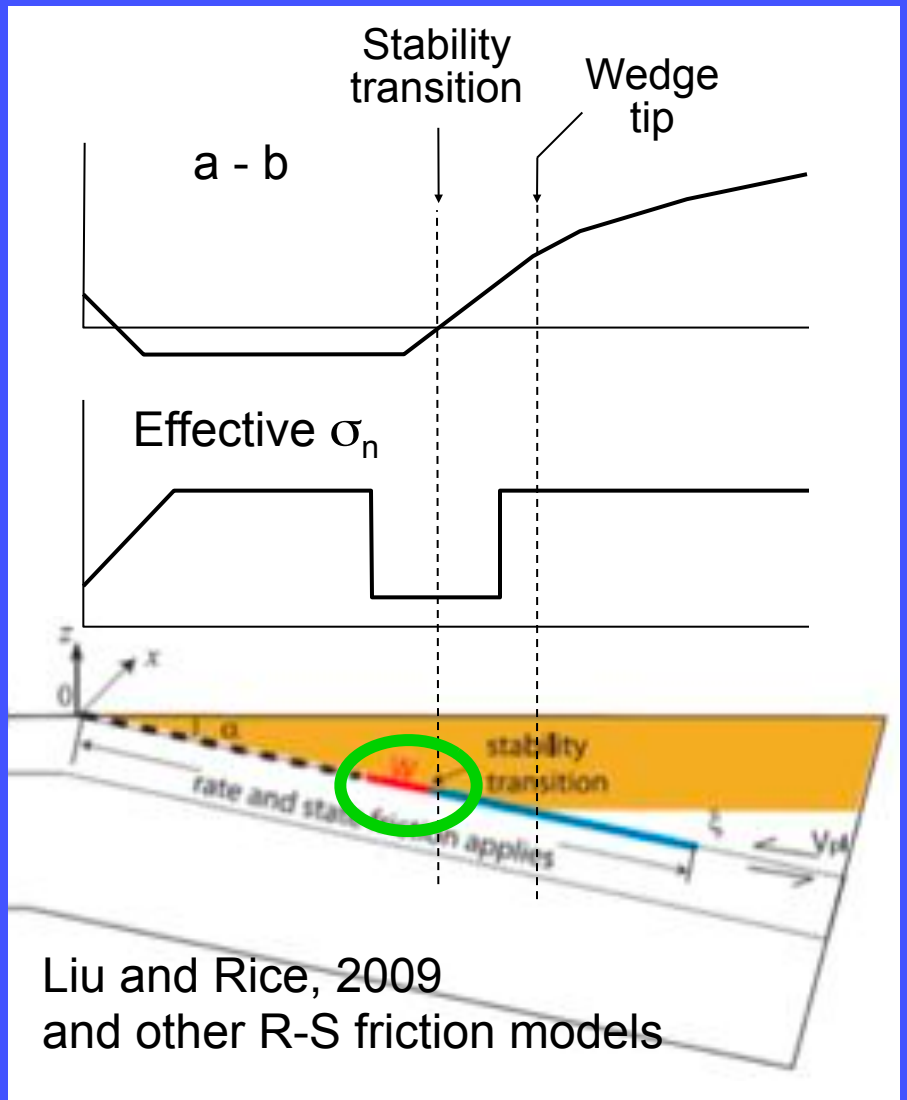

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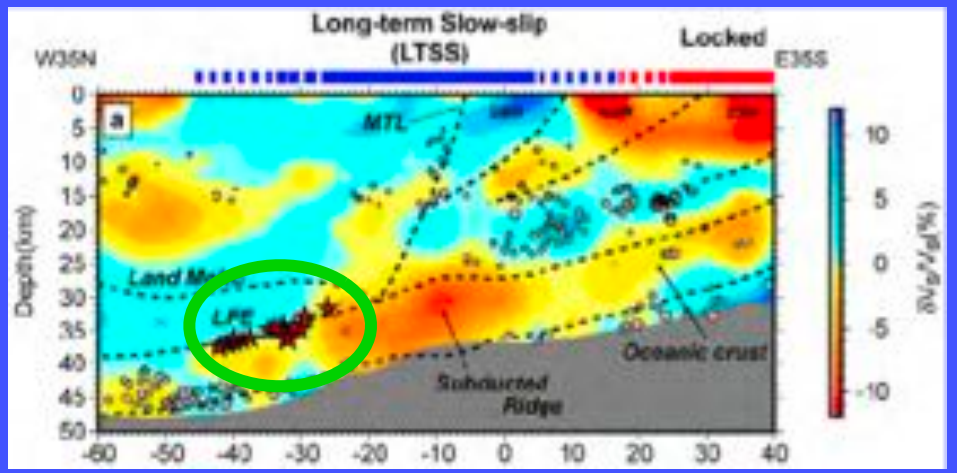

Kato et al., 2010

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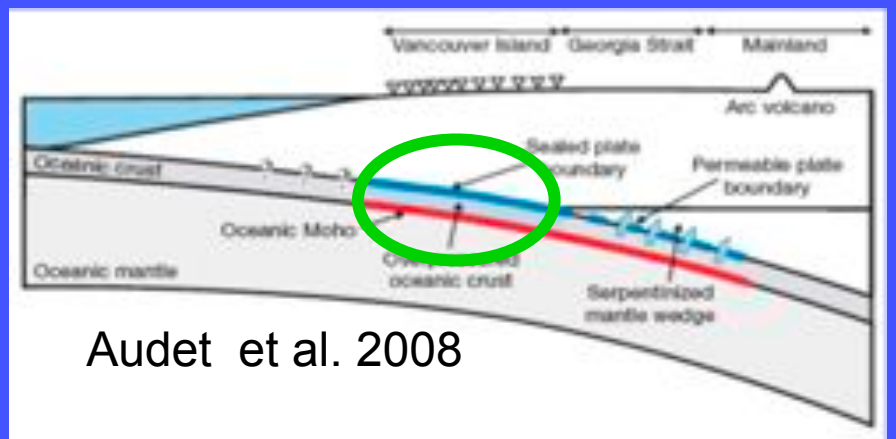

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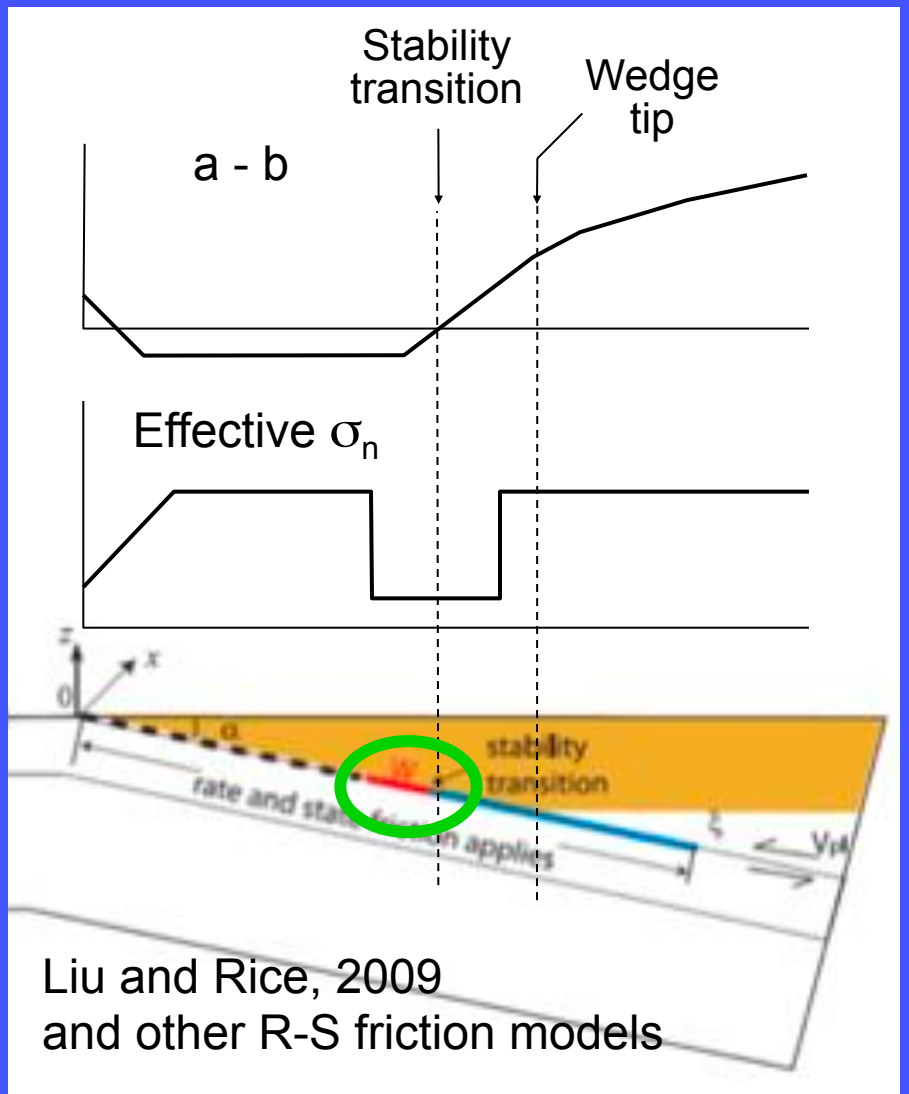

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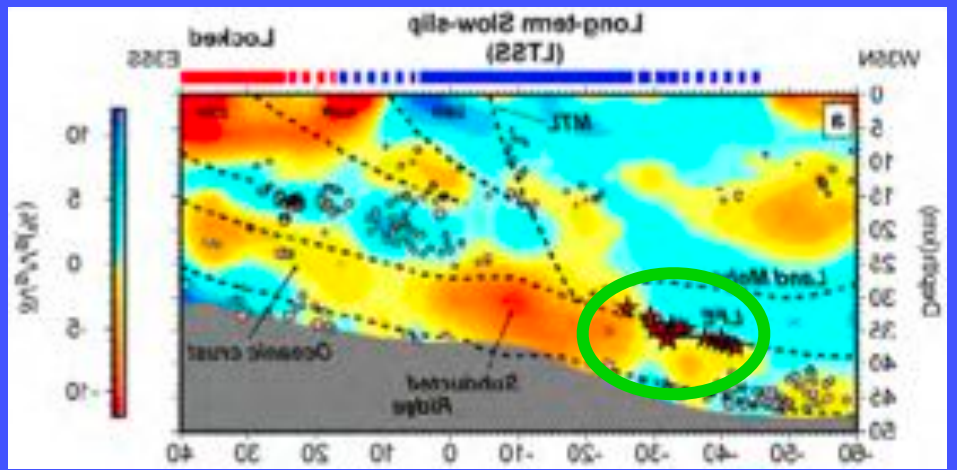

Kato et al., 2010

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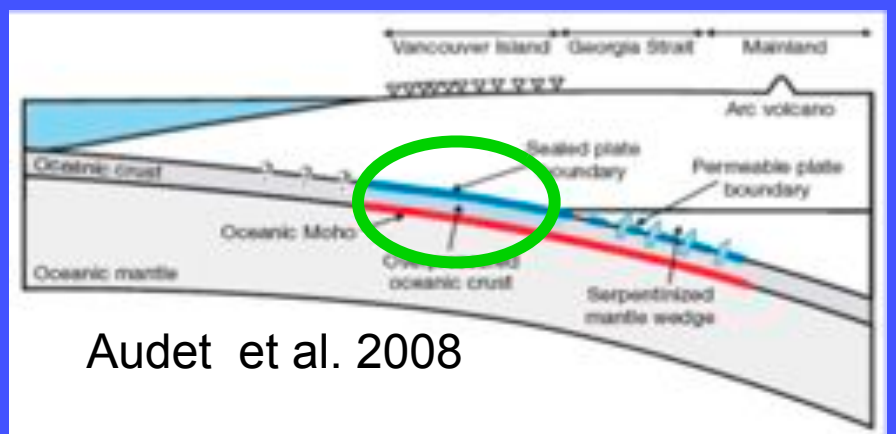
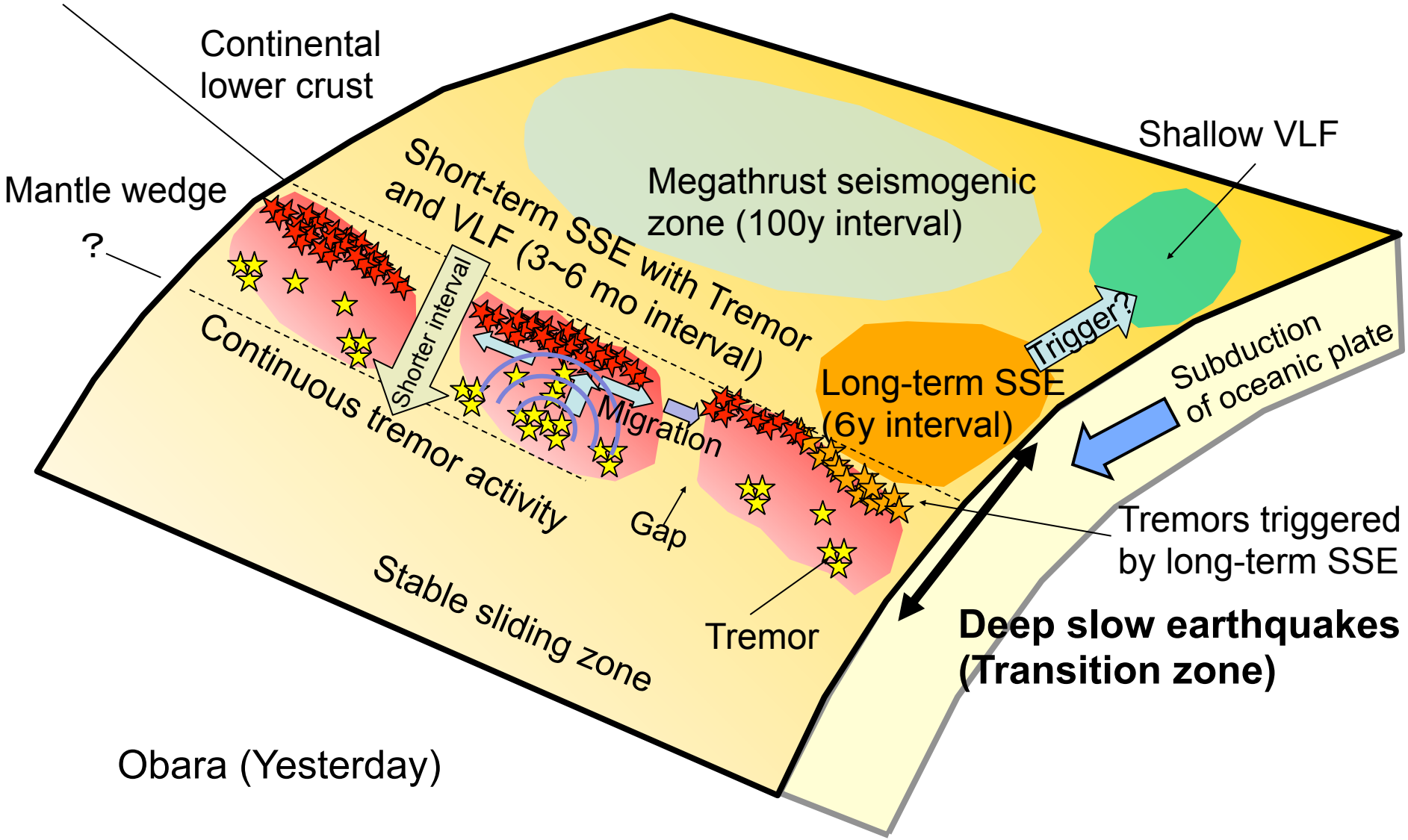
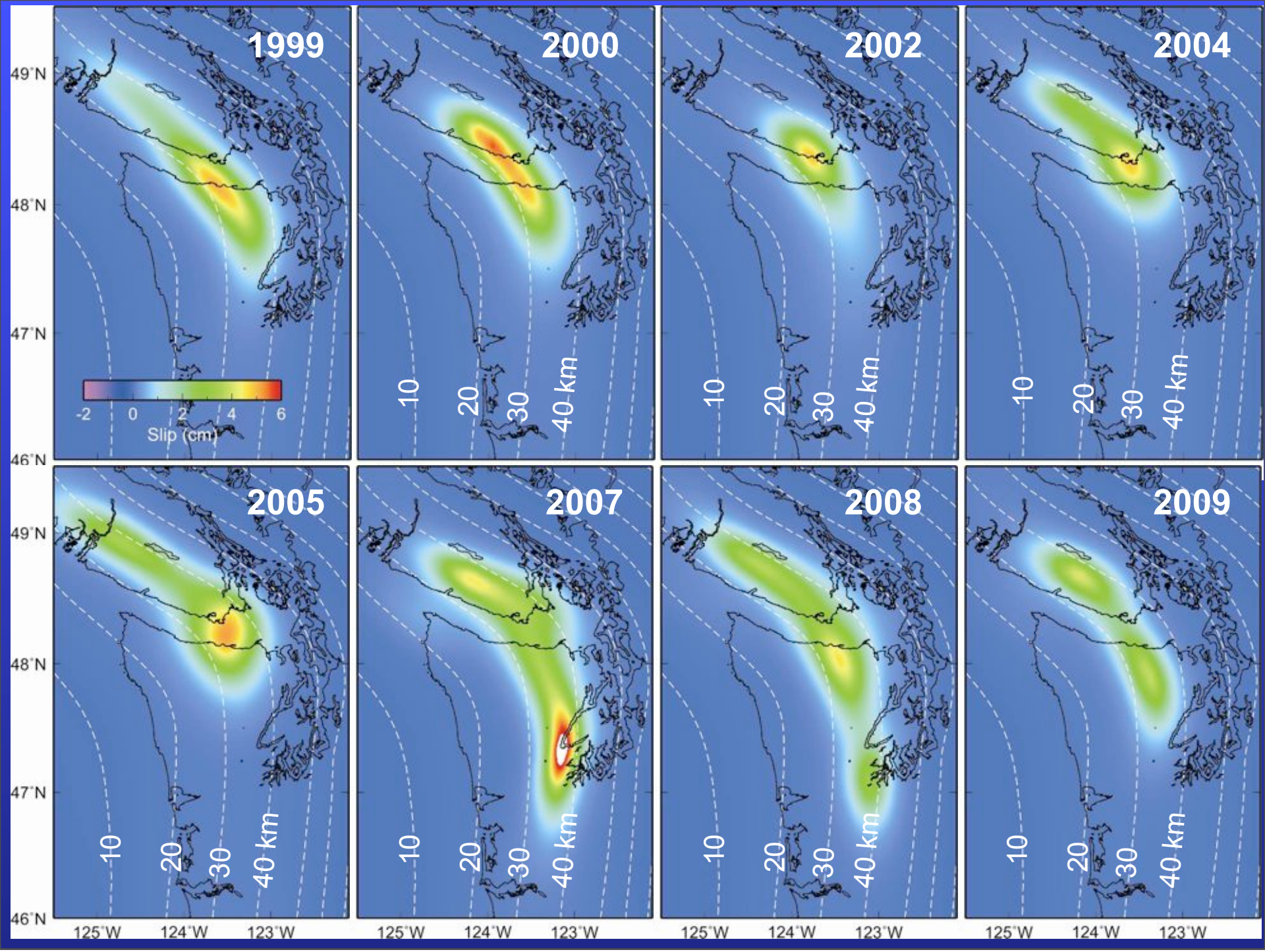
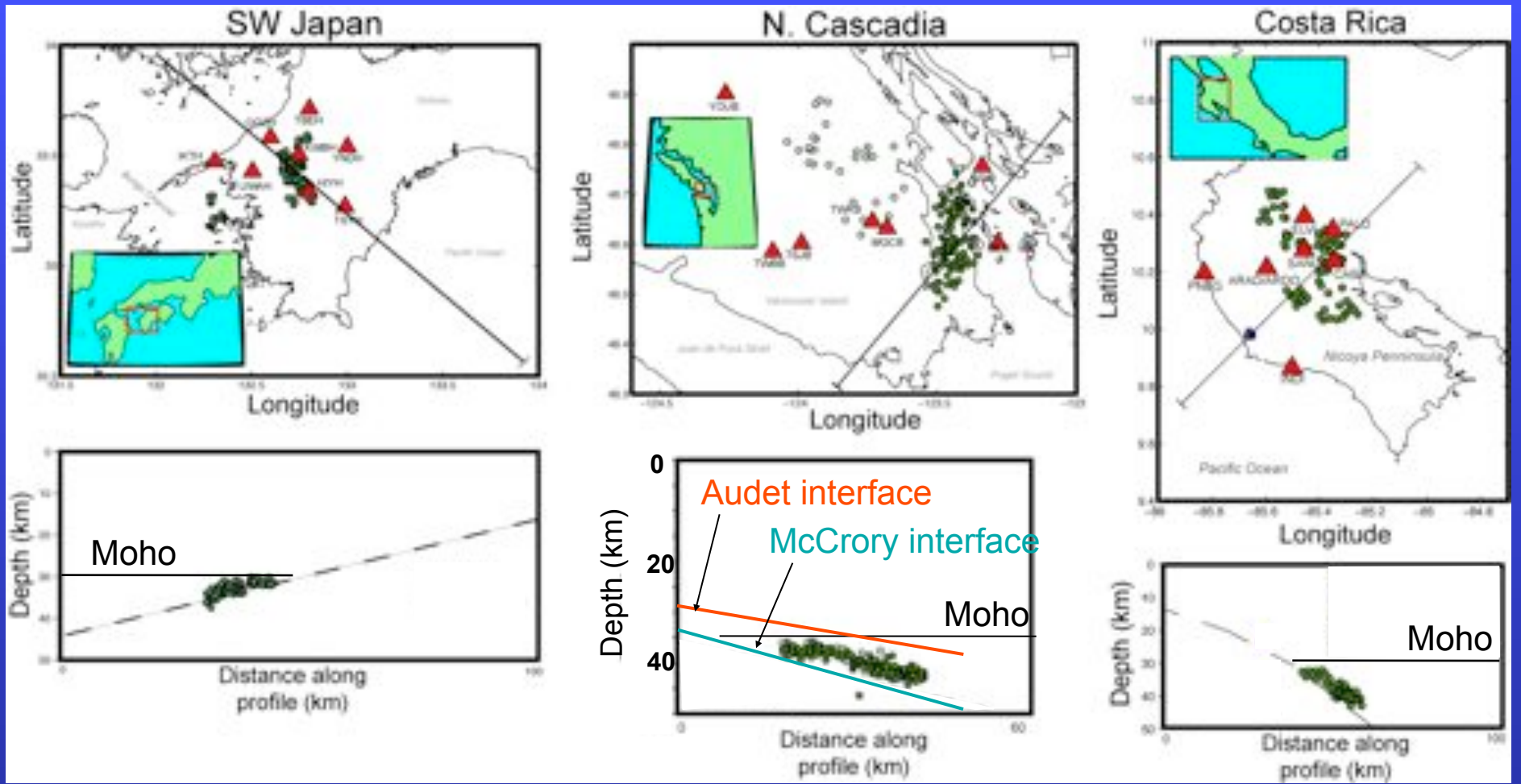


Audet et al. 2008

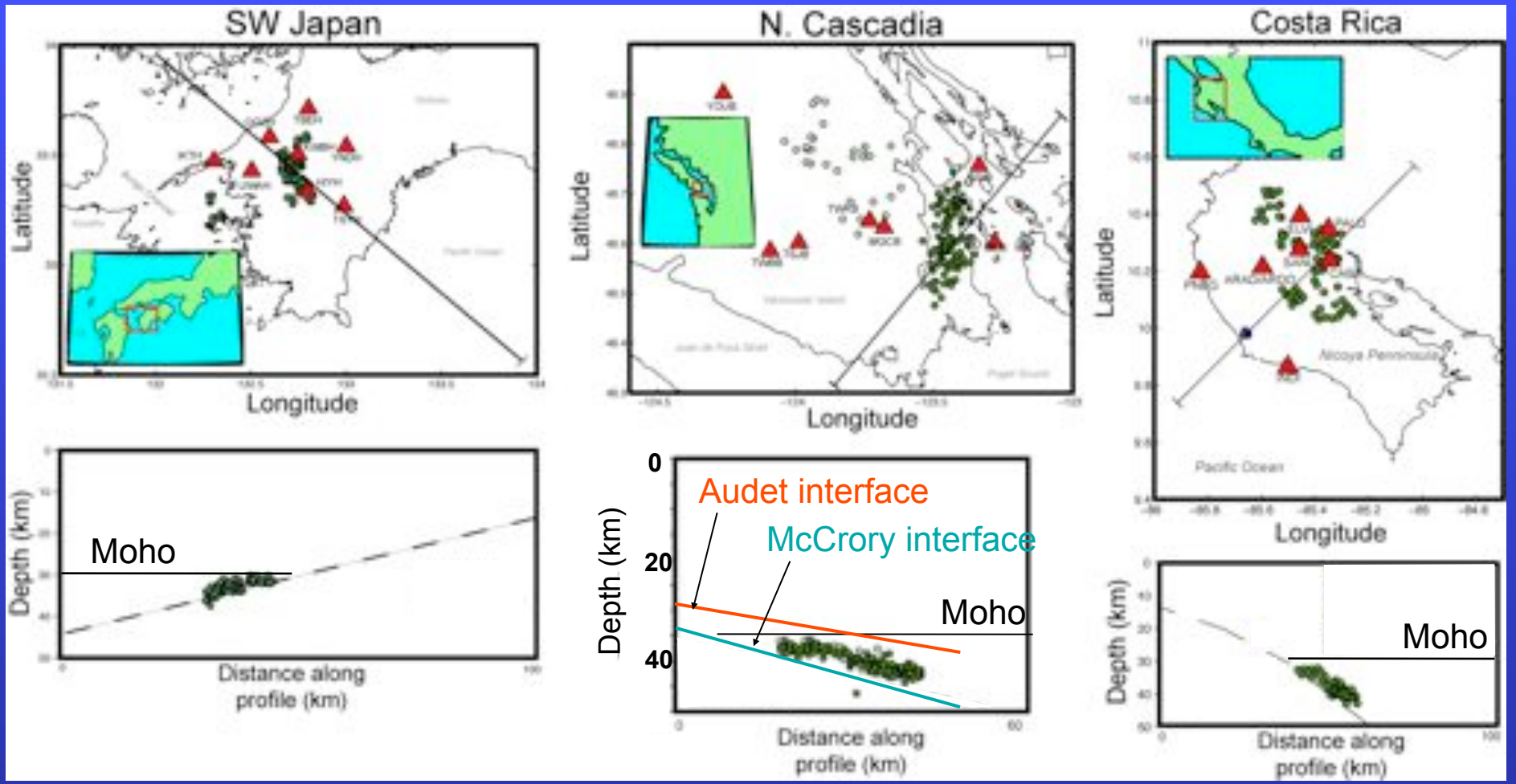

Continental lower crust
Mantle wedge
?
Short-term SSE with Tremor and VLF (3~6 mo interval)
Megathrust seismogenic zone (100y interval)
Shallow VLF
Shorter interval
Continuous tremor activity
Migration
Gap
Trigger?
Long-term SSE (6y interval)
Subduction of oceanic plate
Tremors triggered by long-term SSE
Stable sliding zone
Tremor
Deep slow earthquakes (Transition zone)
Obara (Yesterday)



Monday, November 1, 2010

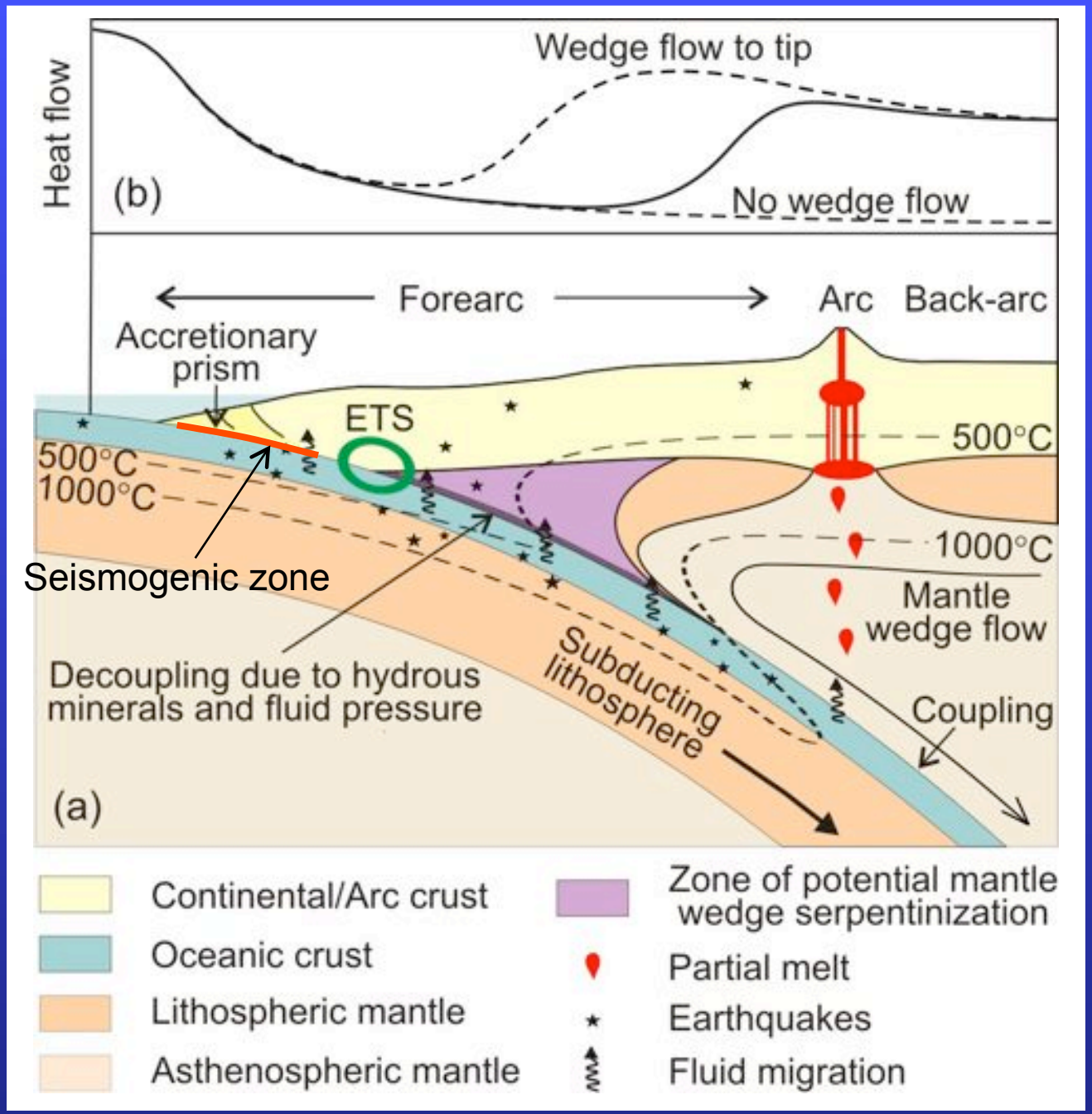


Based on Brown et al (2009)

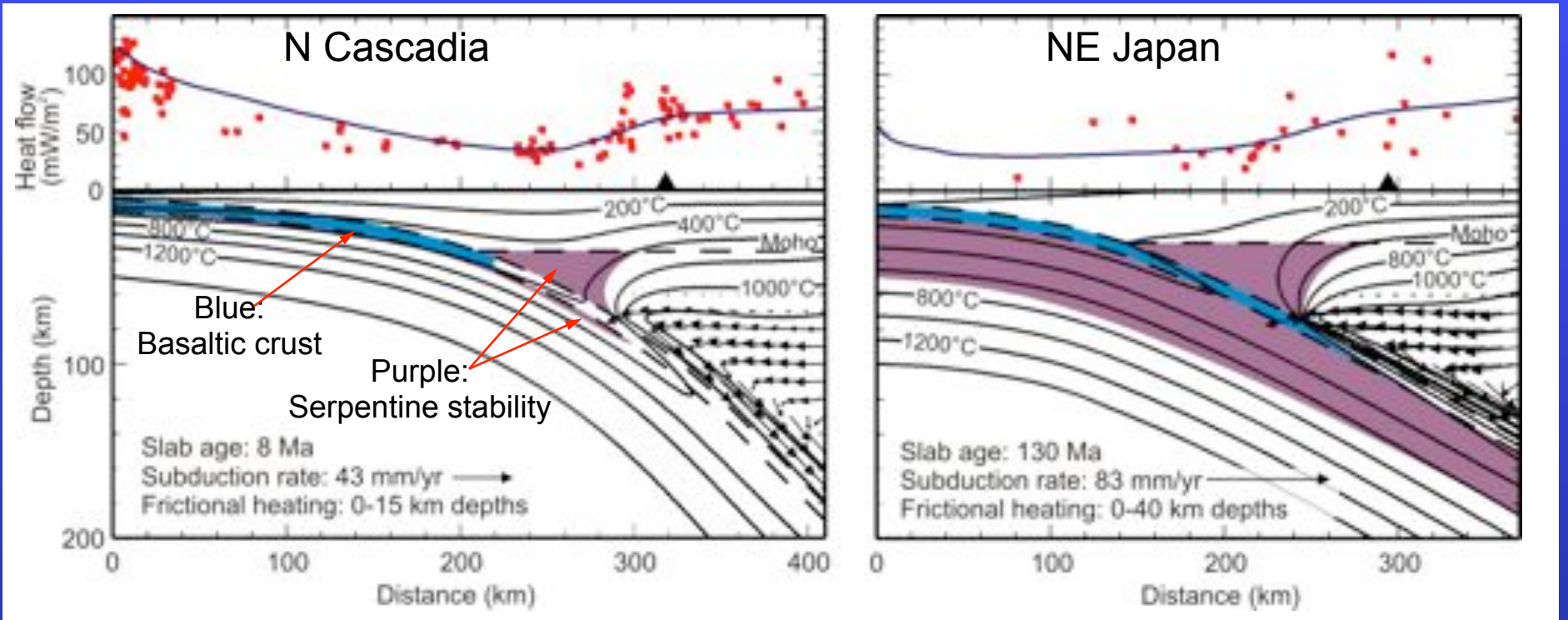


Based on Brown et al (2009)

Unresolved issue: Different types of tremor?
See upper-right corner of poster by Dragert, Wang, and Kao


Heat flow
Wedge flow to tip
(b)
No wedge flow
Forearc
Arc
Back-arc
Accretionary prism
ETS
500°C
1000°C
500°C
1000°C
Seismogenic zone
Mantle wedge flow
Decoupling due to hydrous minerals and fluid pressure
Subducting lithosphere
Coupling
(a)
Continental/Arc crust
Oceanic crust
Lithospheric mantle
Asthenospheric mantle
Zone of potential mantle wedge serpentinization
Partial melt
Earthquakes
Fluid migration

End-member warm-slab and cold-slab subduction zones



Basalt to eclogite ~ 40-50 km depth
Feeble arc volcanism
Serpentinized mantle wedge corner
Intraslab earthquakes to ~90 km depth

Basalt to eclogite ~ 100-140 km
Active arc volcanism
High-velocity wedge corner
Earthquakes to hundreds of km

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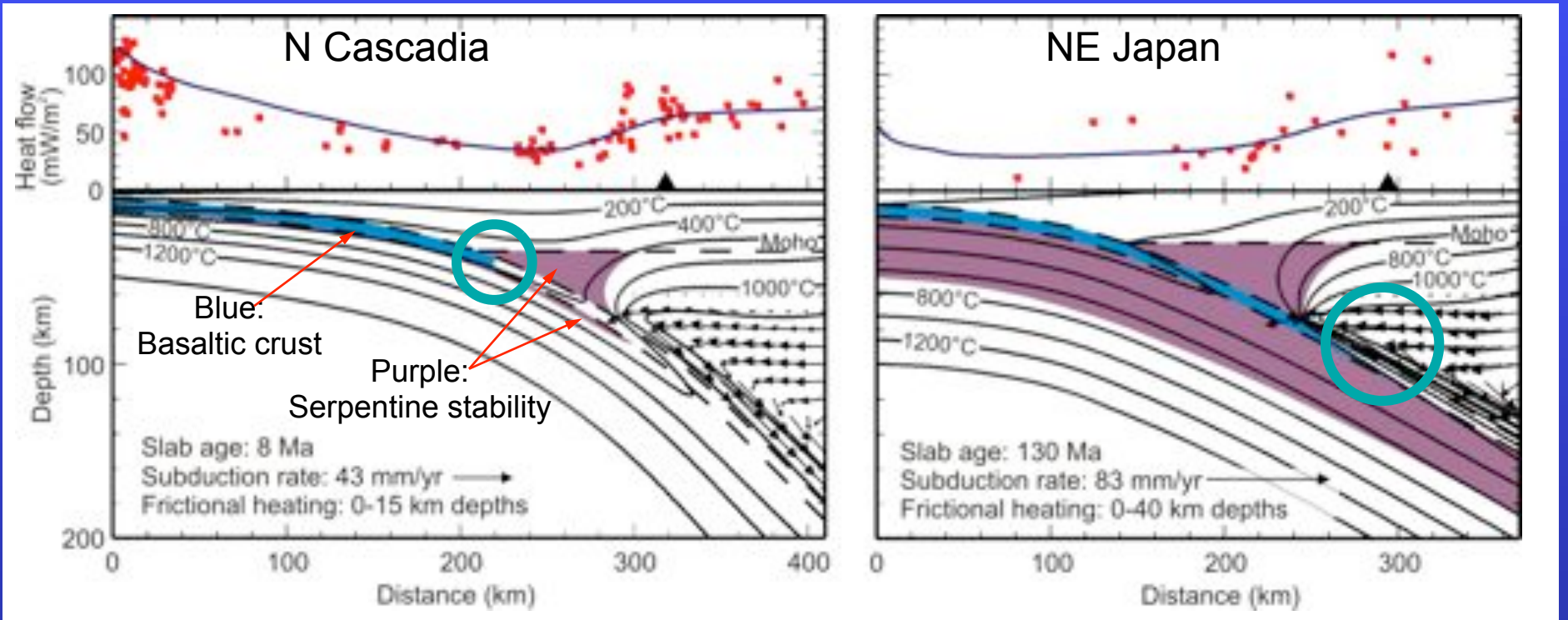

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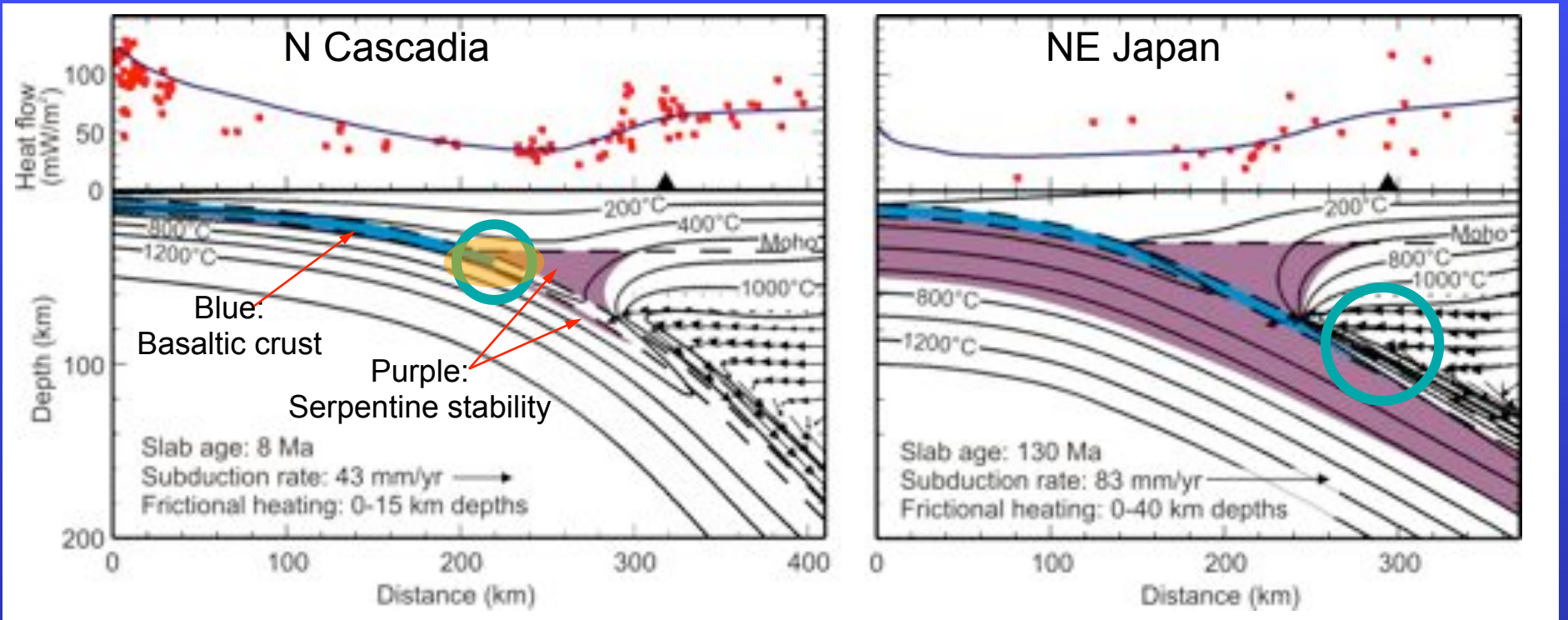

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ETS absent or rare

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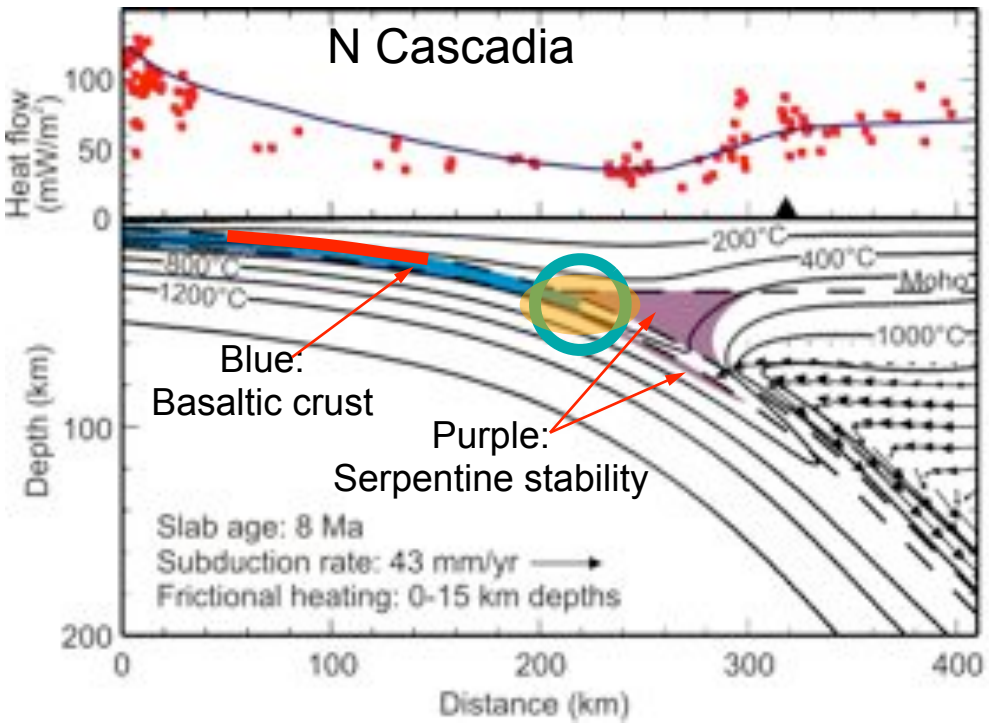

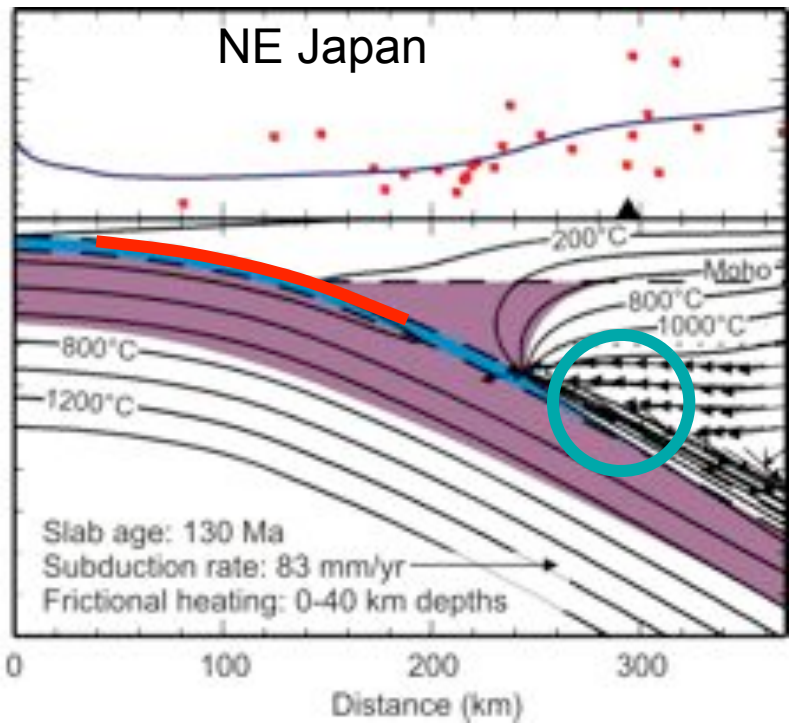

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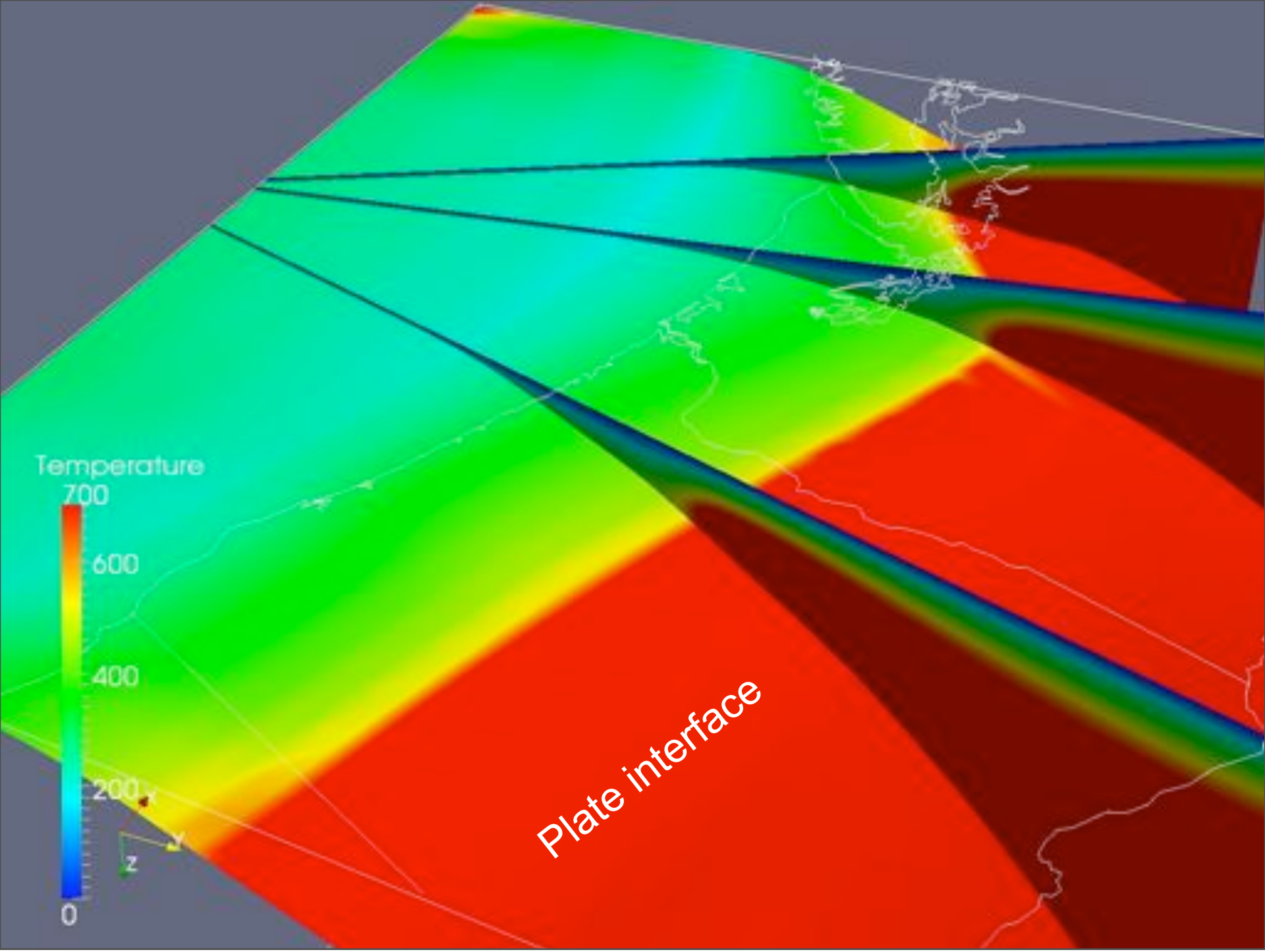
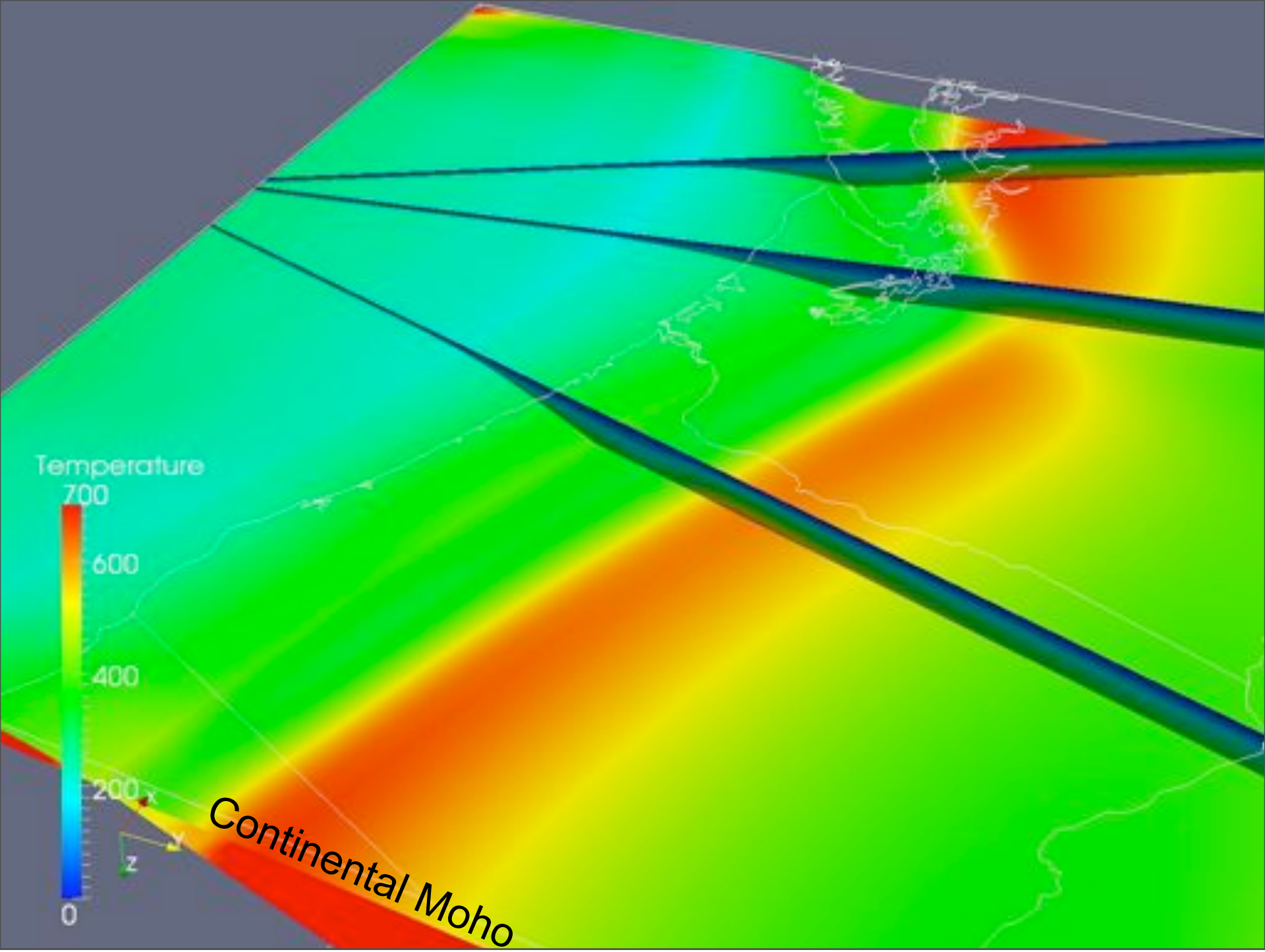
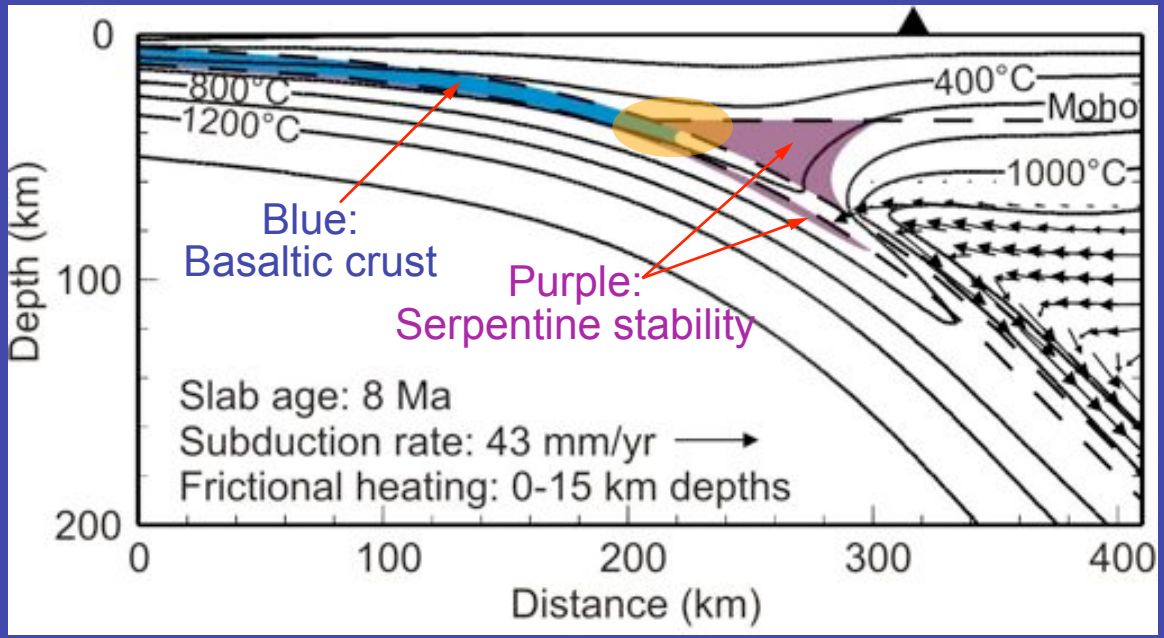
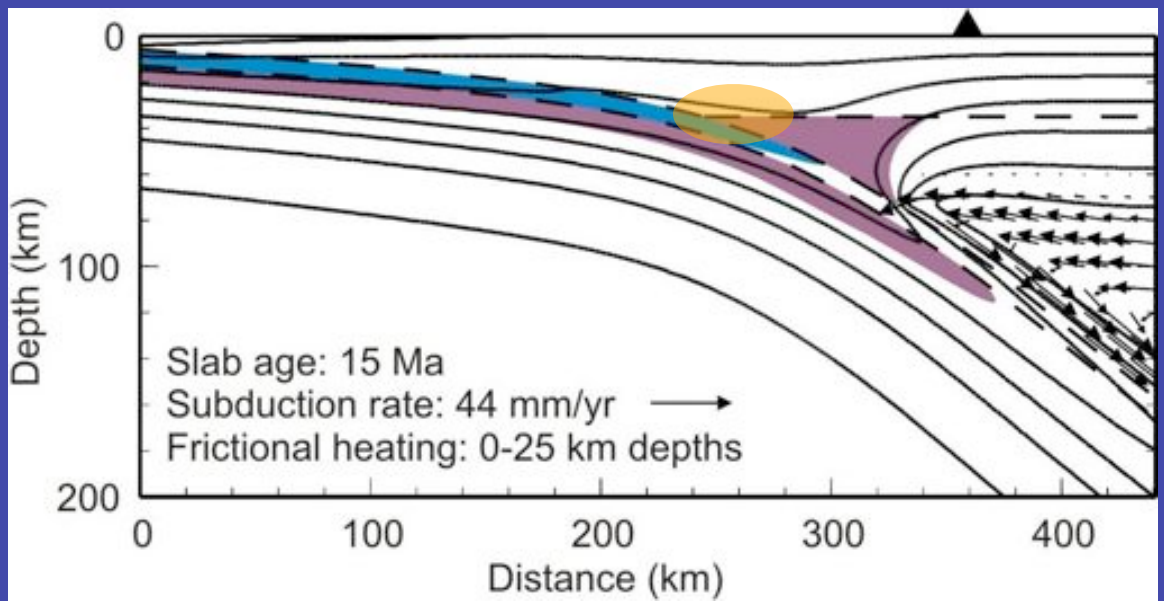

Temperature
700
600
400
200
0
Plate interface


Temperature
700
600
400
200
0
x
y
z
Continental Moho

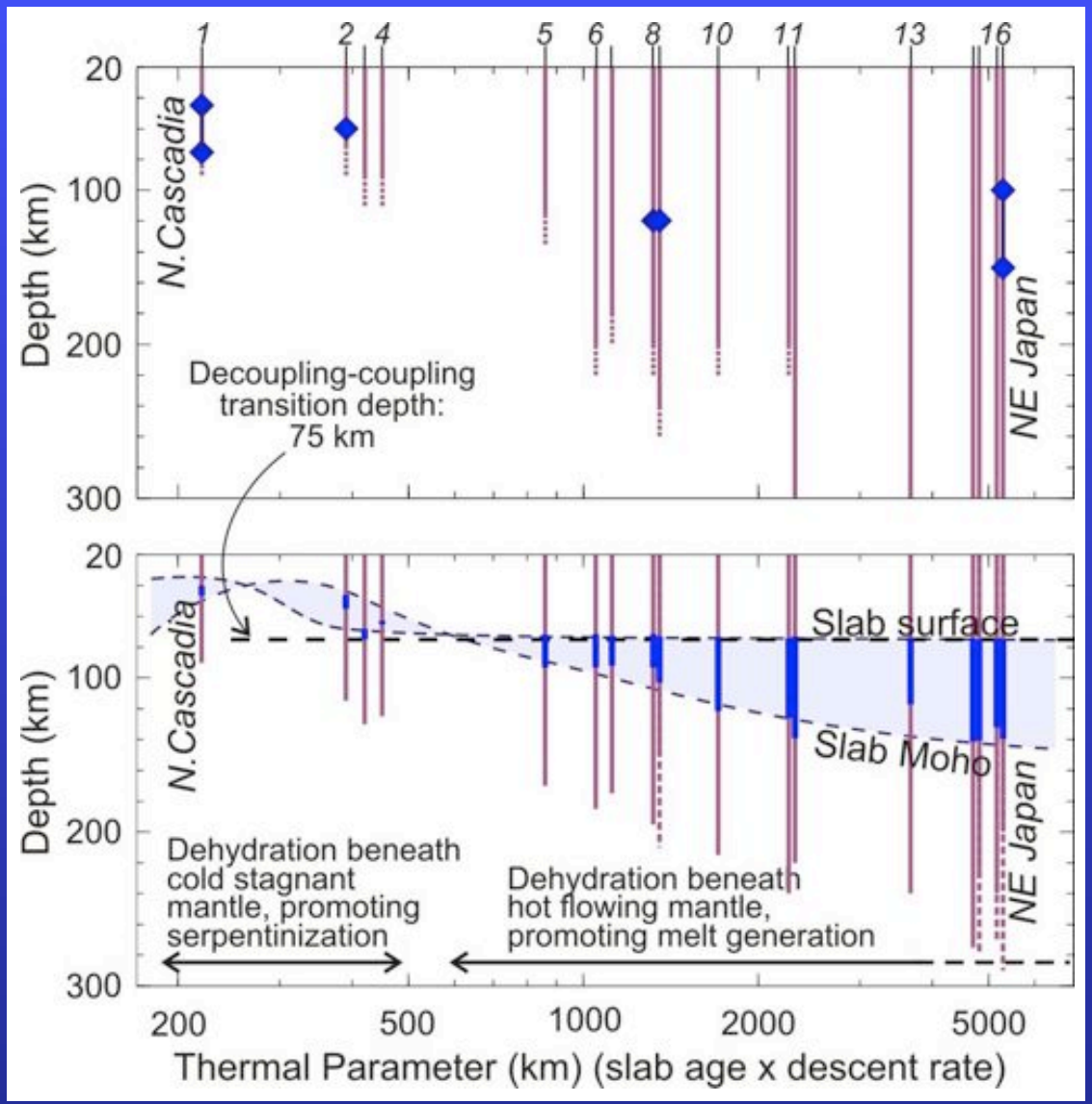
Cascadia



Nankai



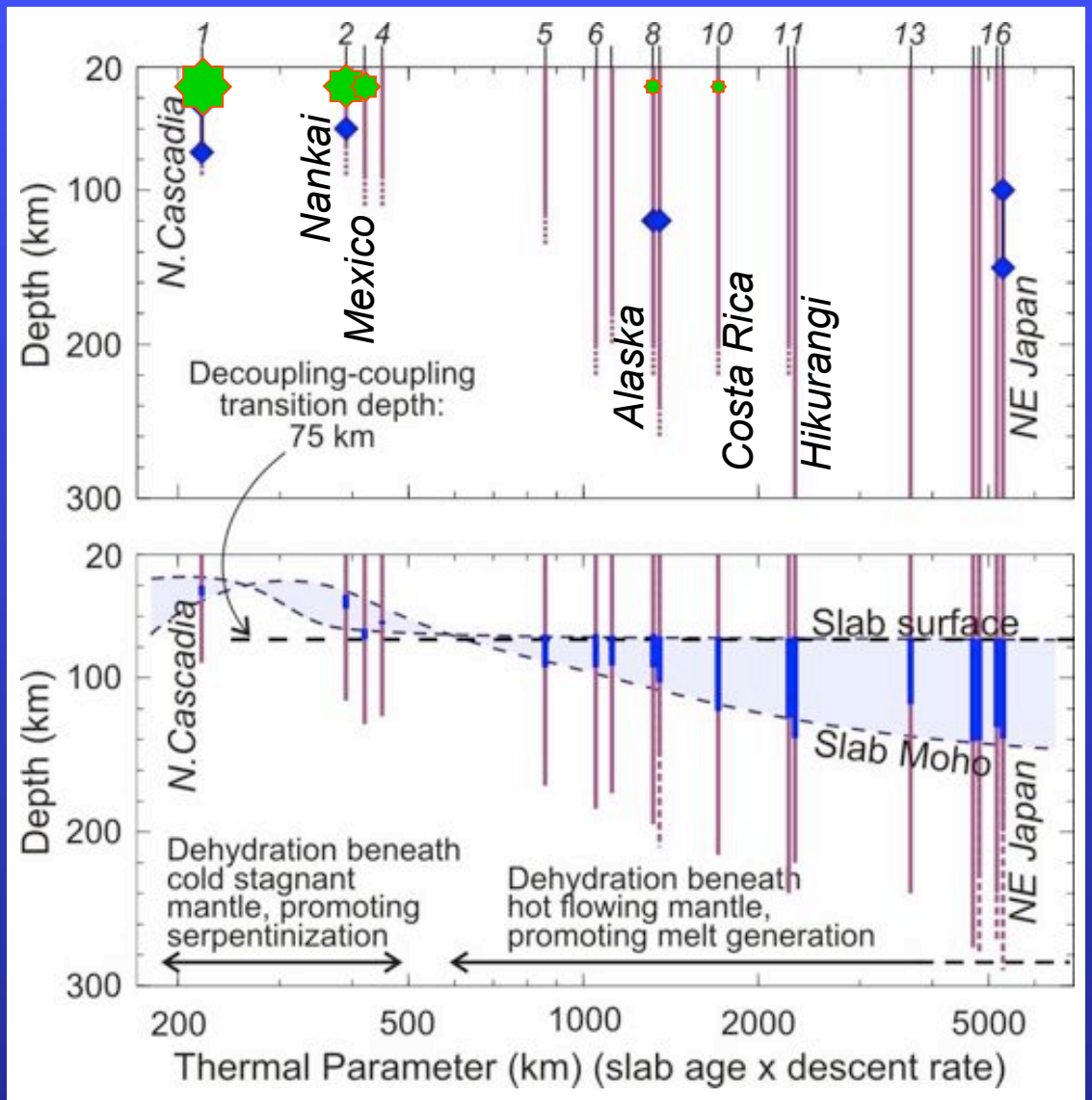
Wada and Wang (2009)



Survival depth of basaltic oceanic crust (blue) and depth range of intraslab earthquakes (purple)

Model-predicted peak dehydration depth (blue) and serpentine stability in subducting slab (purple)

Wada and Wang, 2009



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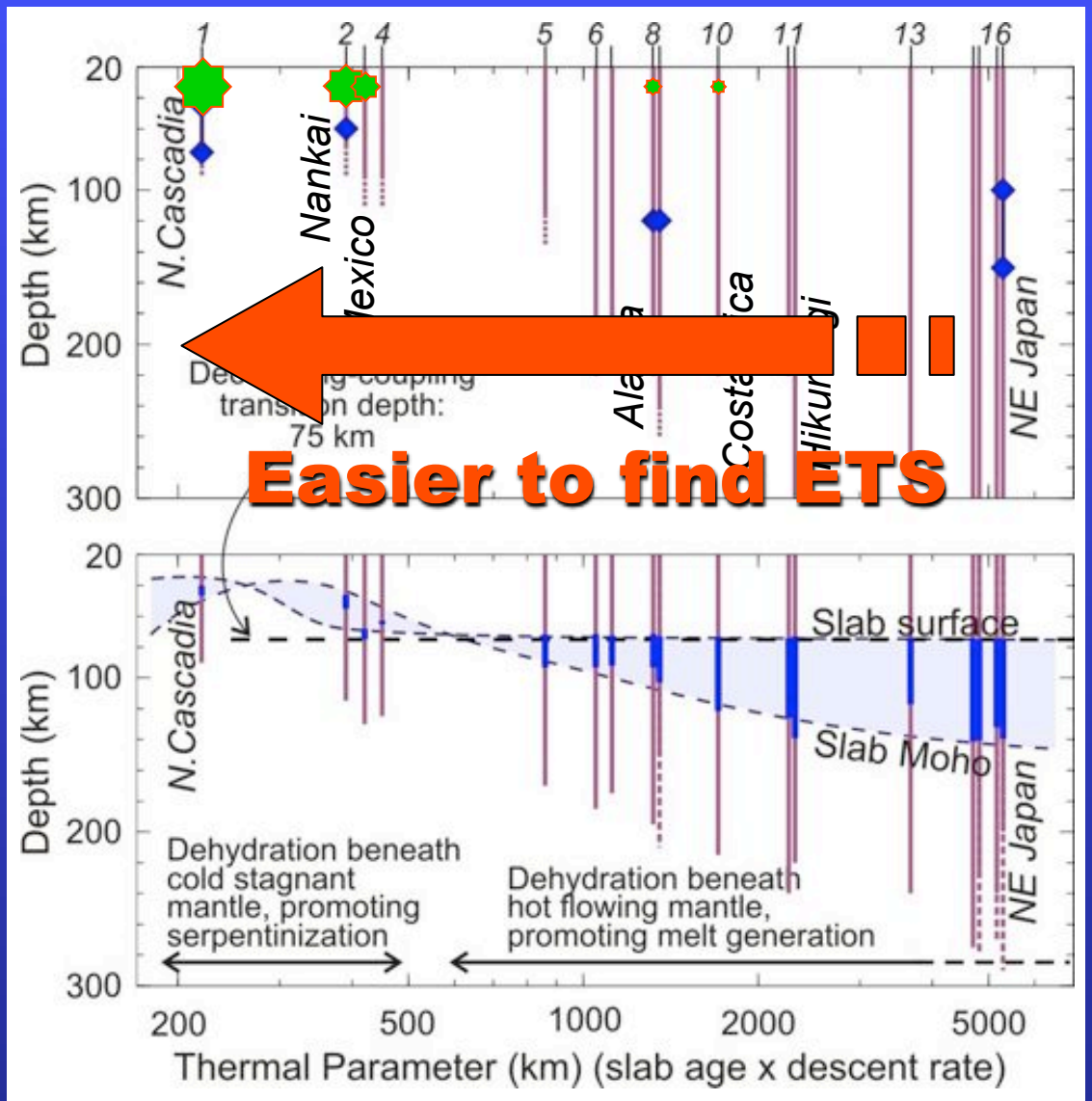

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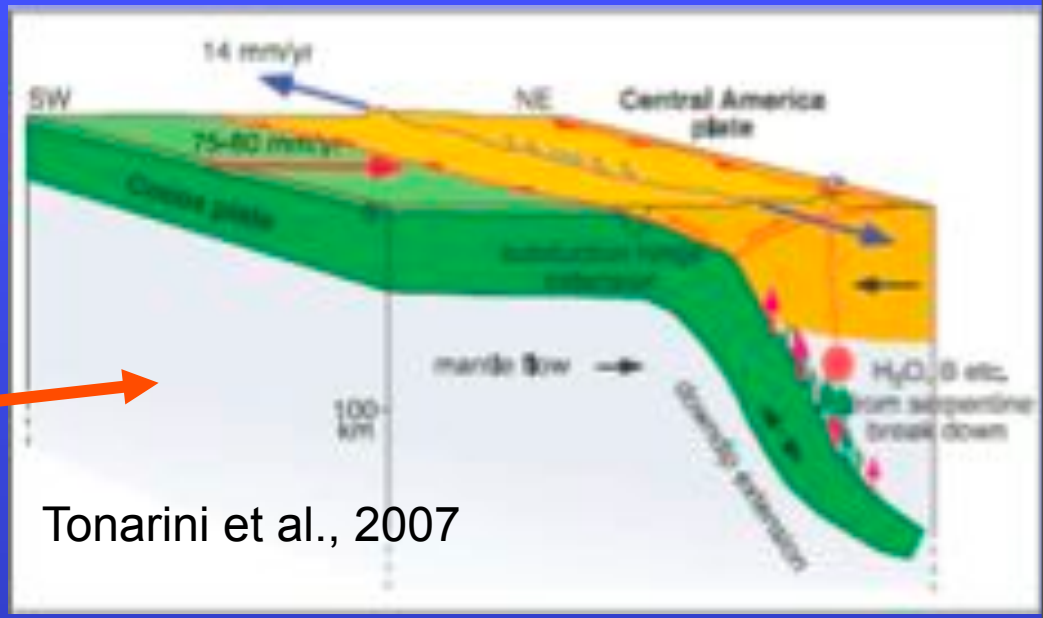
Wada and Wang, 2009

Basal erosion of serpentinized mantle wedge corner

Geochemical evidence for serpentinite slices dragged to large depths



Tonarini et al., 2007

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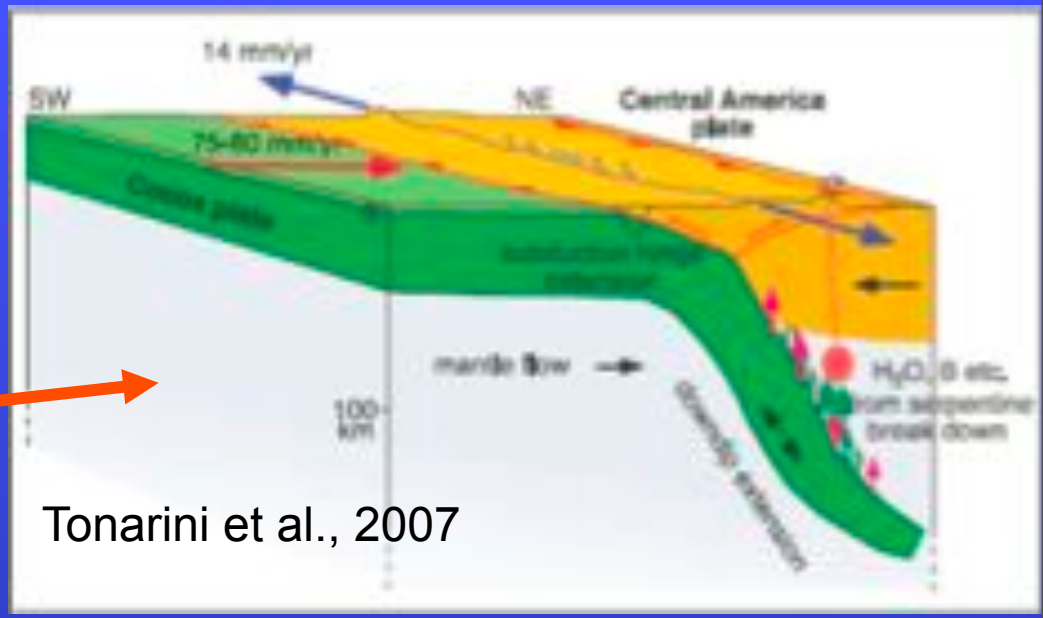

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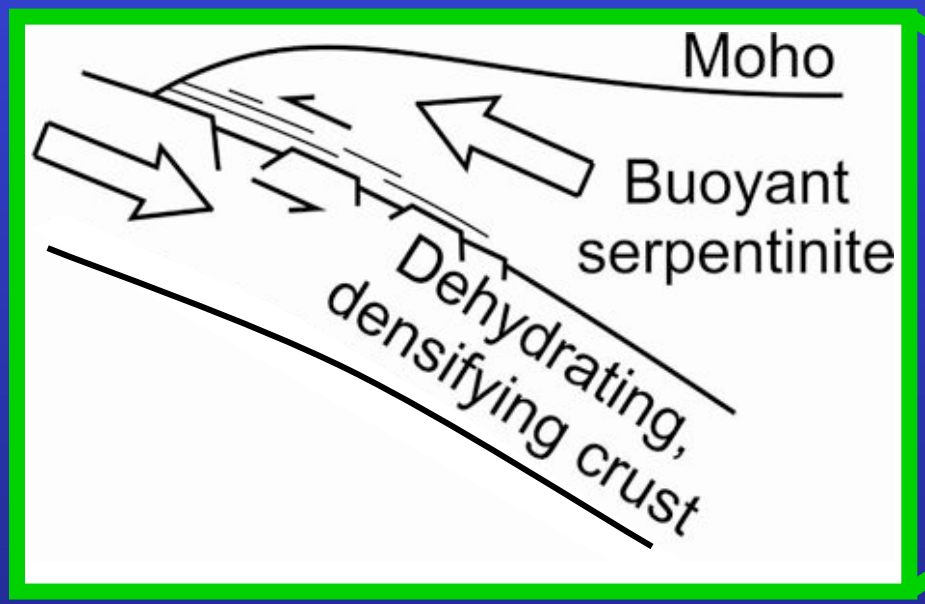

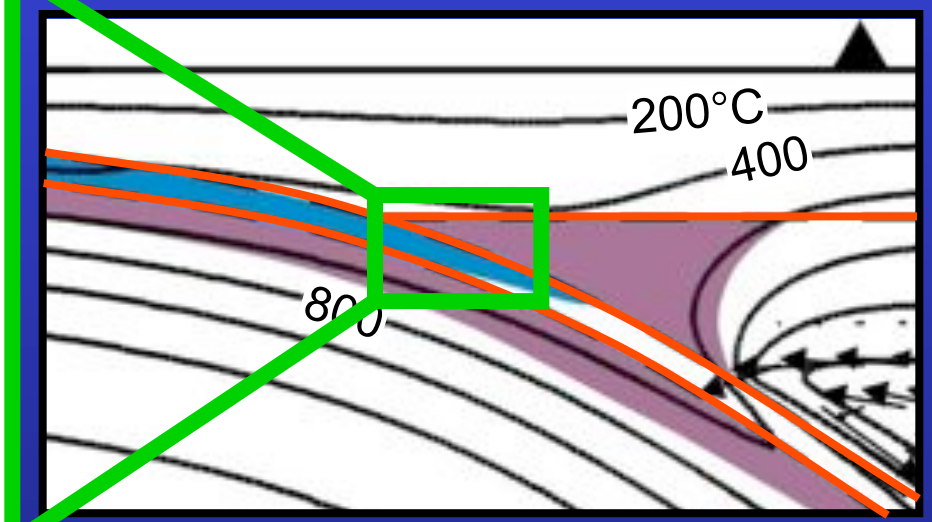

Density of antigorite ~ 2.5 g/cm^3; density of peridotite ~ 3.3 g/cm^3

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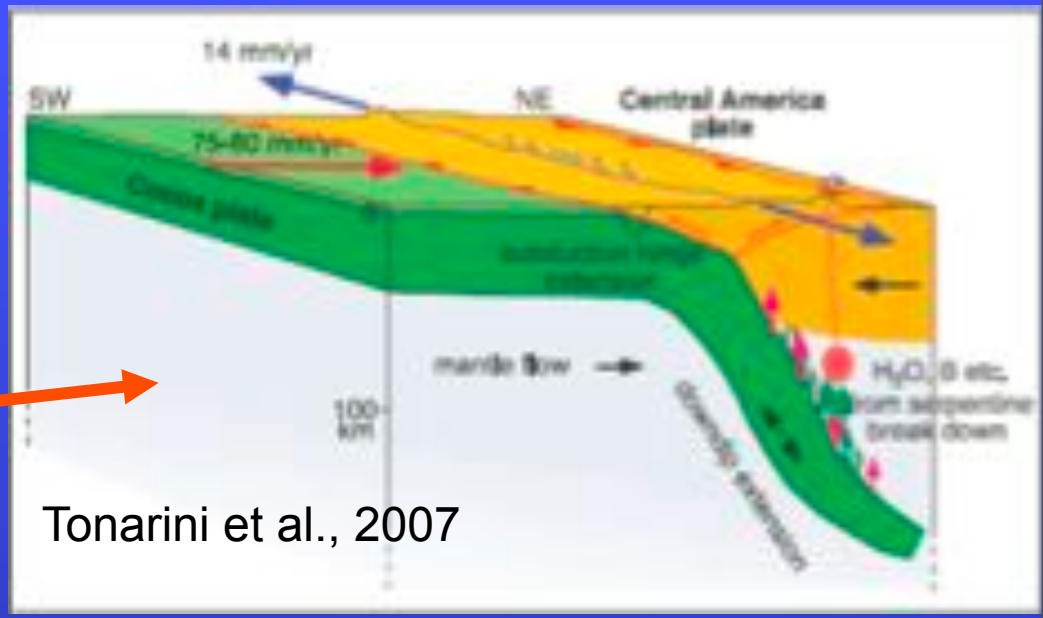

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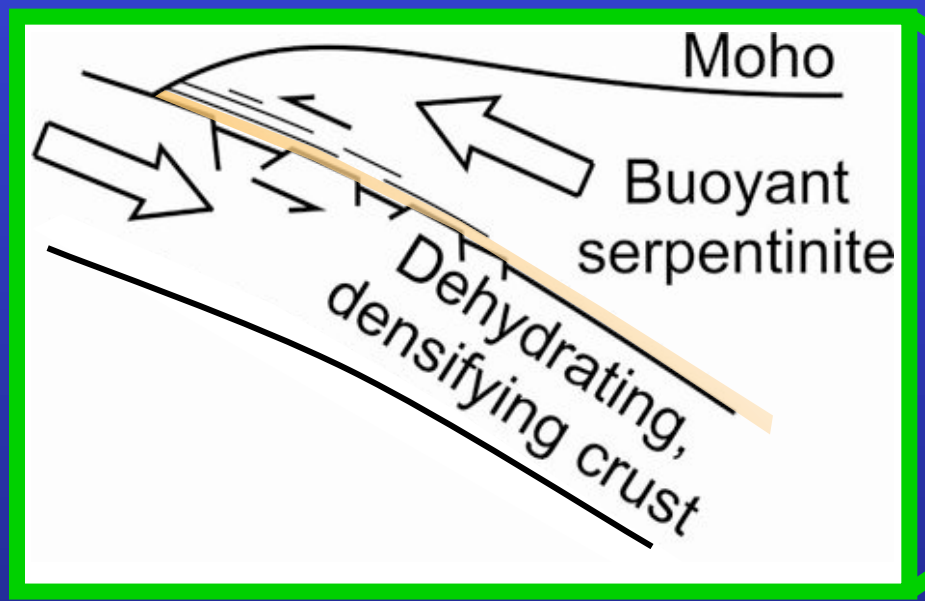

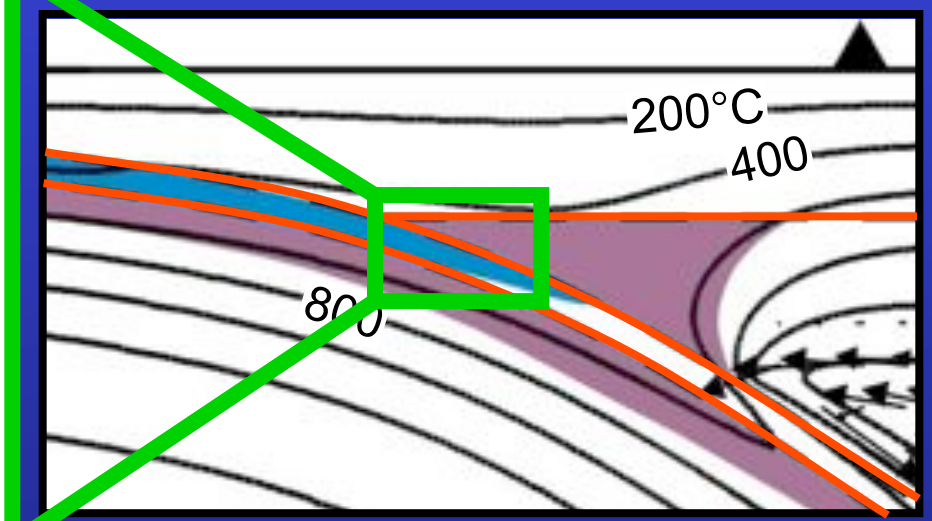

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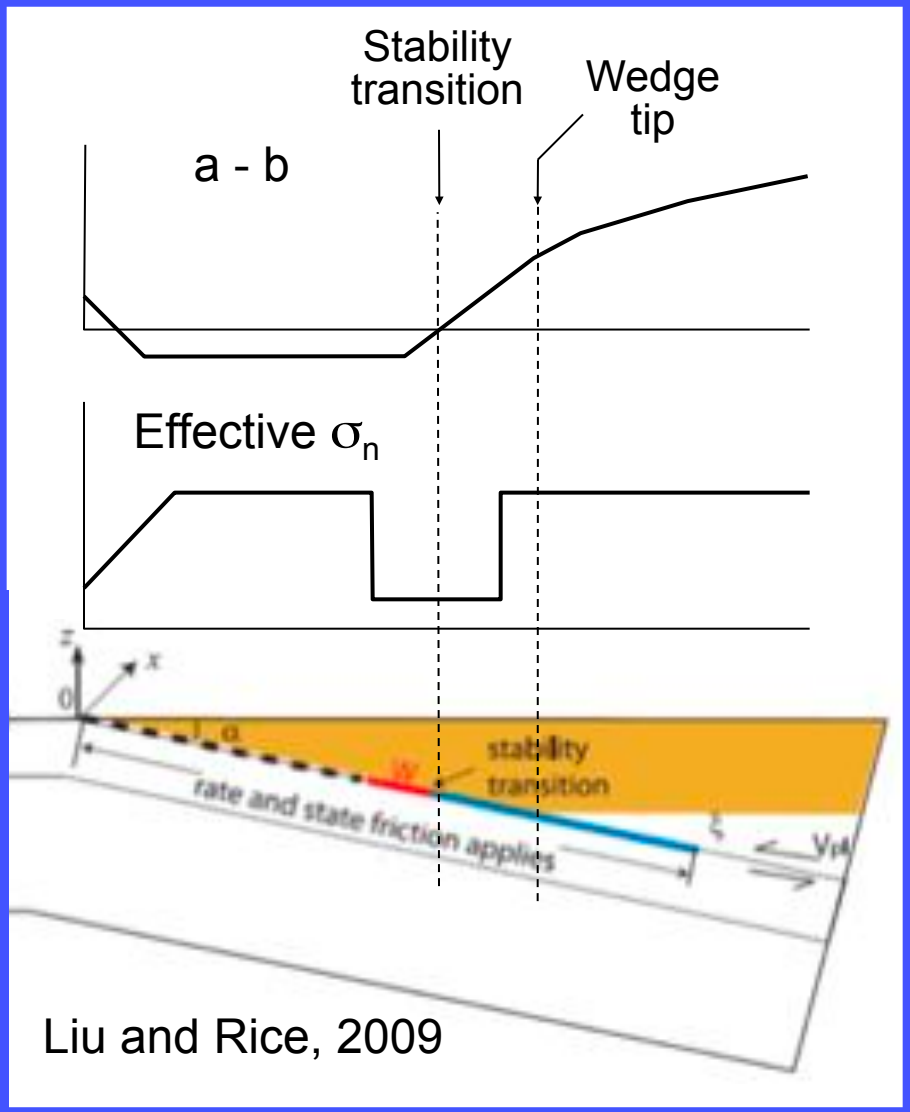
What about the friction stability transition?

Seems necessary, but certainly not sufficient.



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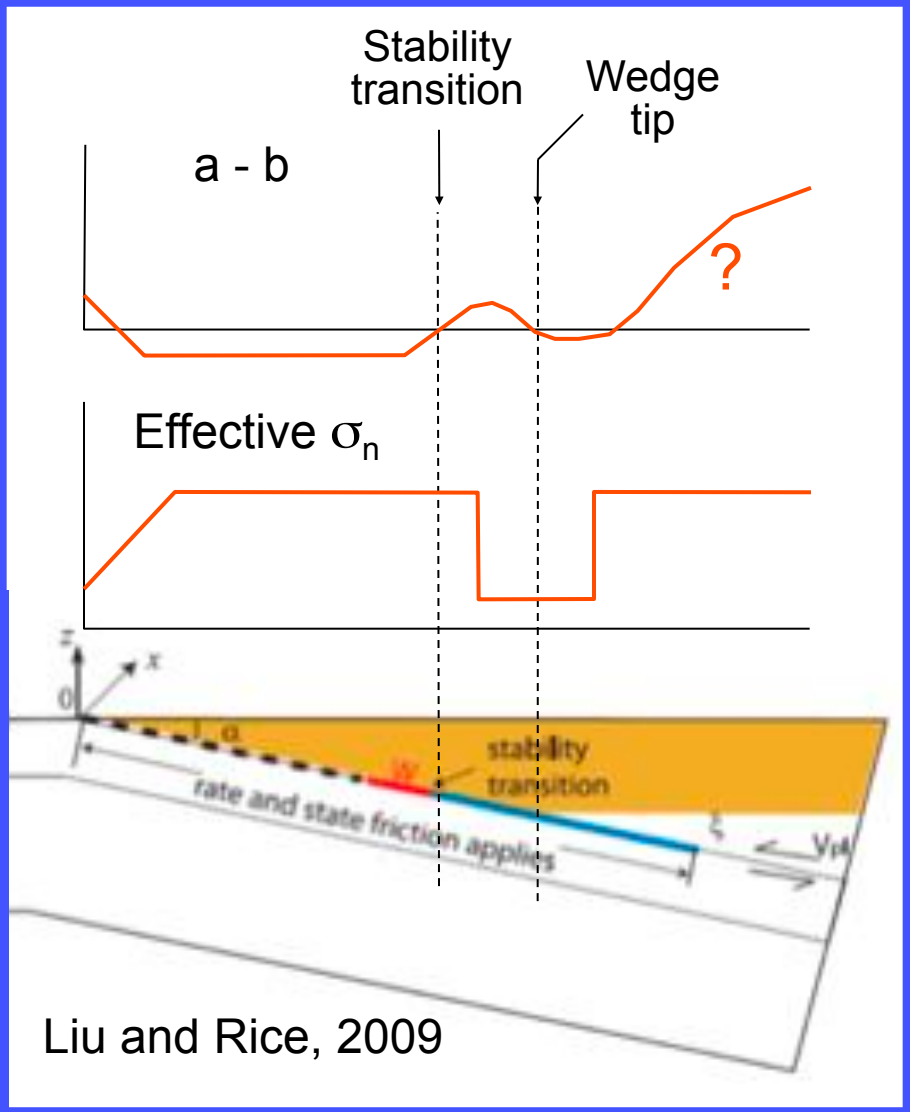
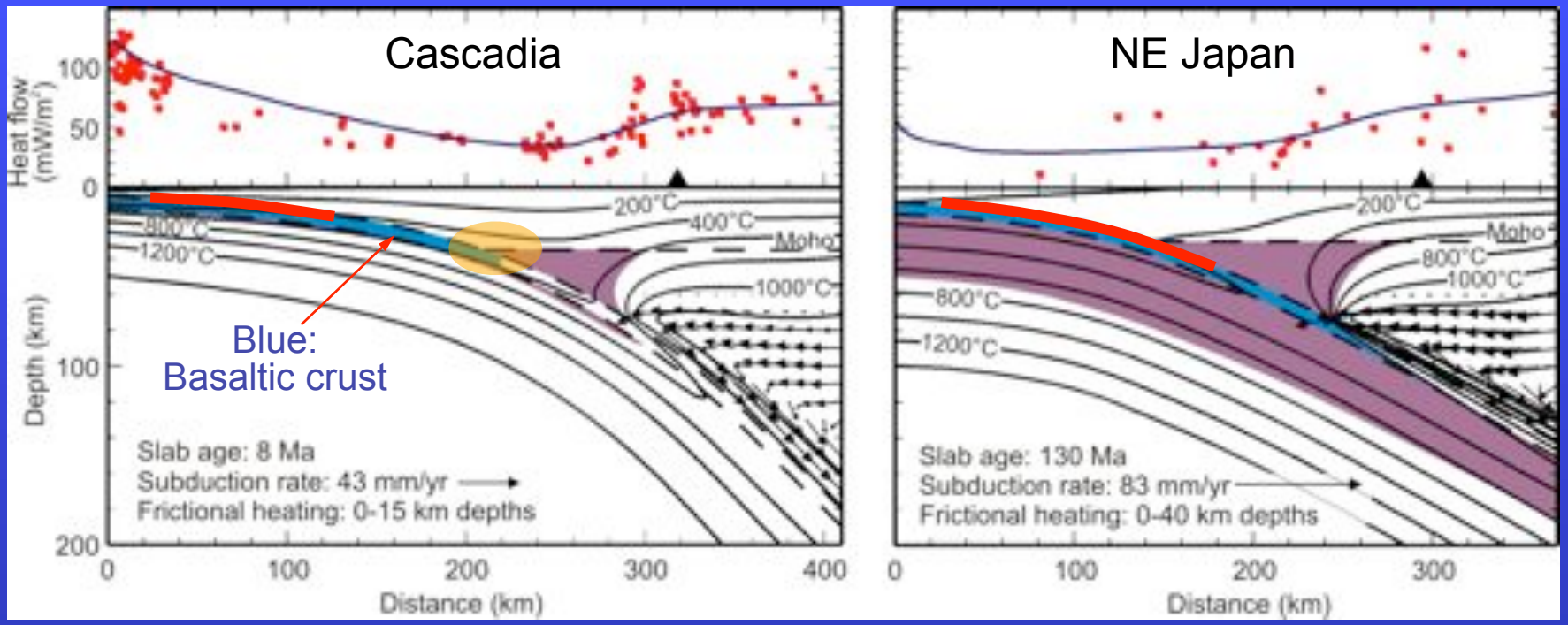
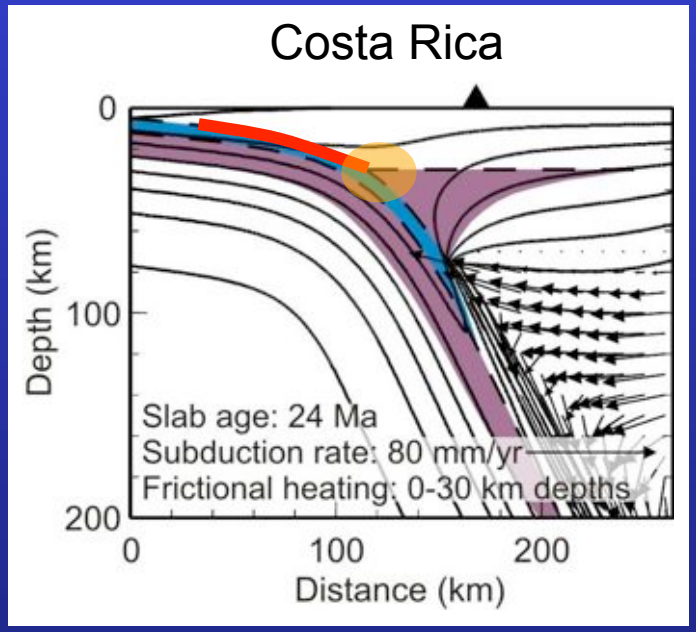
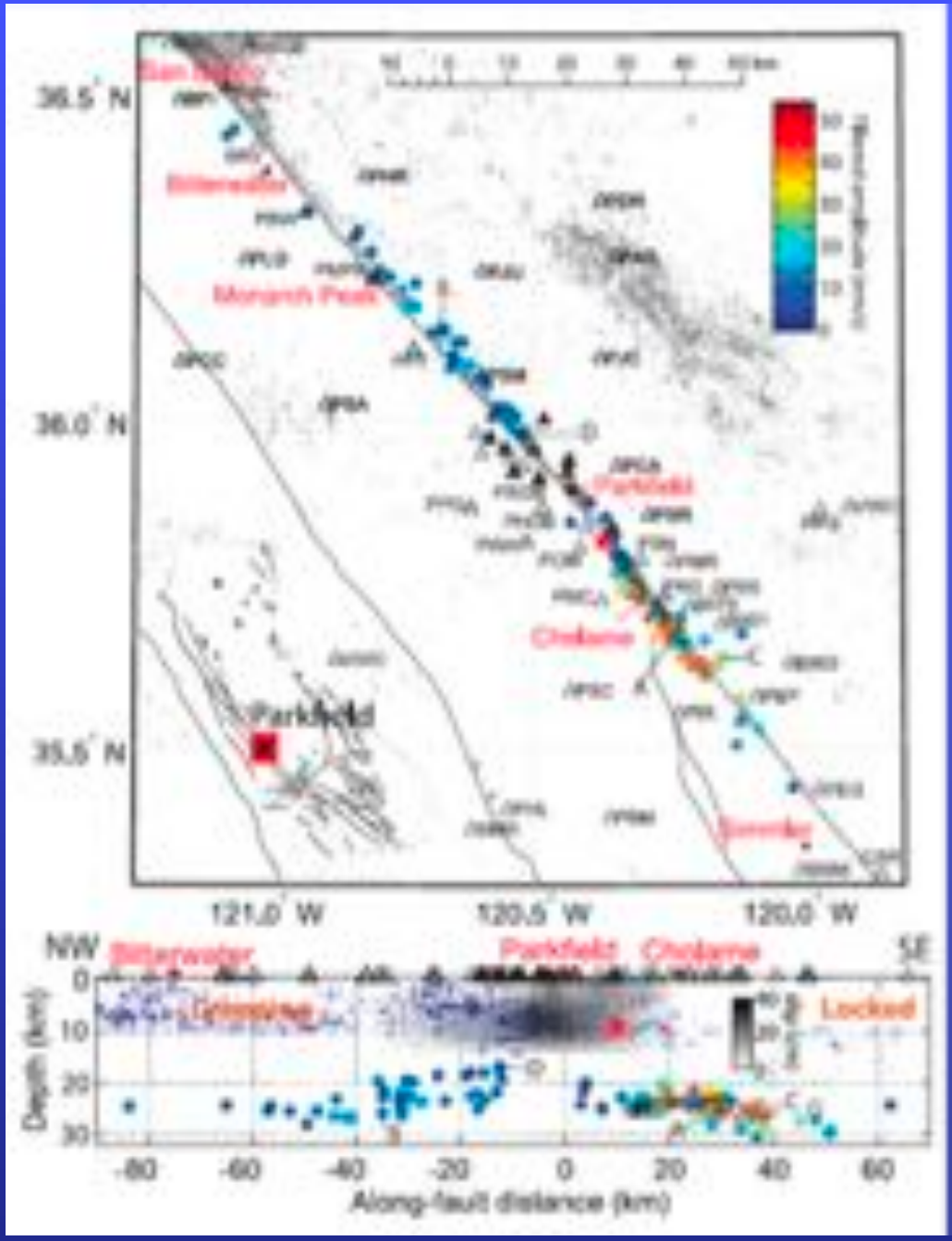


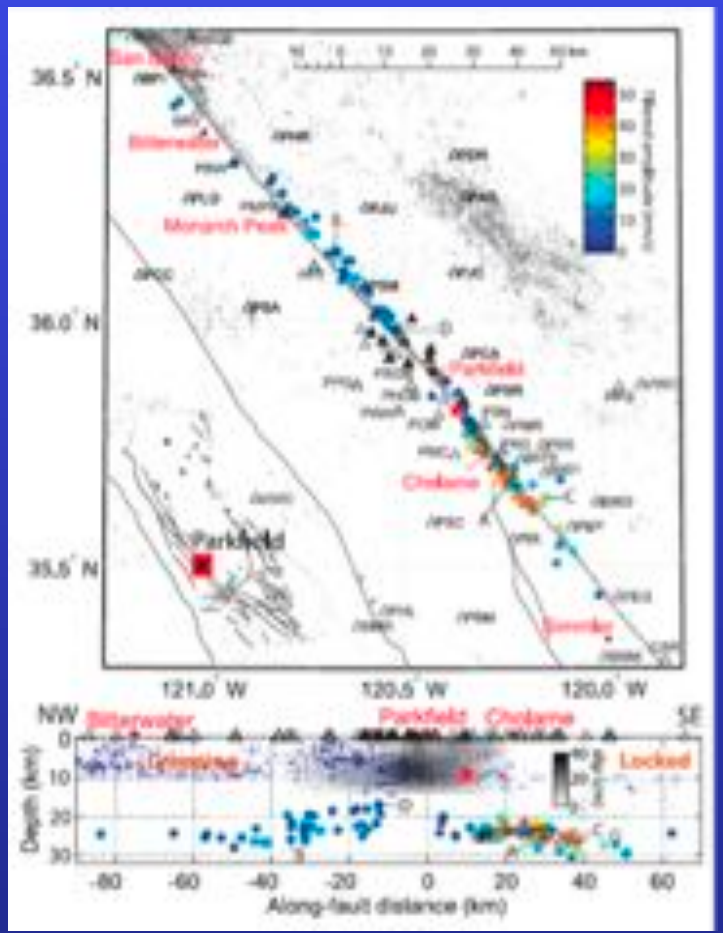
Liu and Rice, 2009

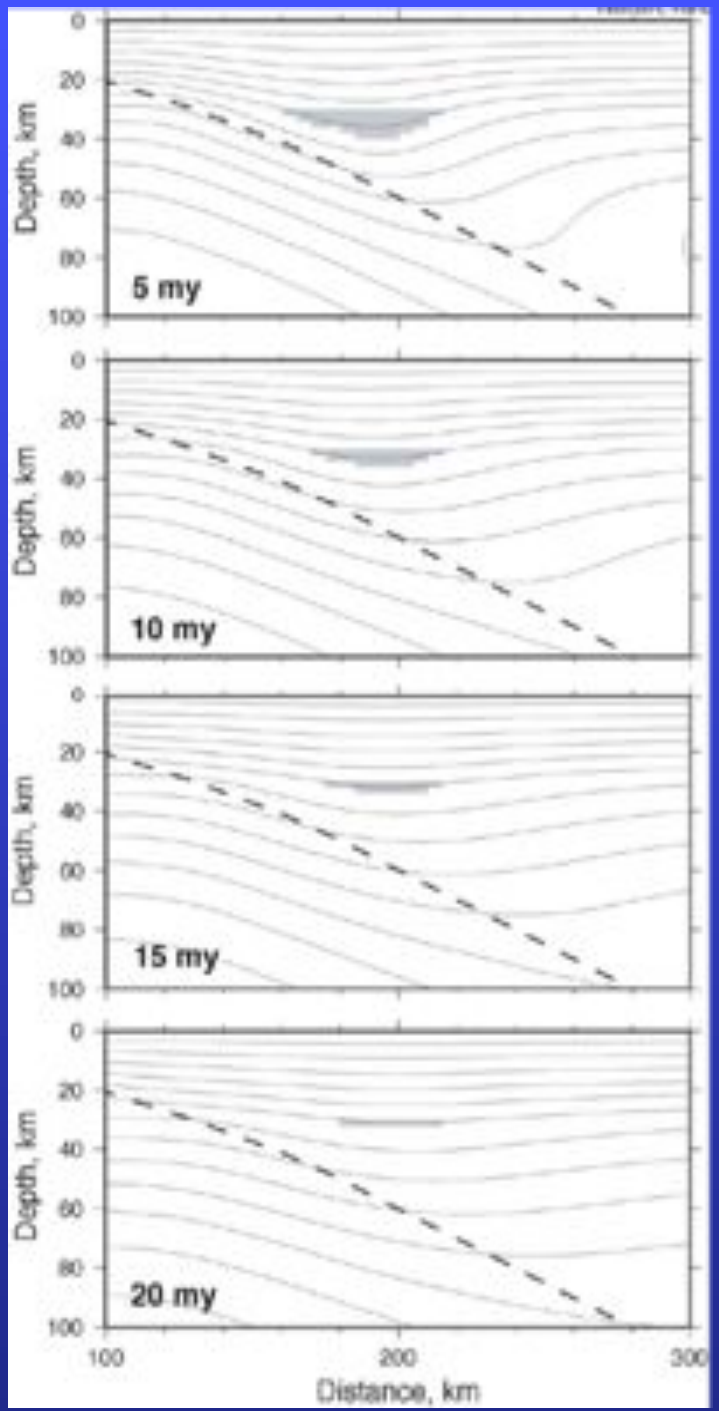

Cascadia
Heat flow (mW/m²)
100
50
0
Depth (km)
100
200
200°C
400°C
Moho
800°C
1200°C
1000°C
Blue:
Basaltic crust
Slab age: 8 Ma
Subduction rate: 43 mm/yr
Frictional heating: 0-15 km depths
0
100
200
300
400
Distance (km)
NE Japan
200°C
Moho
800°C
1000°C
800°C
1200°C
Slab age: 130 Ma
Subduction rate: 83 mm/yr
Frictional heating: 0-40 km depths
0
100
200
300
Distance (km)


Costa Rica
0
Depth (km)
100
200
Slab age: 24 Ma
Subduction rate: 80 mm/yr
Frictional heating: 0-30 km depths
0
100
200
Distance (km)


36.5° N
36.0° N
35.5° N
121.0° W
120.5° W
120.0° W
Bitterwater
Monarch Peak
Parkfield
Cholame
Parkfield
NW
SE
Bitterwater
Parkfield
Cholame
Creeping
Locked
Depth (km)
0
10
20
30
-80
-60
-40
-20
0
20
40
60
Along-fault distance (km)

In the wake of the Mendocino triple junction moving north: Dehydrating and diminishing serpentinized mantle wedge
-- a very long lasting process





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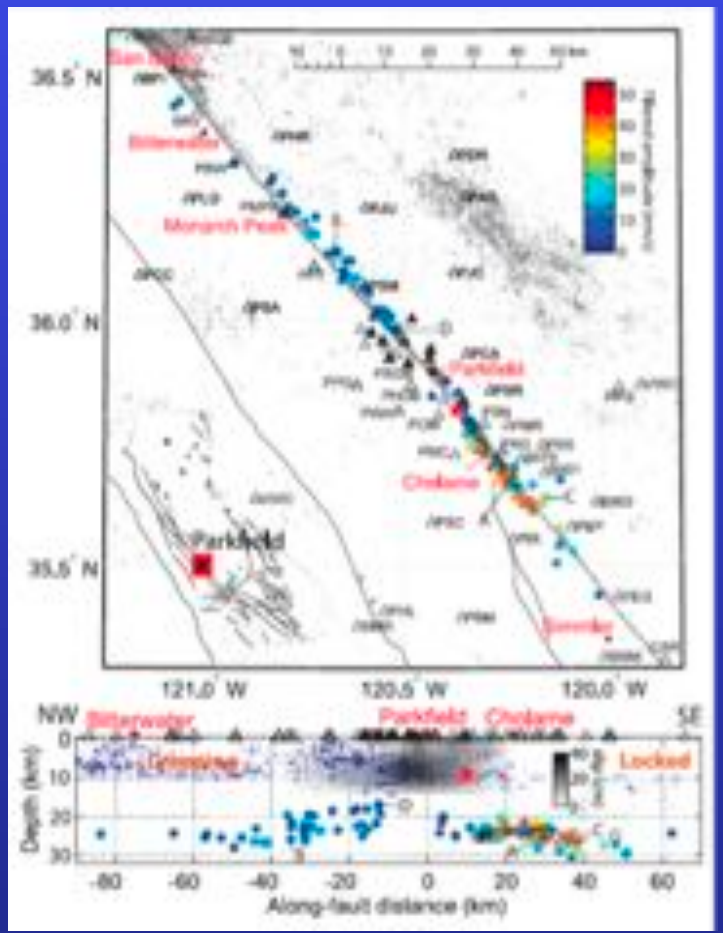

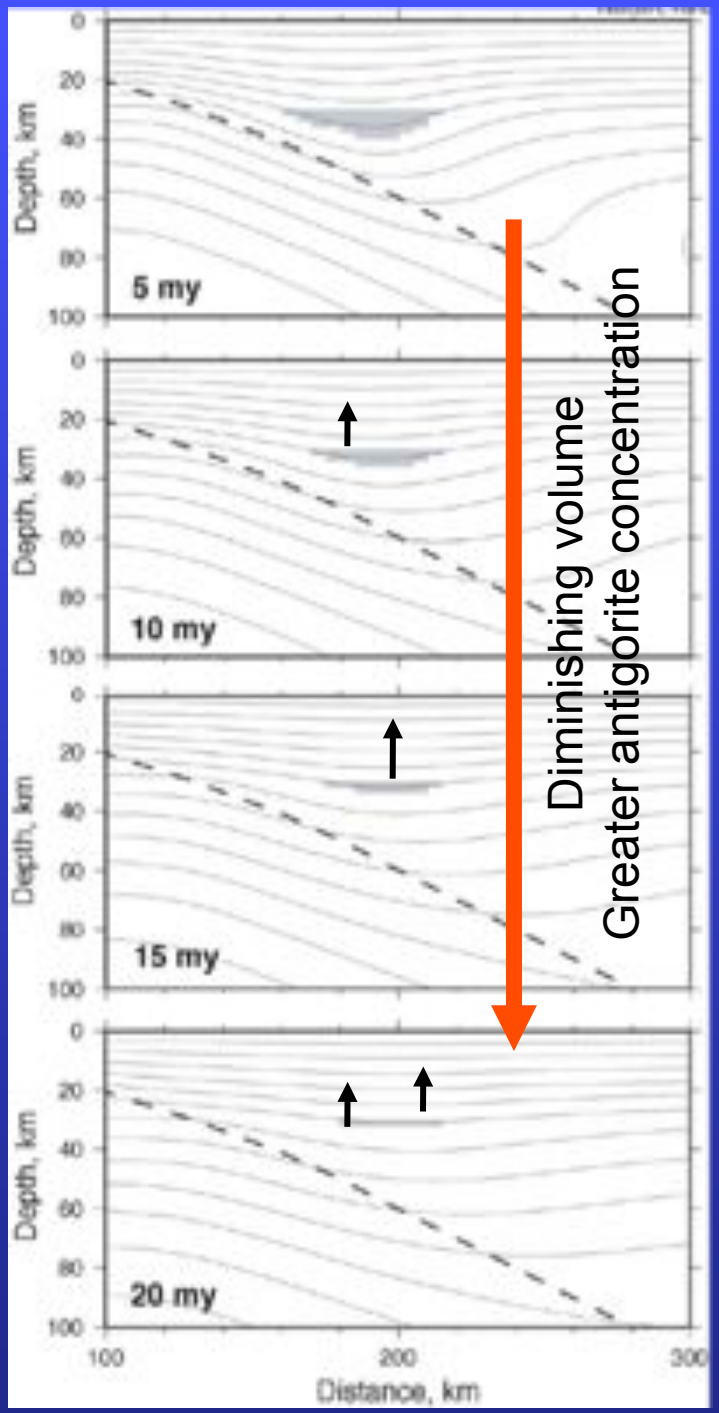

Conclusions

- ETS is a subset of the ubiquitously present SSEs.
- ETS is more abundant at the mantle wedge corner of subduction zones (or the like), but rare in other tectonic environments.
- ETS is most abundant in warm-slab subduction zones.
- ETS **definitely** requires more than being near the friction stability transition.
- The presence of fluid saturated (antigorite) serpentinite is a very likely additional condition.
- Warm-slab subduction leads to higher degree of serpentinization of the mantle wedge tip, greater availability of free water.
- ETS may indicate active basal erosion of highly serpentinized mantle wedge.