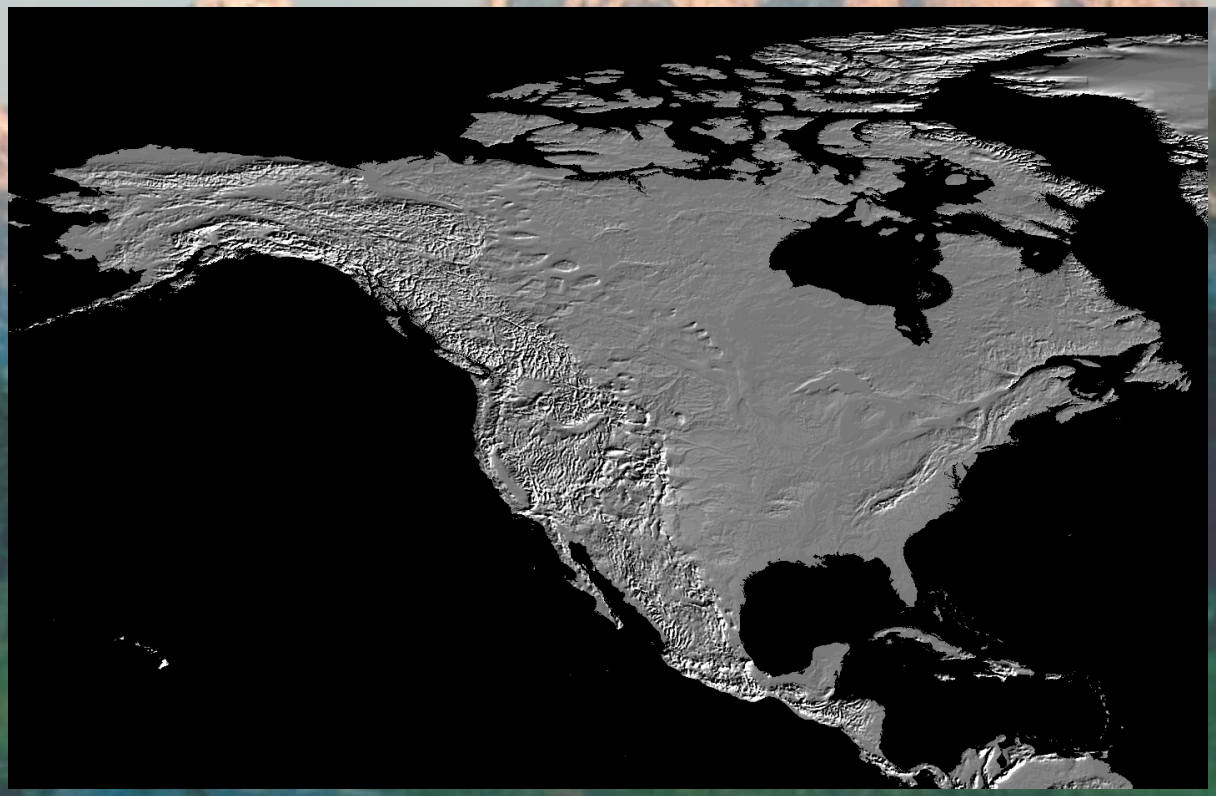
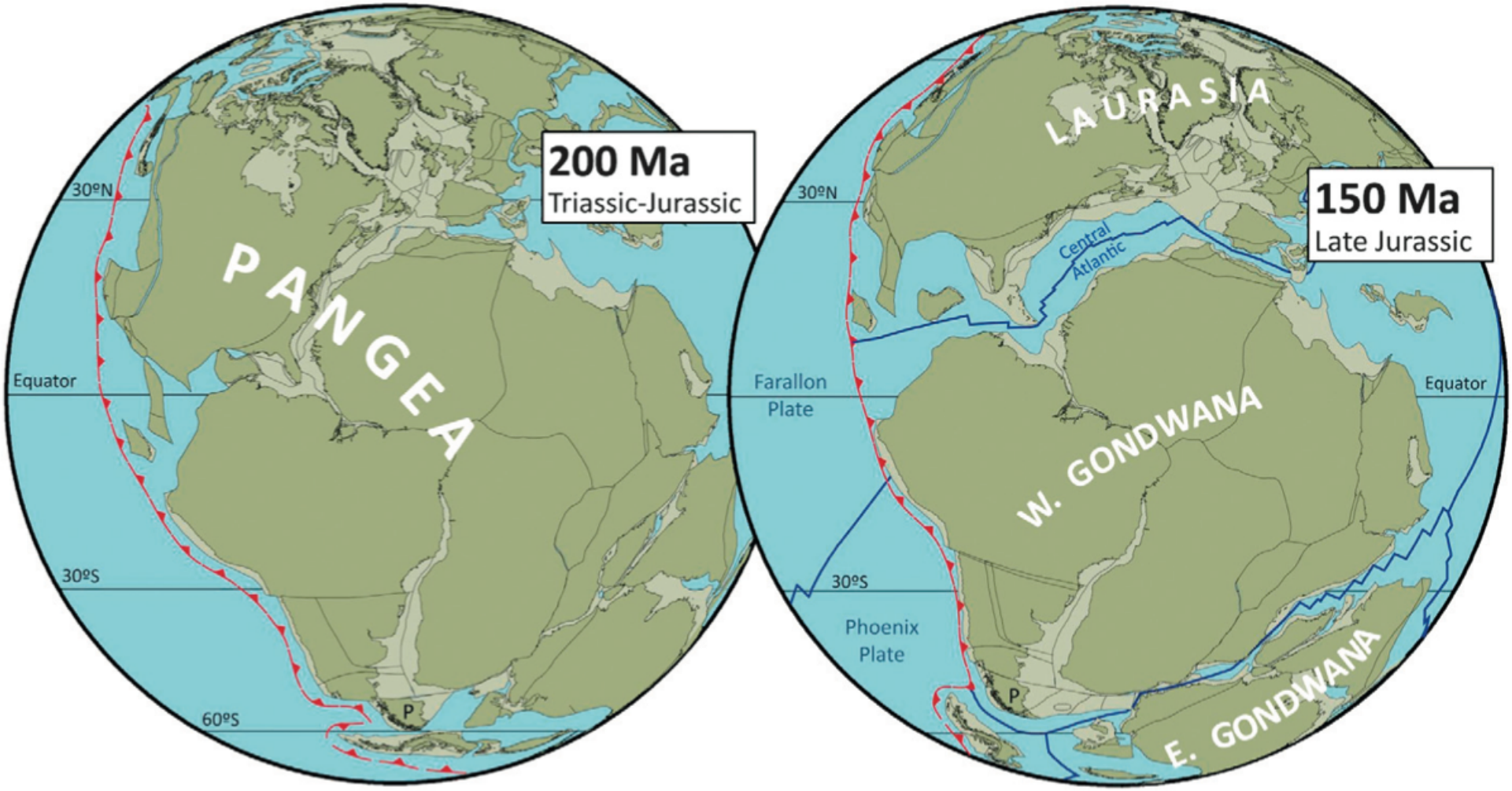
Seismic tomography explains where the North American Cordillera came from



Karin Sigloch, University of Munich (LMU)
joint work with Mitch Mihalynuk, Geol. Survey of British Columbia

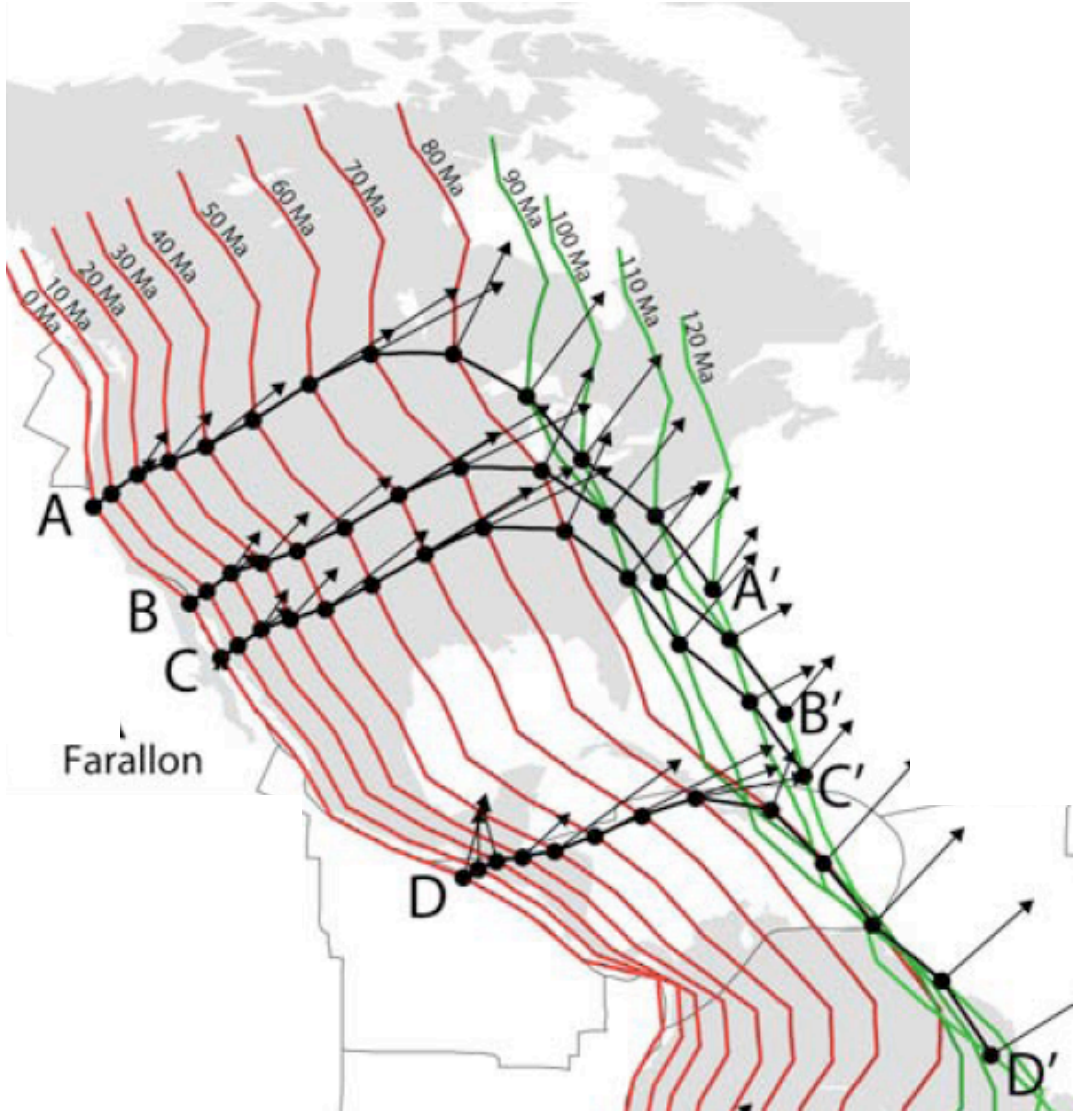
Starting point: Pangaea, bounded by Andean-type subduction at its western edge(?)



Torsvik et al. 2012

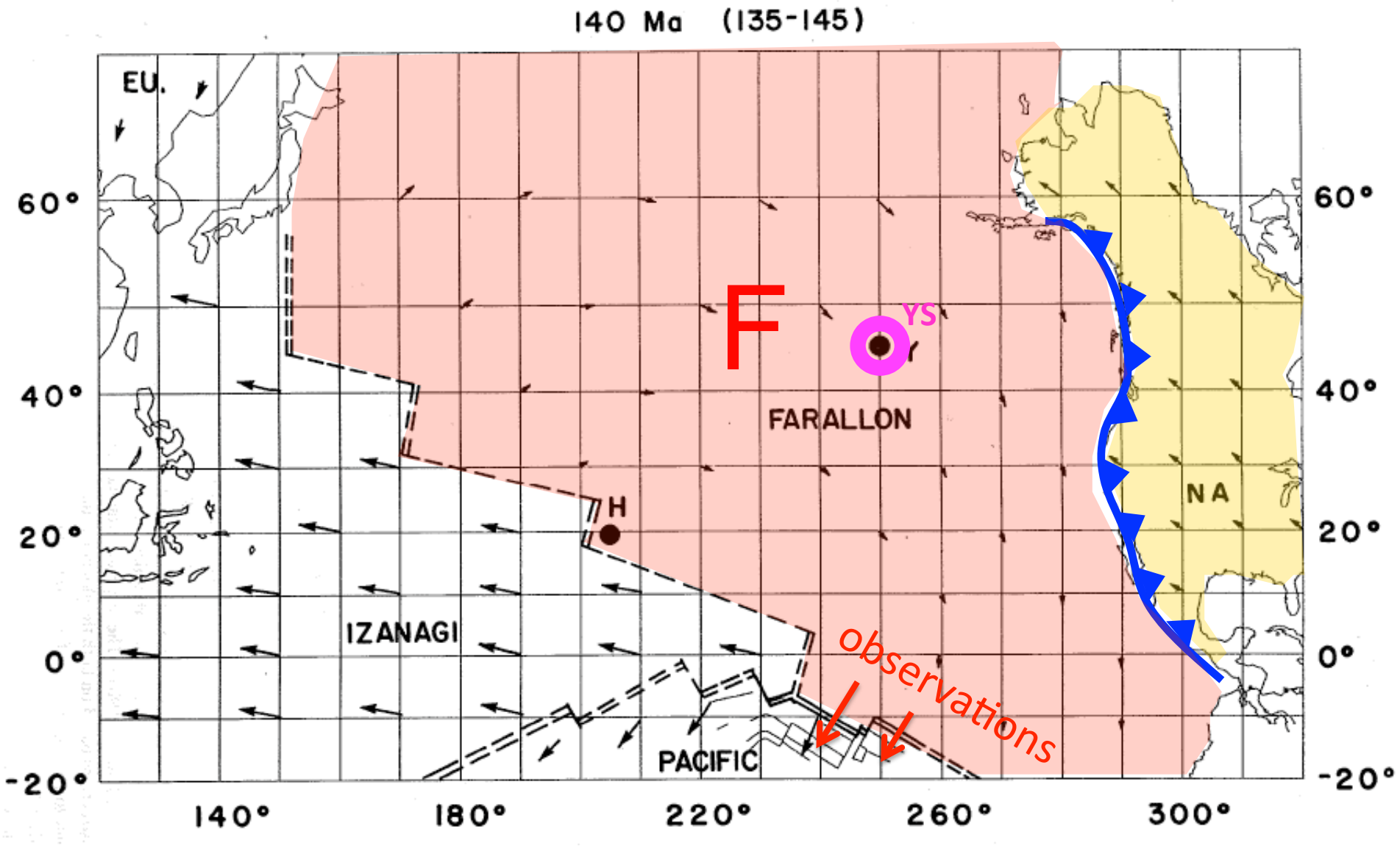
Since 180 Ma, North America has moved west in an absolute sense

- Motion plotted in a hotspot reference frame, time increment 10 Ma.
- Constrained by magnetic stripes on the Atlantic seafloor.
- Was there always a trench along the west coast?



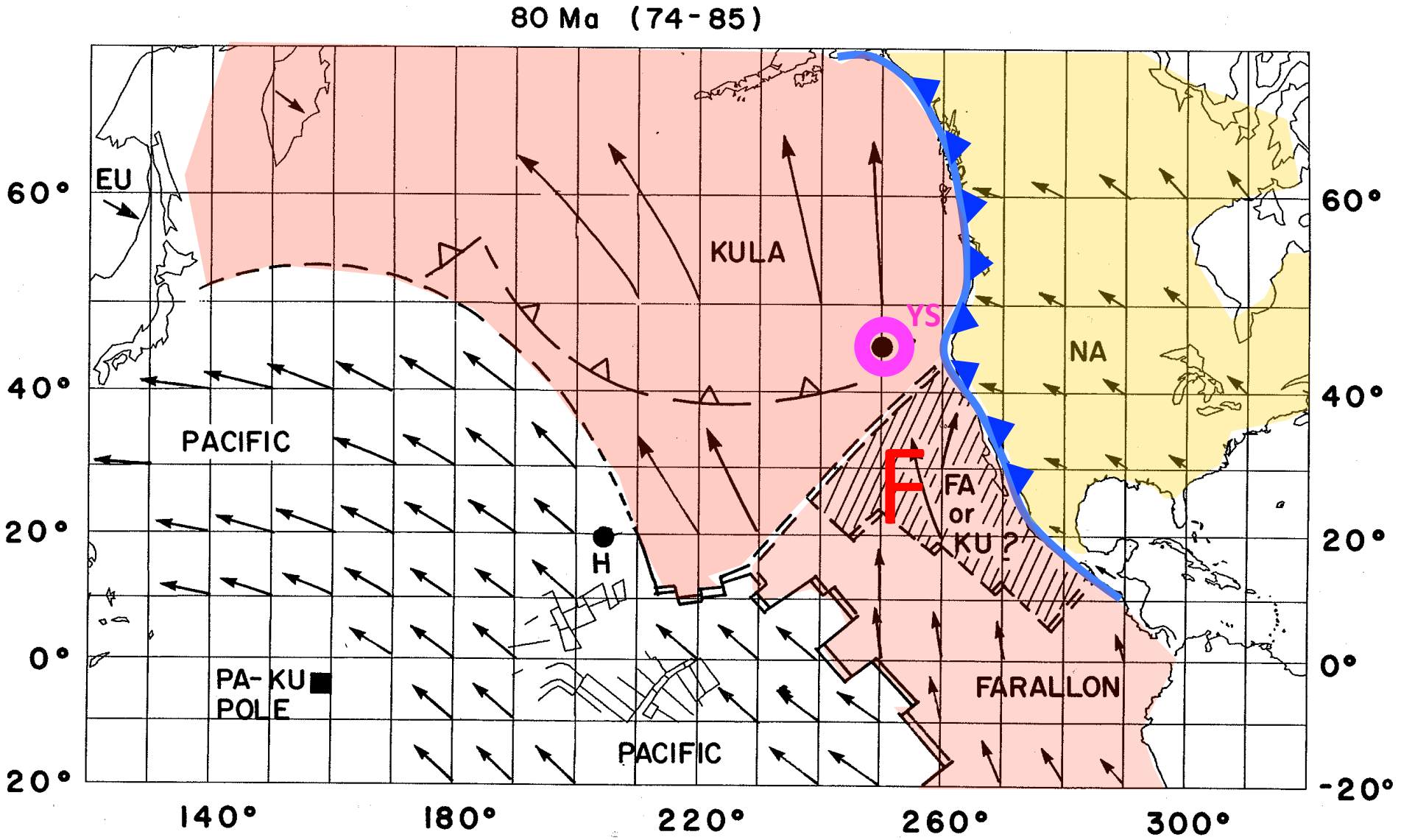
Reconstructed western margin of North America over time (Ren et al. 2007).

Standard model: Pacific basin 140 Myr ago…



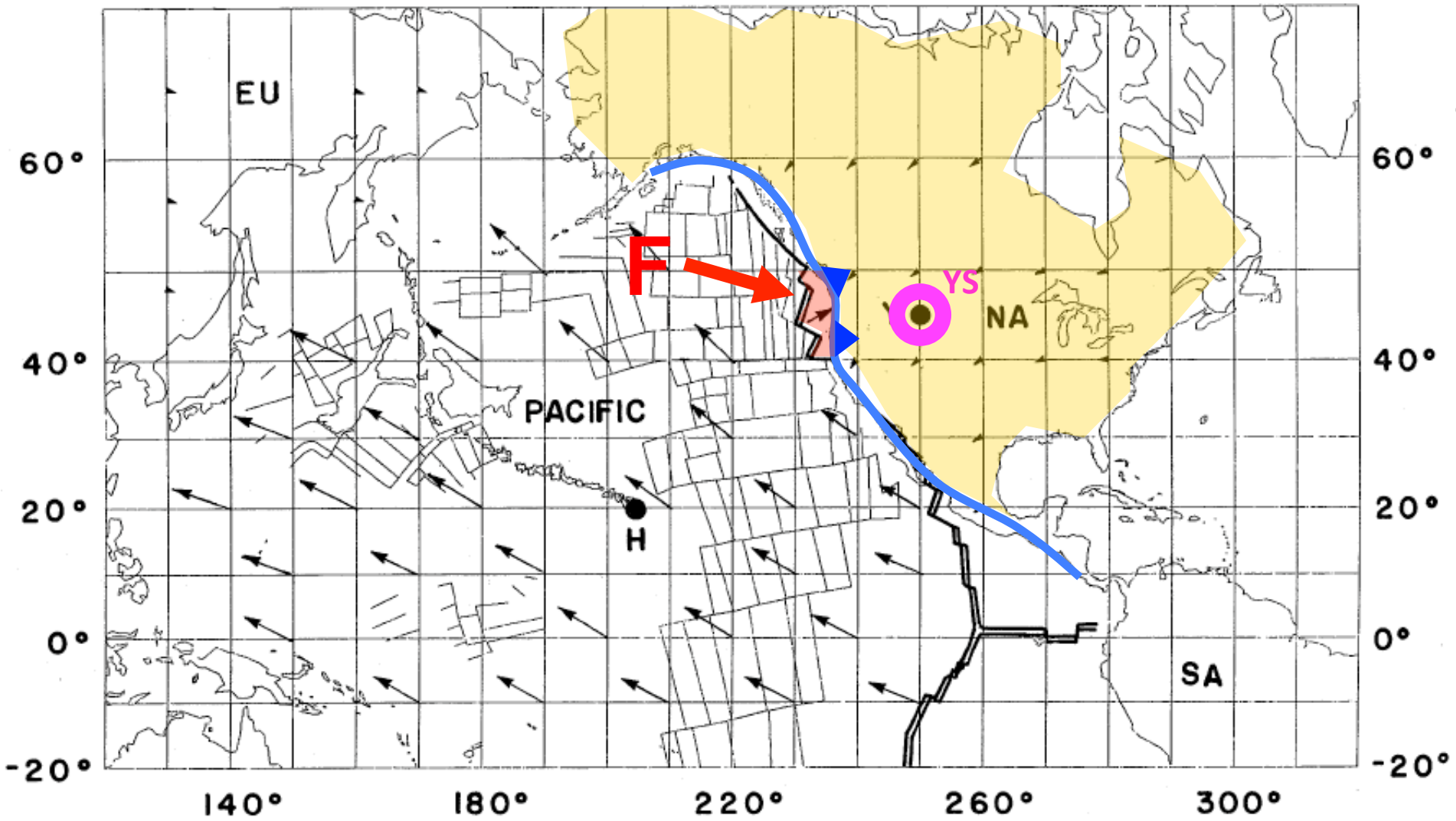
Engebretson et al. 1985

…and 80 Myr ago…



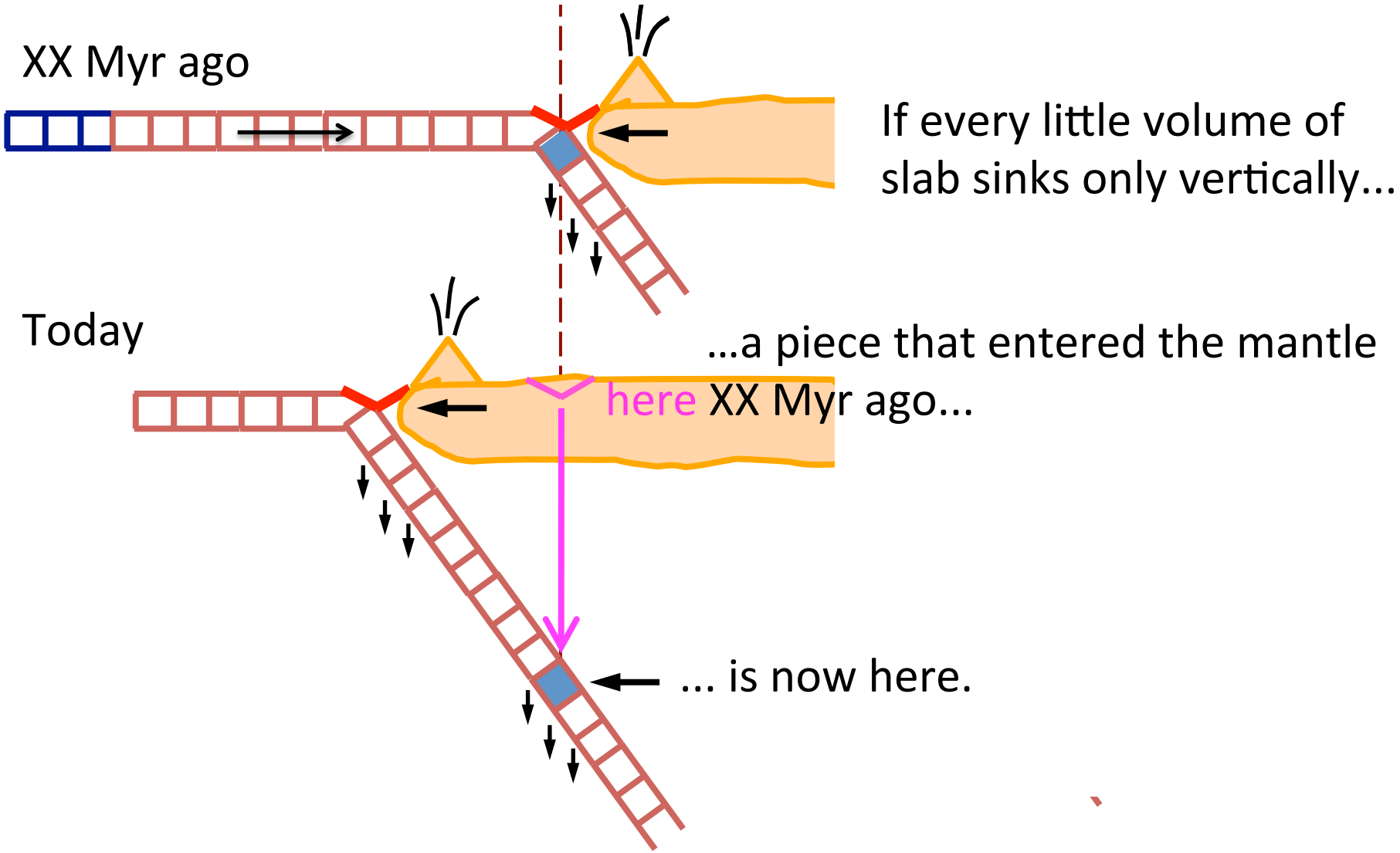
Engebretson et al. 1985

…and today. This scenario is constrained by marine magnetic anomalies only.



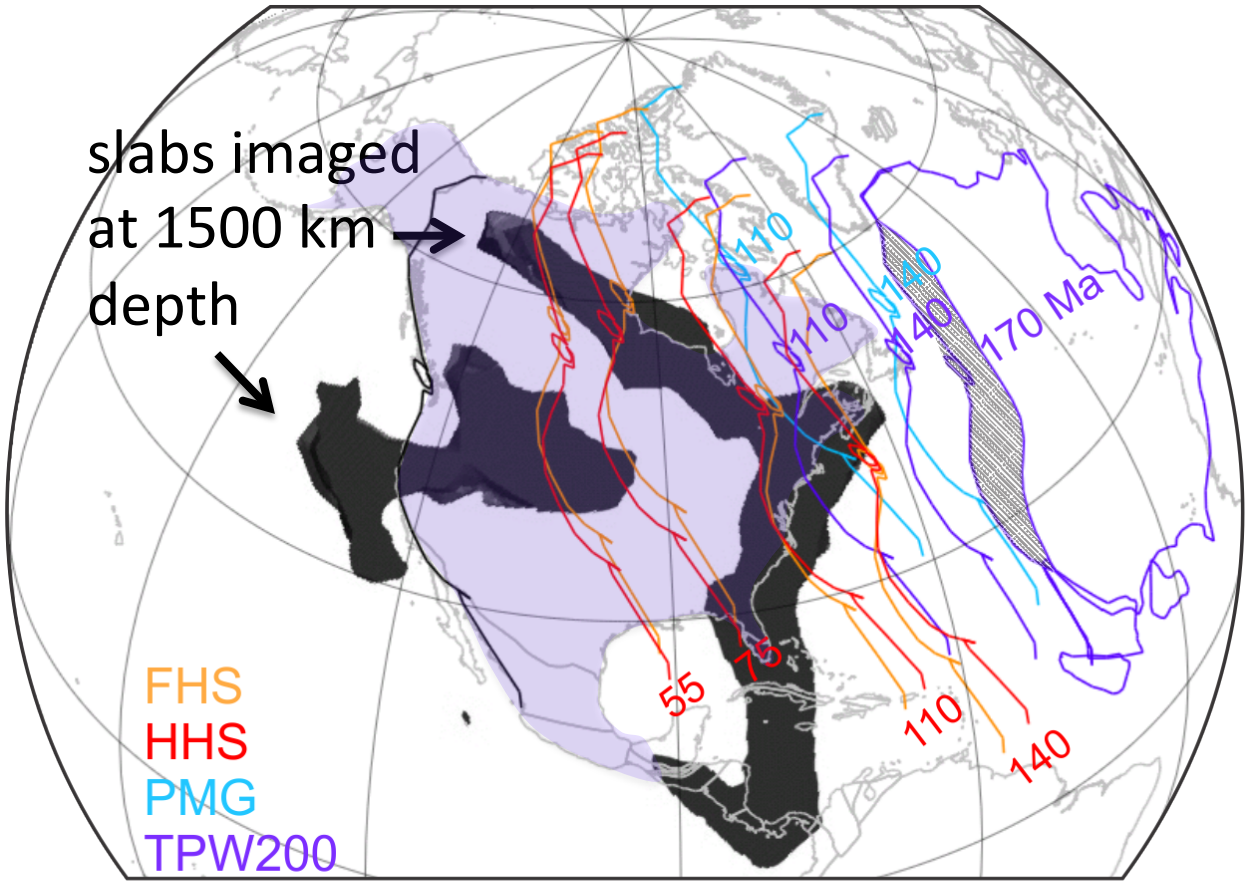
Engebretson et al. 1985

Vertical slab sinking beneath a migrating margin



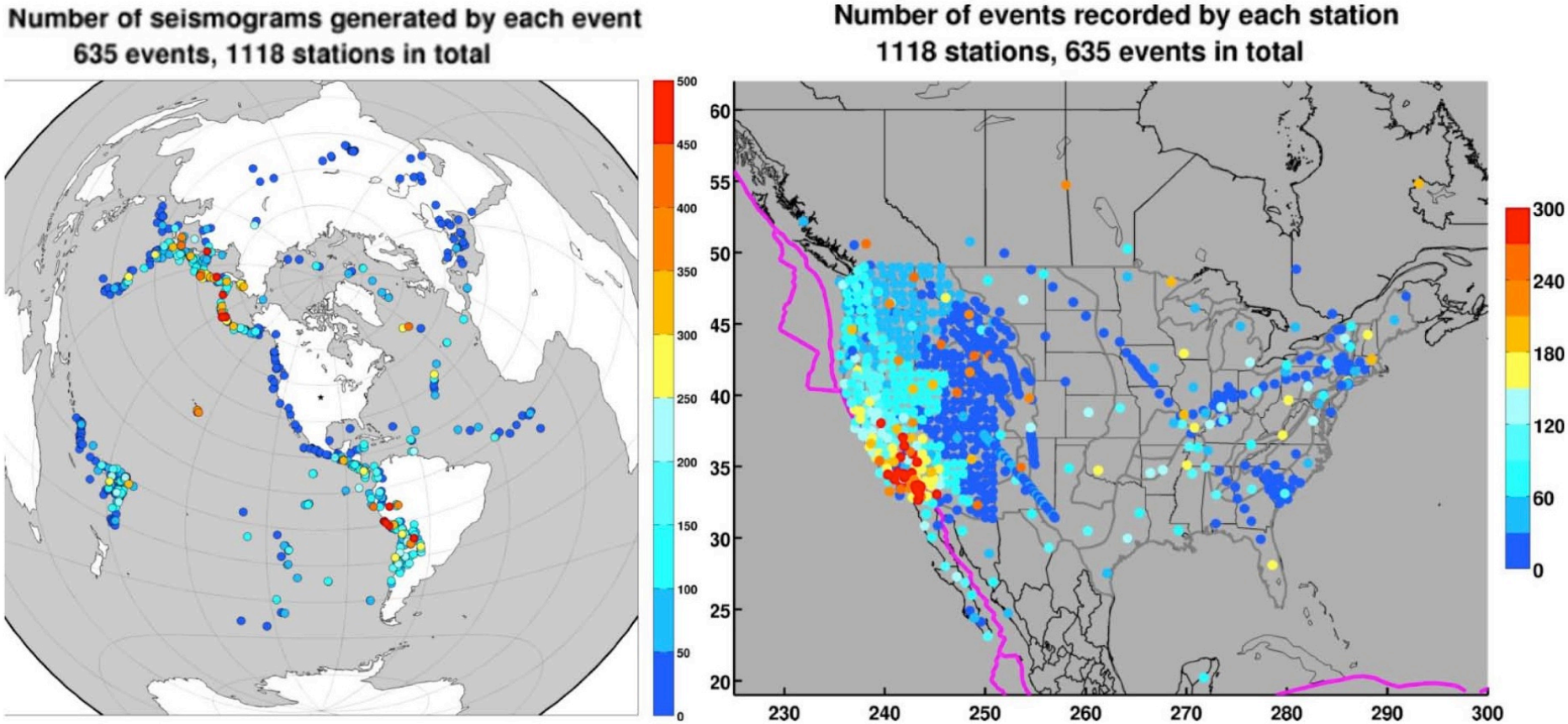
Contribution of seismic tomography: 3-D images of subducted, proto-Pacific seafloor

- Slabs represent paleo-oceans and paleo-trenches (in some sense).
- Slab distribution is very uneven.
- Outlines of west coast do not match outlines of the slabs.



Sigloch & Mihalynuk 2013 Nature

Contribution of seismic tomography: 3-D images of subducted, proto-Pacific seafloor



sources (teleseismic earthquakes)

receivers (broadband seismometers)

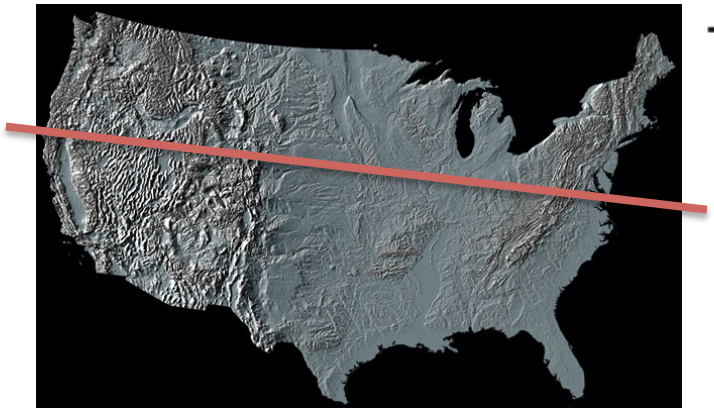
Discussion is based on my most recent waveform inversion of teleseismic P-waves (multi-frequency tomography, Sigloch 2011 G-cubed).

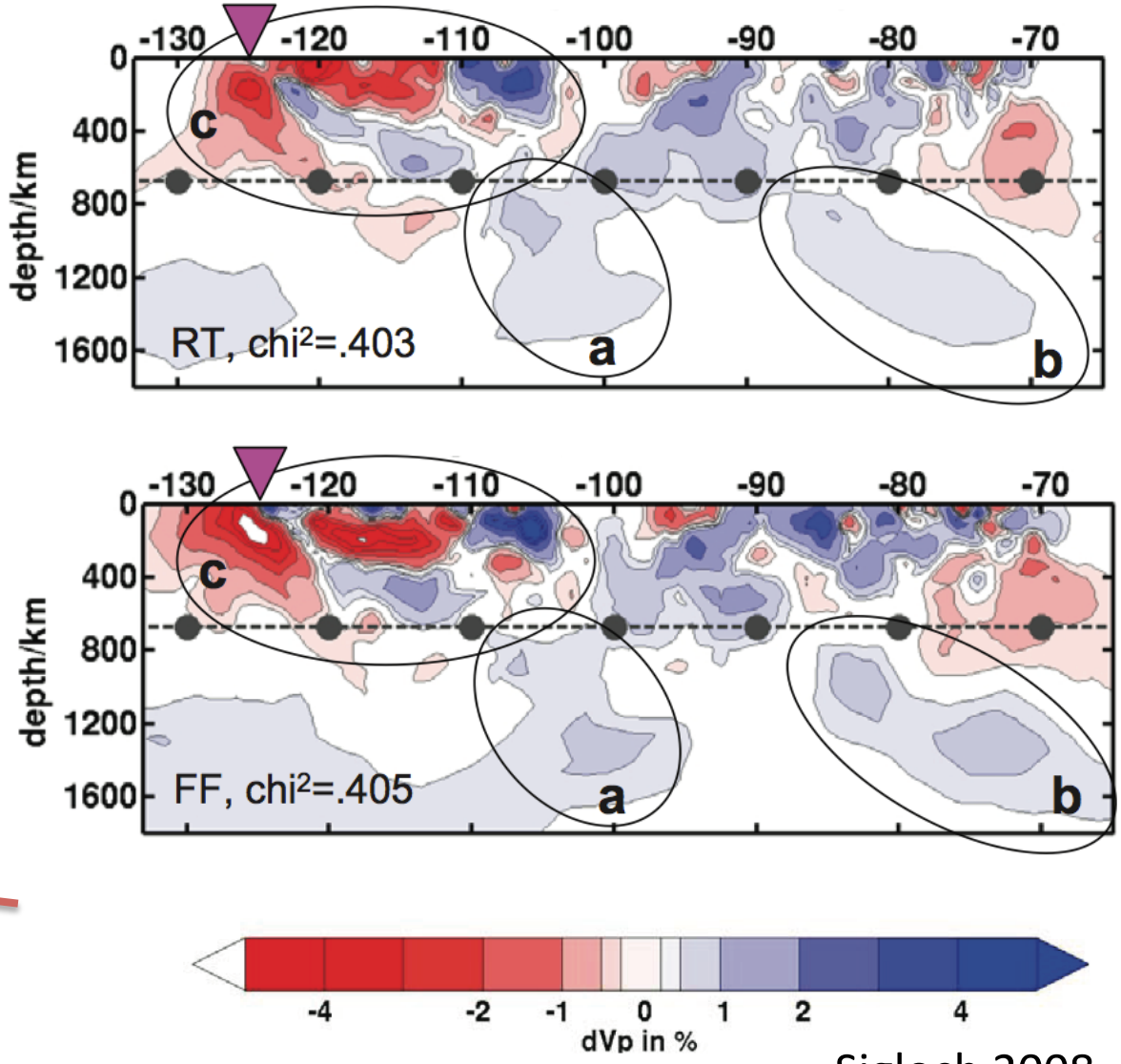
Technical advances: Finite-frequency tomography images deeper into the mantle

P-velocity anomalies,
E-W section at 40°N:

a) from traditional, ray-theoretical tomography

b) from finite-frequency tomography

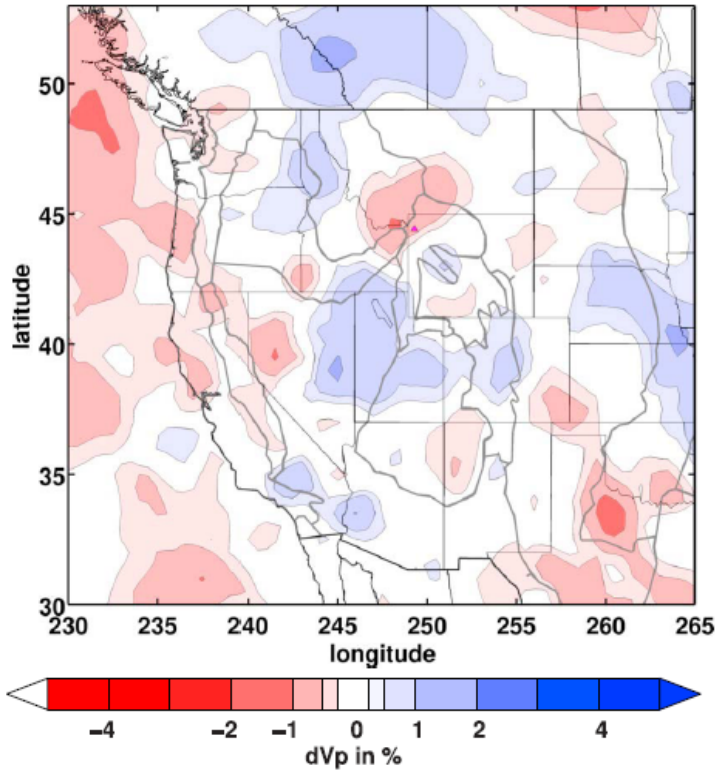


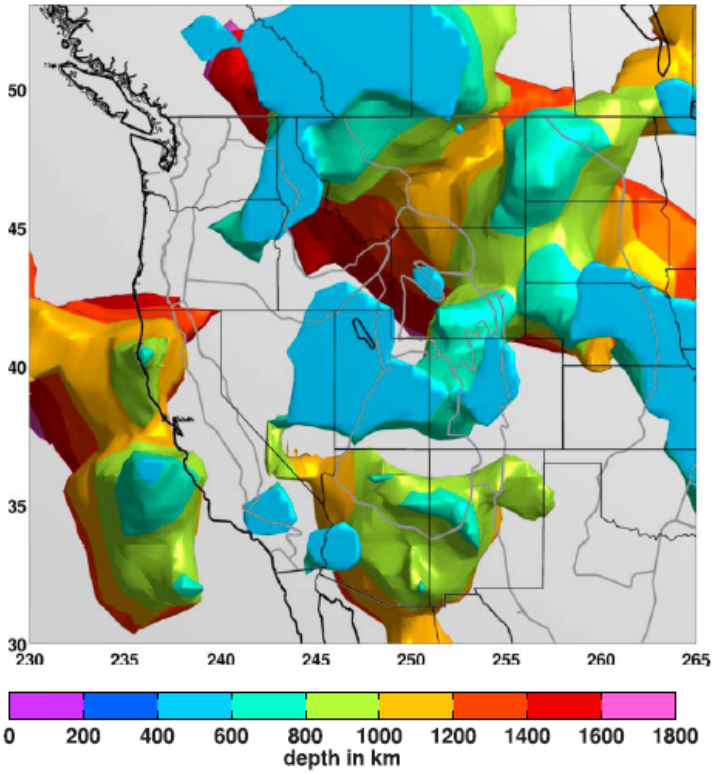


Sigloch 2008

Tomographic P-velocity model, rendered in 3-D

Velocity anomalies are resolved down to
1500-2000 km depth under North America.

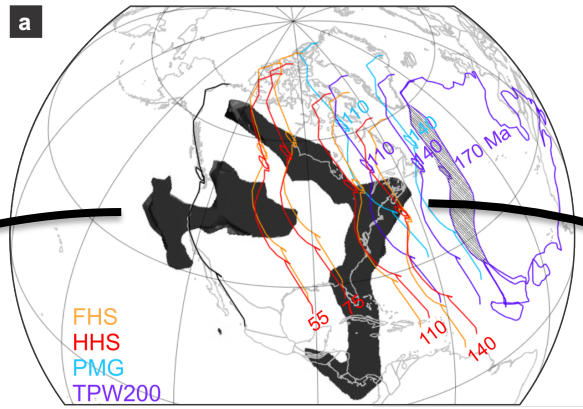


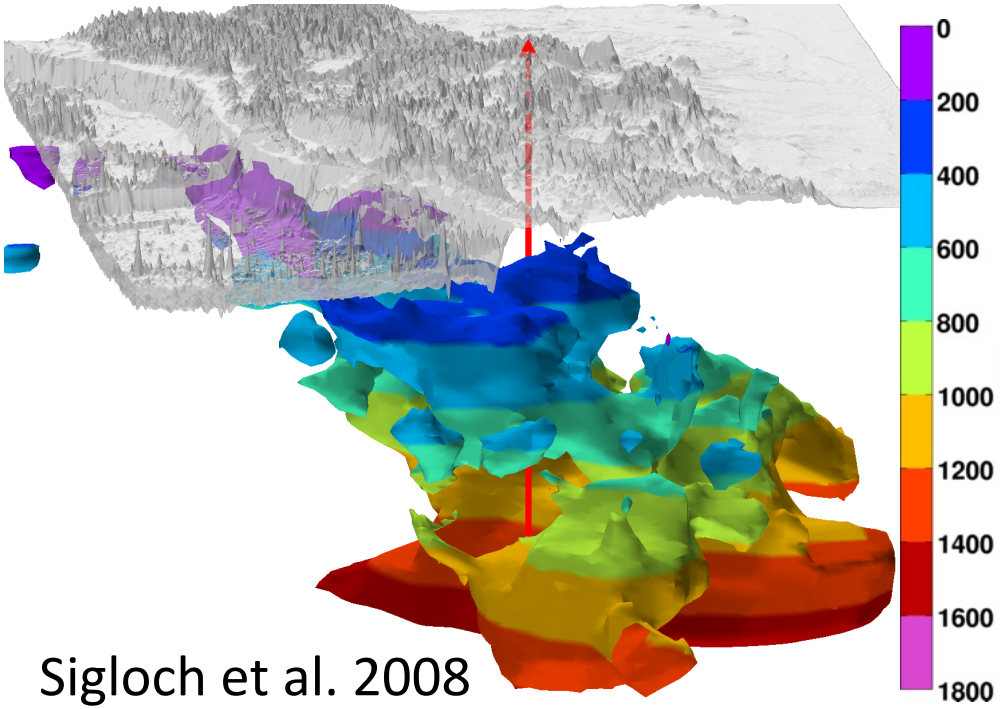


Conventional rendering of a tomographic model: 2-D section at a fixed depth (600 km).

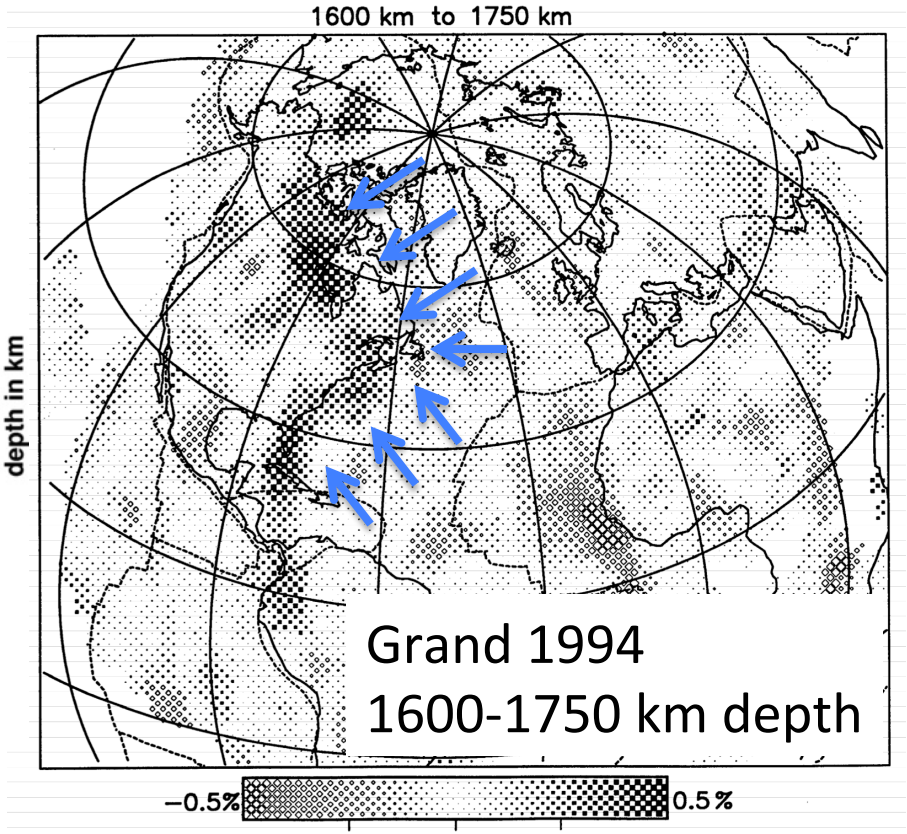
My renderings: 3-D isosurface enclosing all FAST structure (=subducted slabs) *at and below* 600 km depth.

Seismically fast domains in the lower mantle

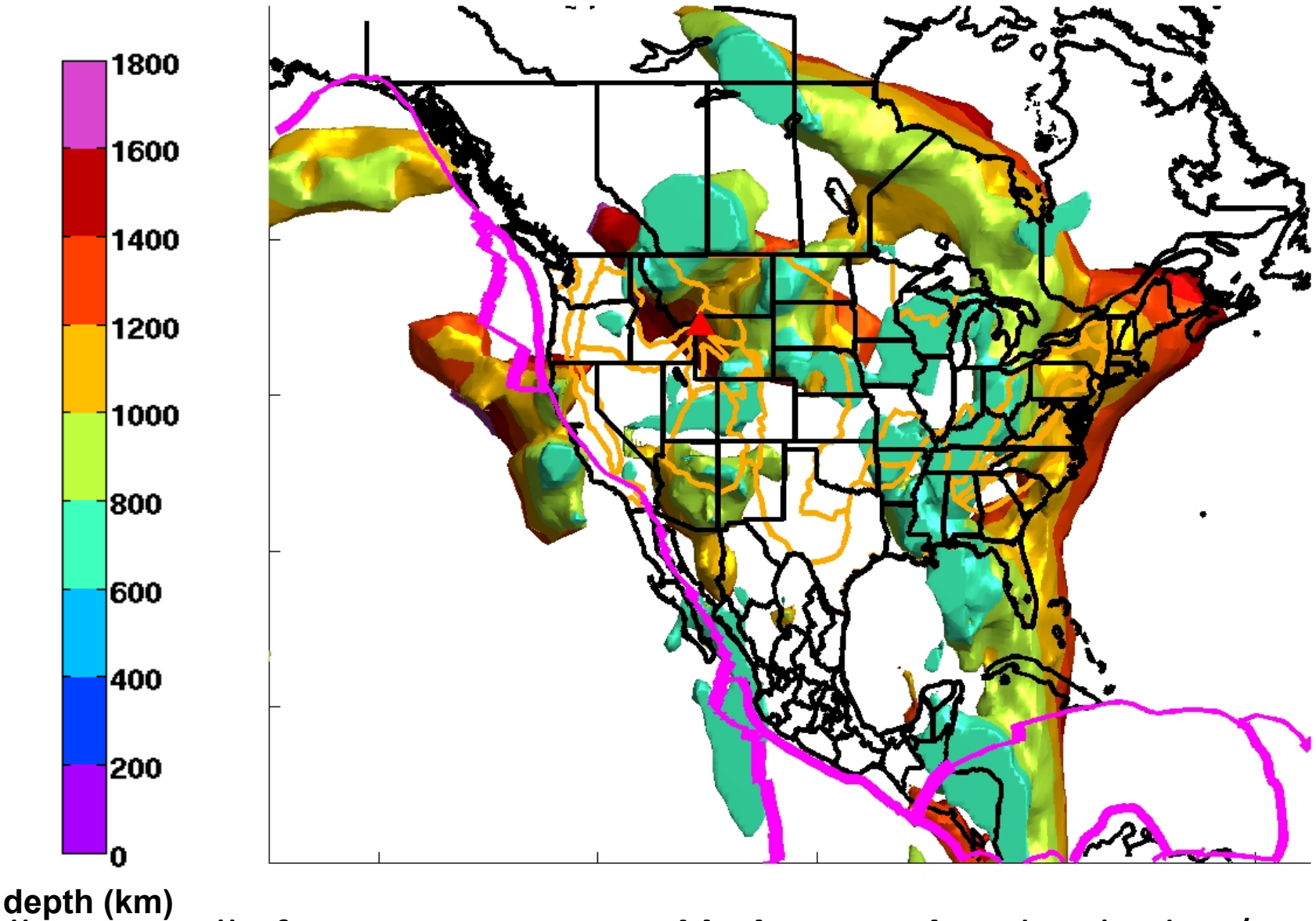




Sigloch et al. 2008

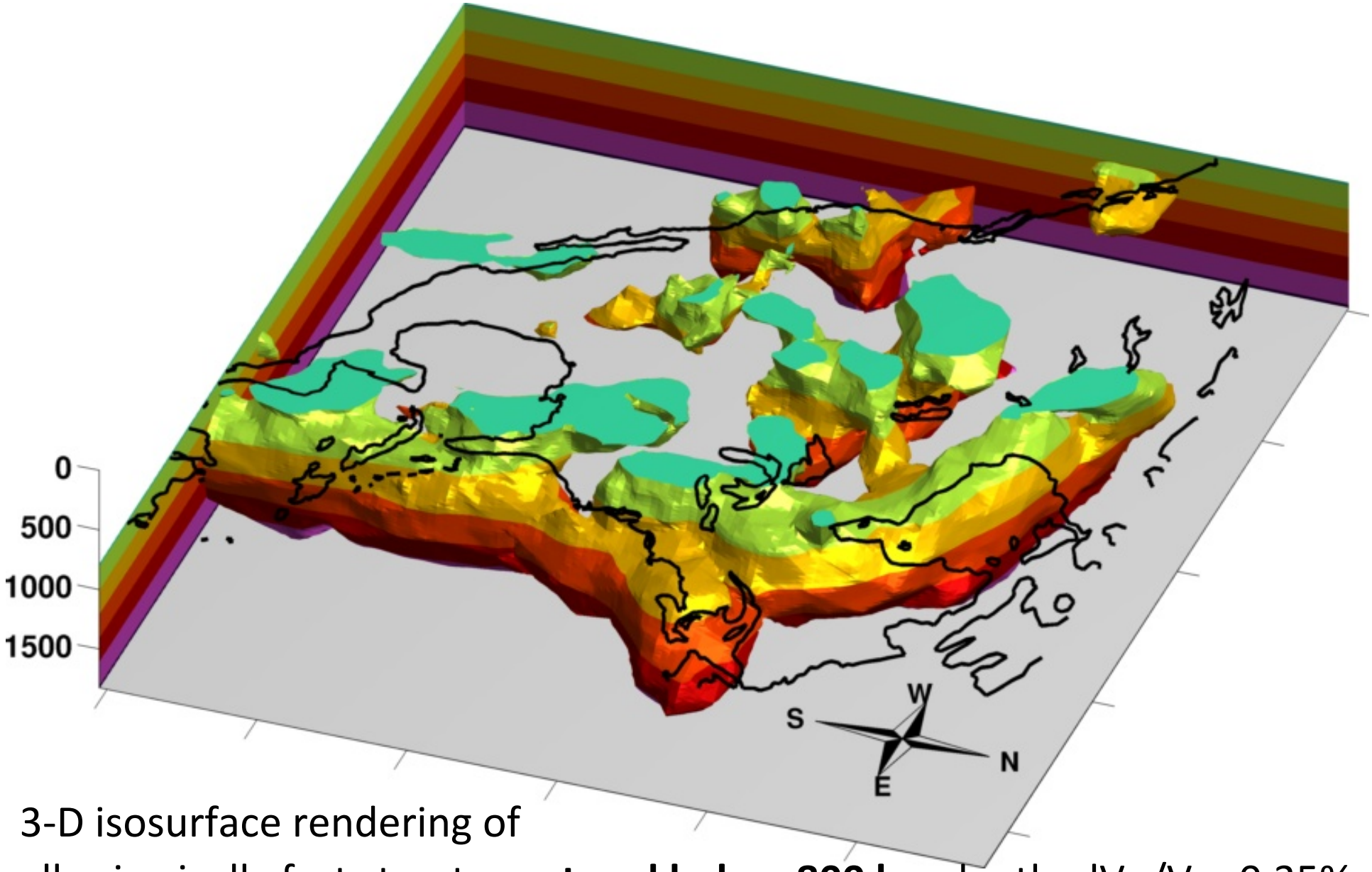


Slab walls under North America



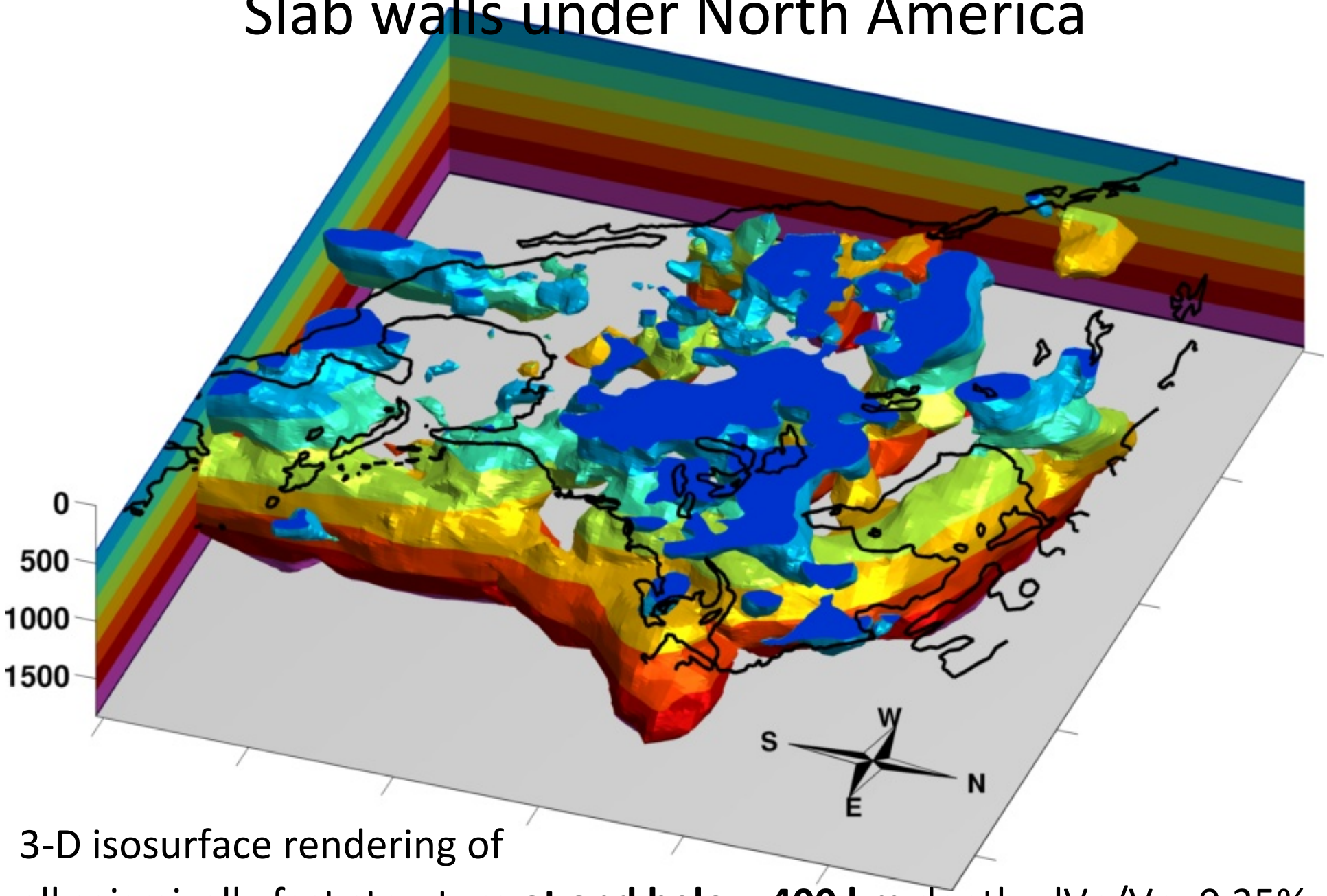
All seismically fast structure **at and below 700 km** depth, dVp/Vp=0.35%

Slab walls under North America



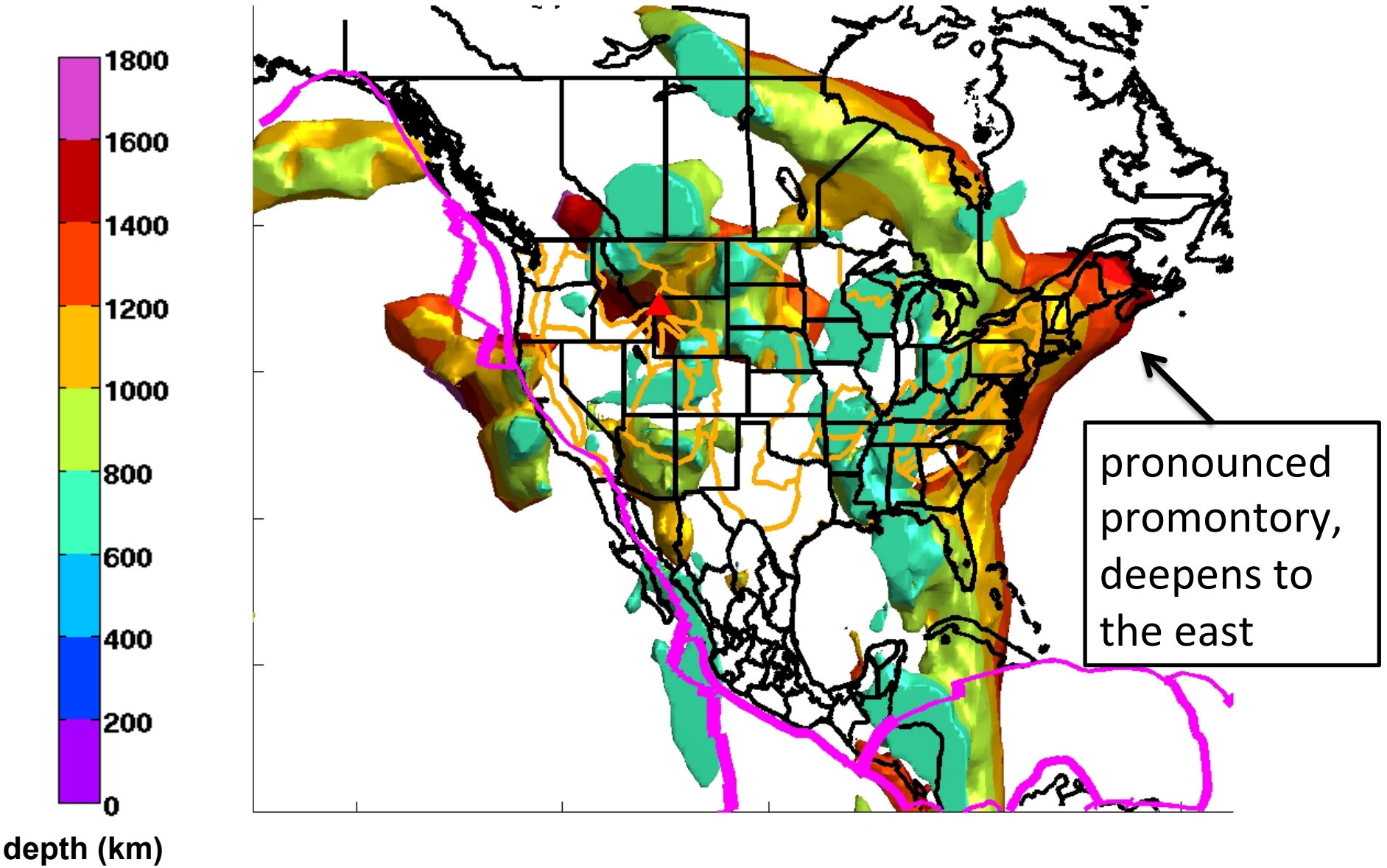
3-D isosurface rendering of
all seismically fast structure **at and below 800 km** depth, dVp/Vp=0.35%

Slab walls under North America



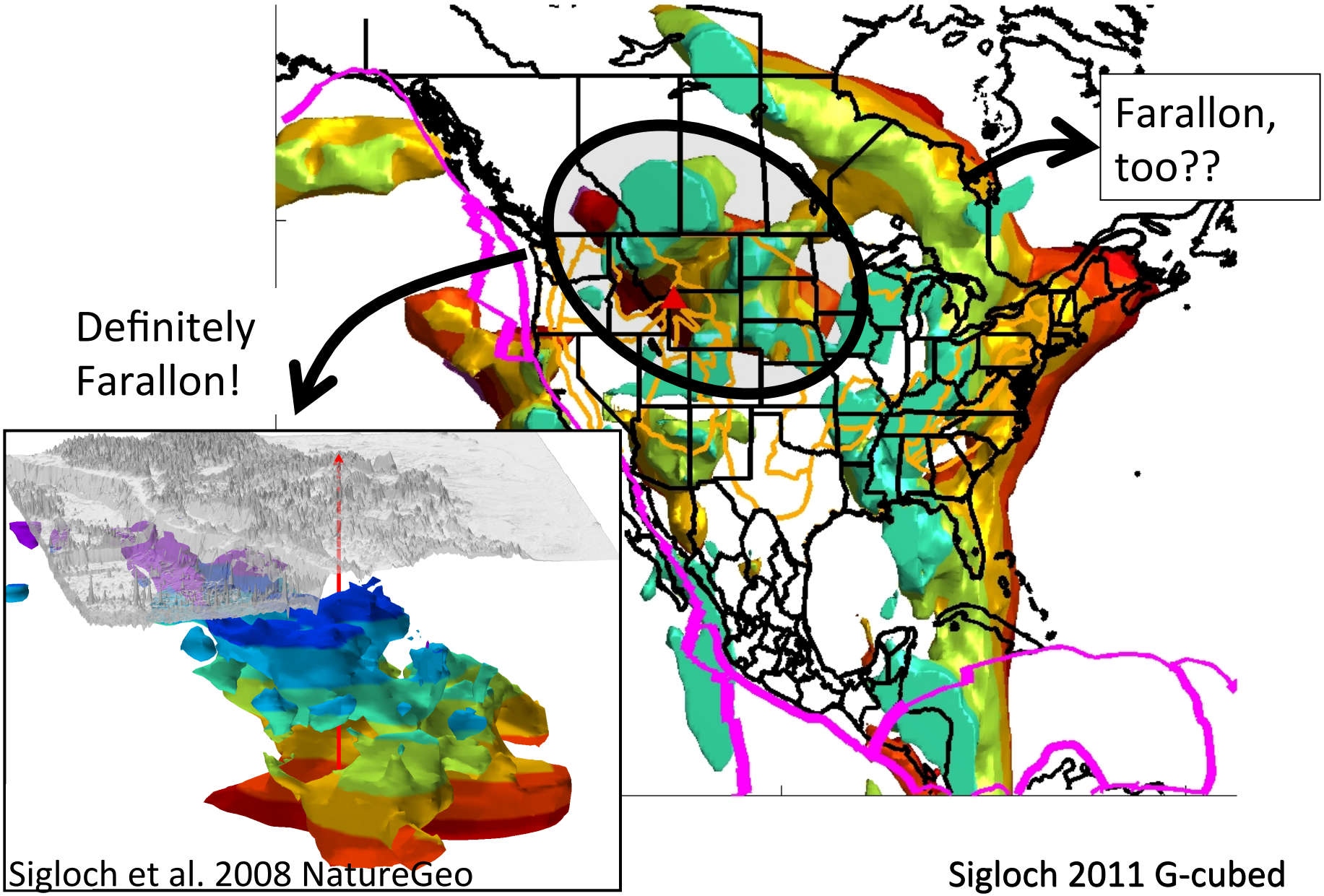
3-D isosurface rendering of
all seismically fast structure **at and below 400 km** depth, dVp/Vp=0.35%

Slab walls at and below 700 km depth

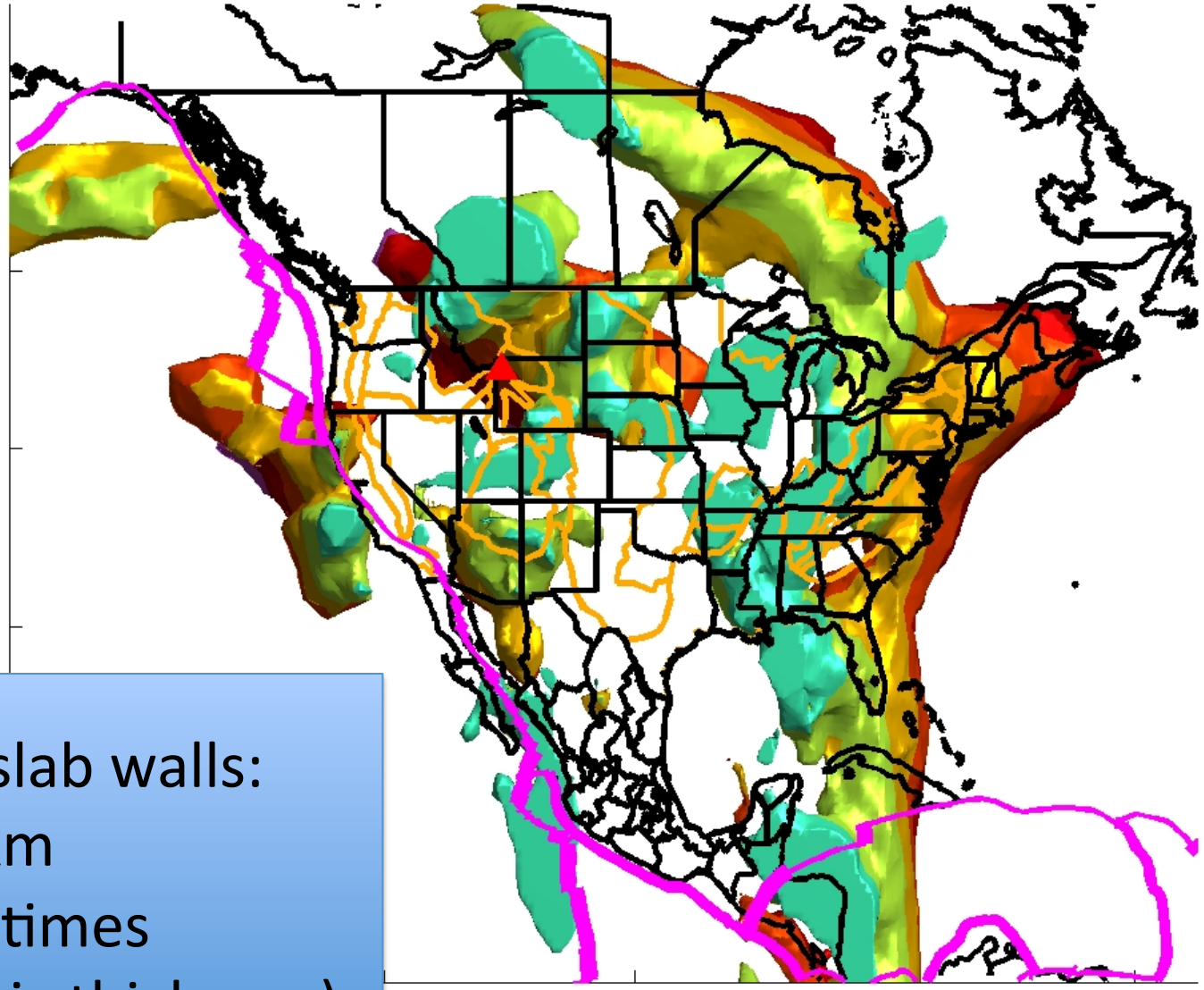


Sigloch 2011 G-cubed

Slab walls at and below 700 km depth



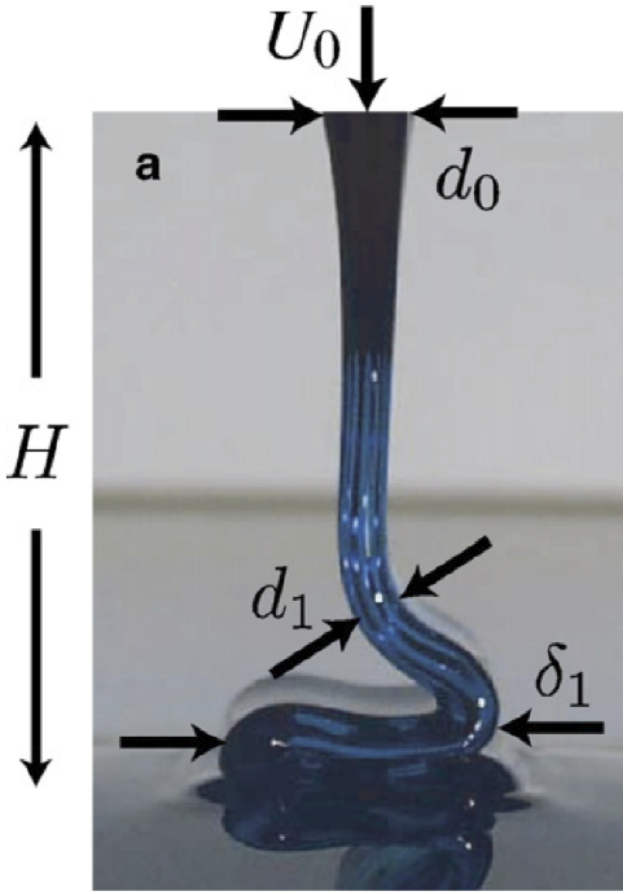
Slab walls at and below 700 km depth



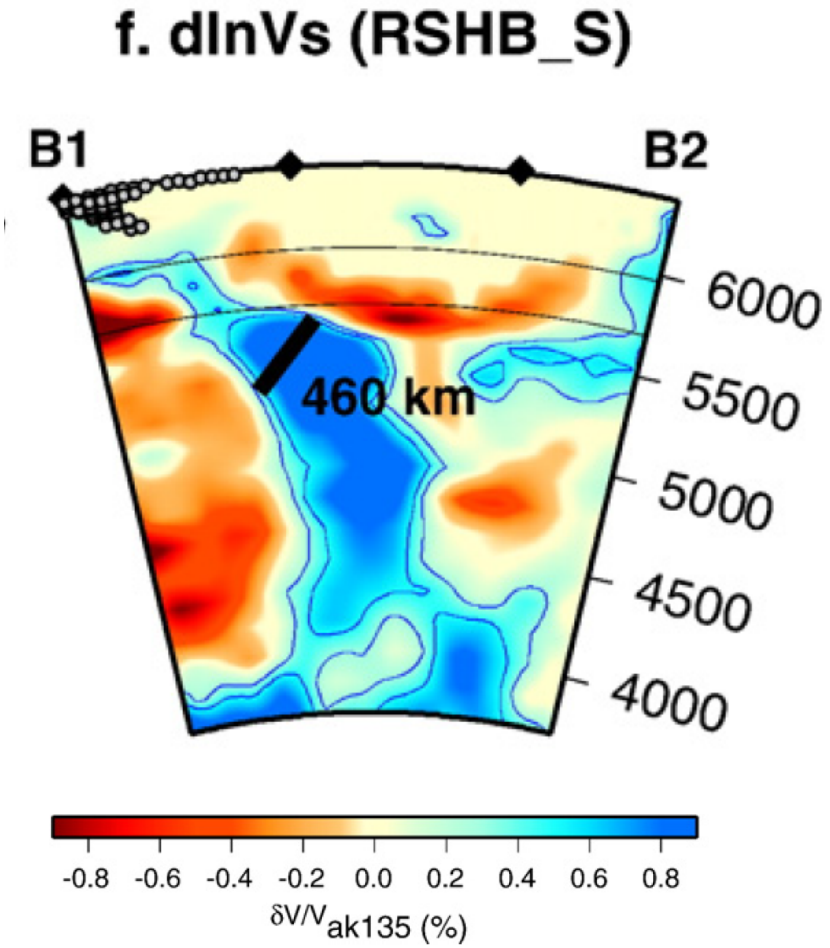
Width of slab walls:
400-600 km
(i.e., 4-6 times lithospheric thickness)

Sigloch 2011 G-cubed

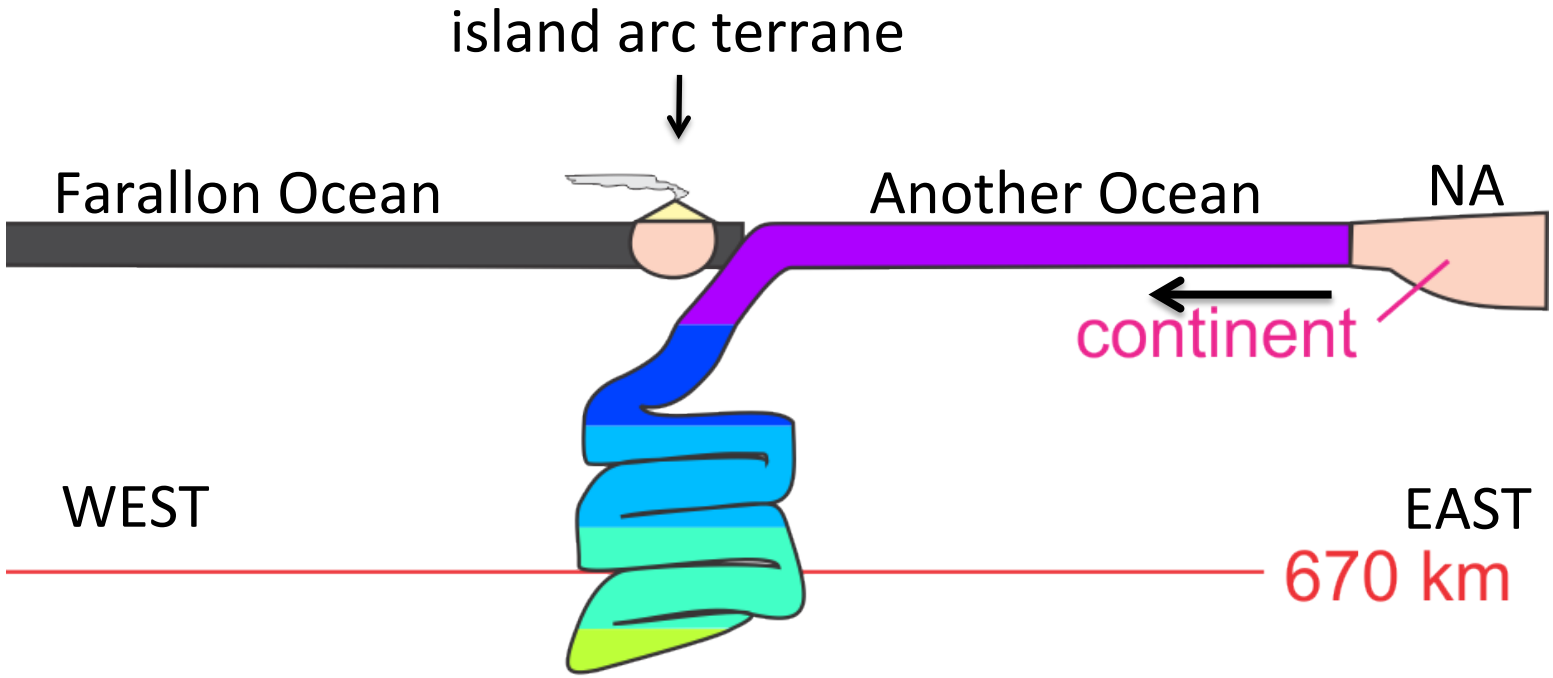
How to deposit a widened, vertical slab wall: a long-lived, *stationary* trench – and a slab that folds beneath it.



Ribe et al. 2007 EPSL



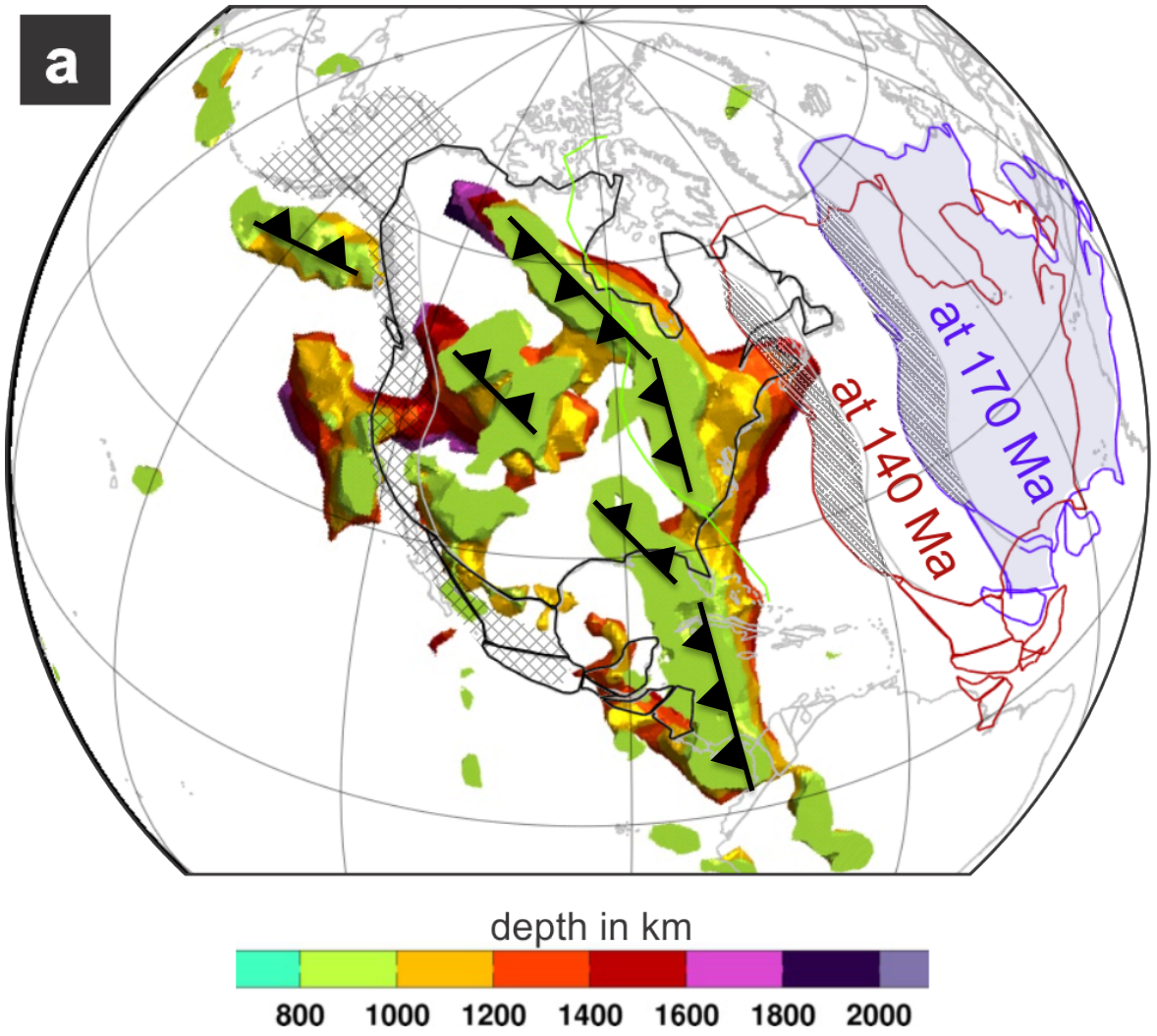
Stationary trench plus vertical sinking deposit a vertical slab wall.



Stationary trench? Only possible if trench was intra-oceanic (west of westward-moving North America).

Did North America override an archipelago of island arcs during Cretaceous times?

- How old are the slab walls?
- Old enough to have originated beneath intra-oceanic trenches?
- If so, where are their associated arc terranes now?

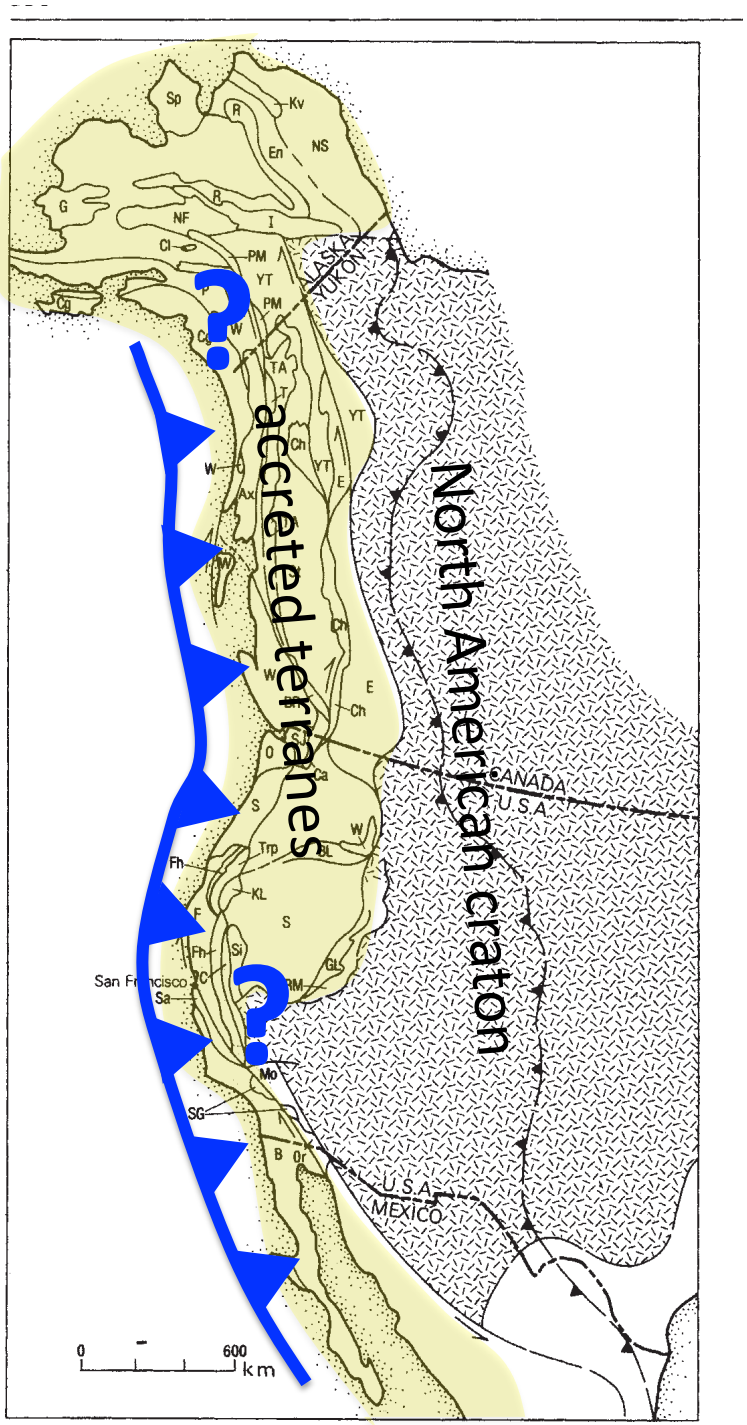


Sigloch & Mihalynuk, 2013 Nature

70% of the North American Cordillera is made up of 'suspect terranes'

- Relatively young rocks (<400 Ma).
- Terranes arrived at western NA margin between ~200 Ma and 50 Ma.
- "…most of them display […] rock sequences that are of oceanic affinity rather than continental."

Coney et al. 1980



The proto-Pacific in Jurassic/Cretaceous times?

Moores 1998: “Whimsical tectonic map,” from Simkin et al. 1989.

Proposed an archipelago of island arcs, based on land geological observations.

Stages of arc override

a: Oceanic trench active.

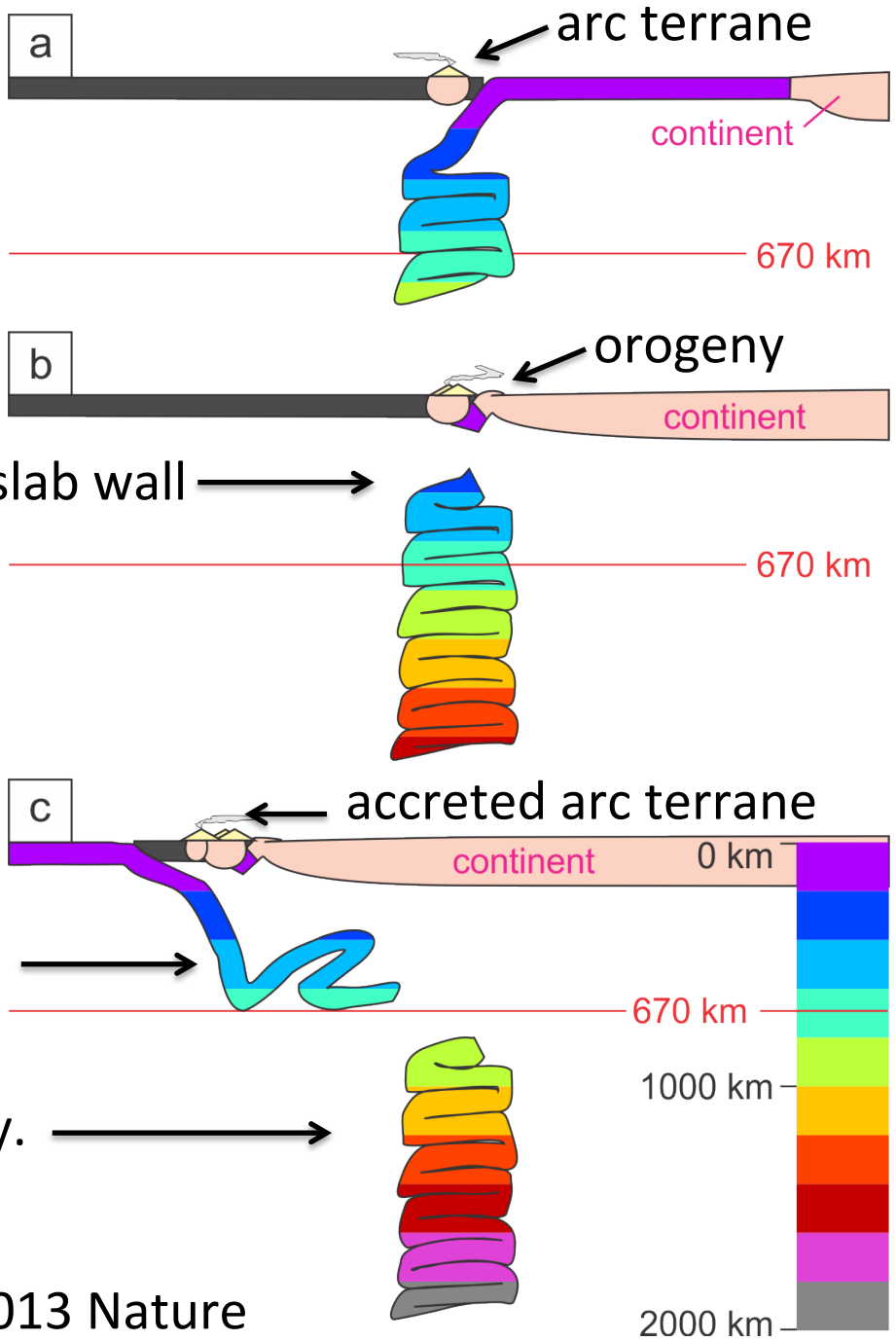
b: Shortly after arc override.

sharp upward truncation of slab wall →

c: Long after arc override.

new Andean-style margin produces → smeared out upper-mantle slab.

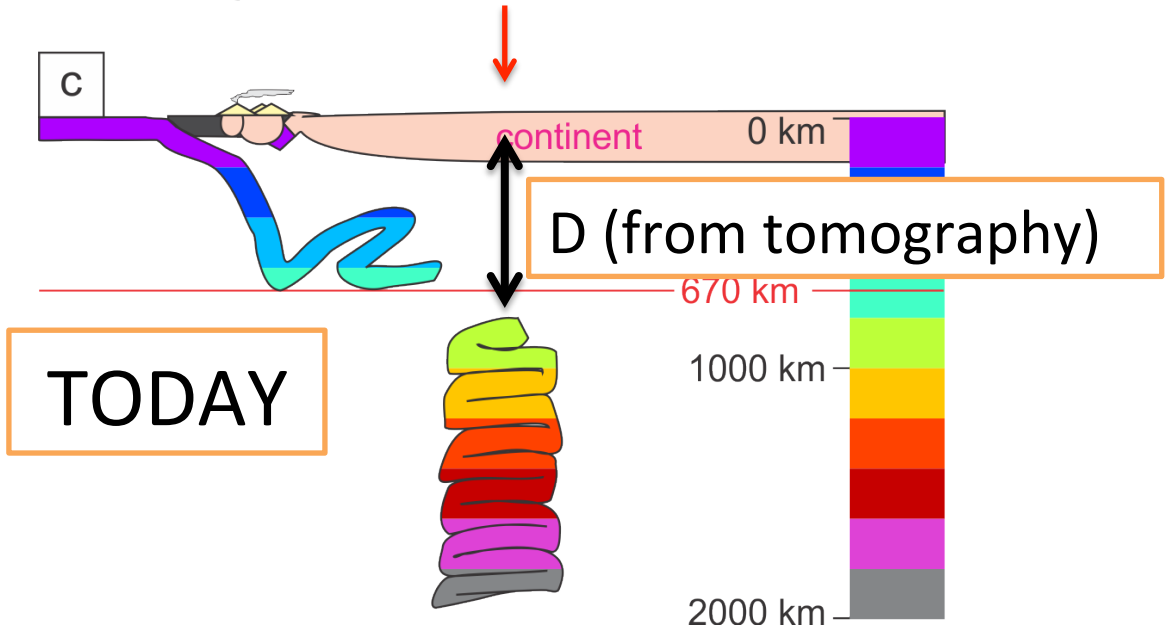
Slab wall continues to sink vertically. →



Sigloch & Mihalynuk 2013 Nature

Quantifying slab ages and slab sinking rates

Plate reconstruction: "Margin was here at time T."

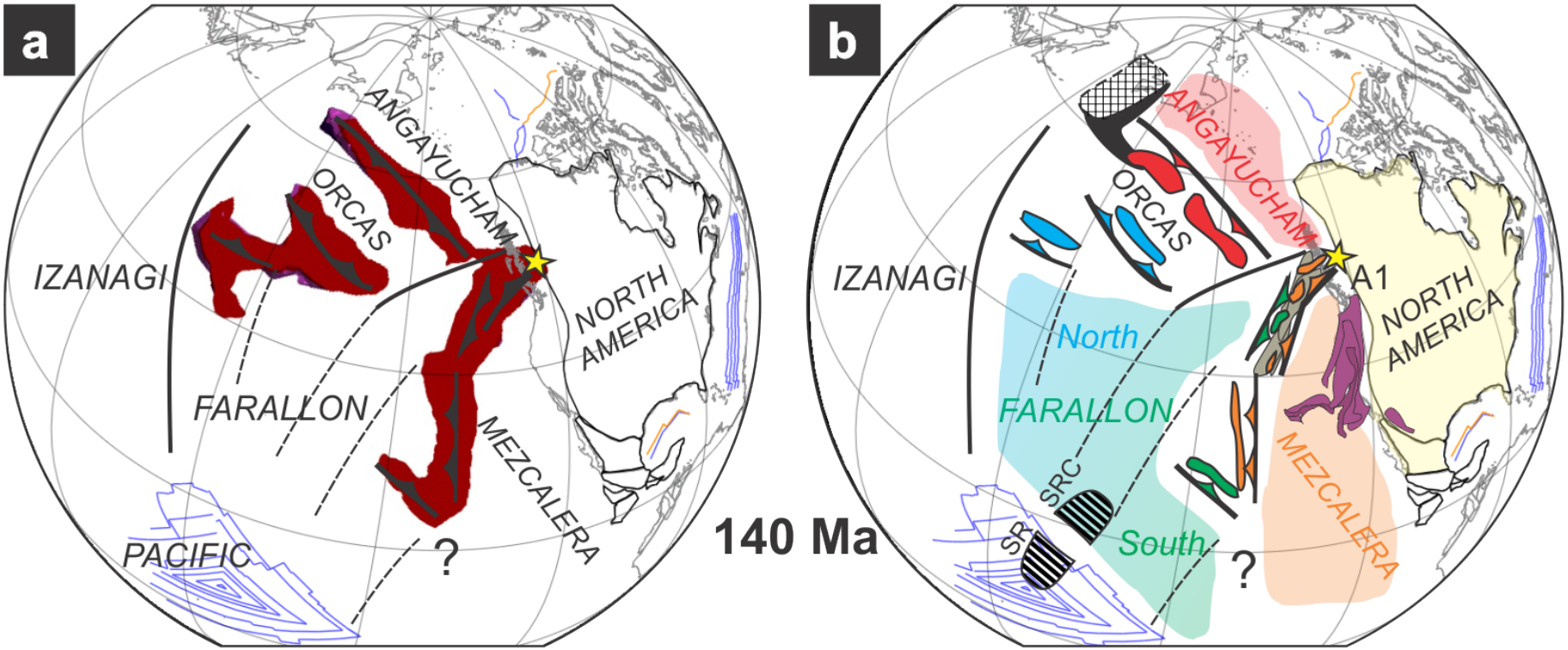


Sinking rate = D/T ≈ (10 ± 2) mm/yr

⇒ Slab age, example: D = 1000 km depth ≙ T= 100 Ma since subduction

T is also the time of predicted terrane collision and mountain building.

Before 140 Ma: Stationary oceanic trenches acted as “terrane stations”

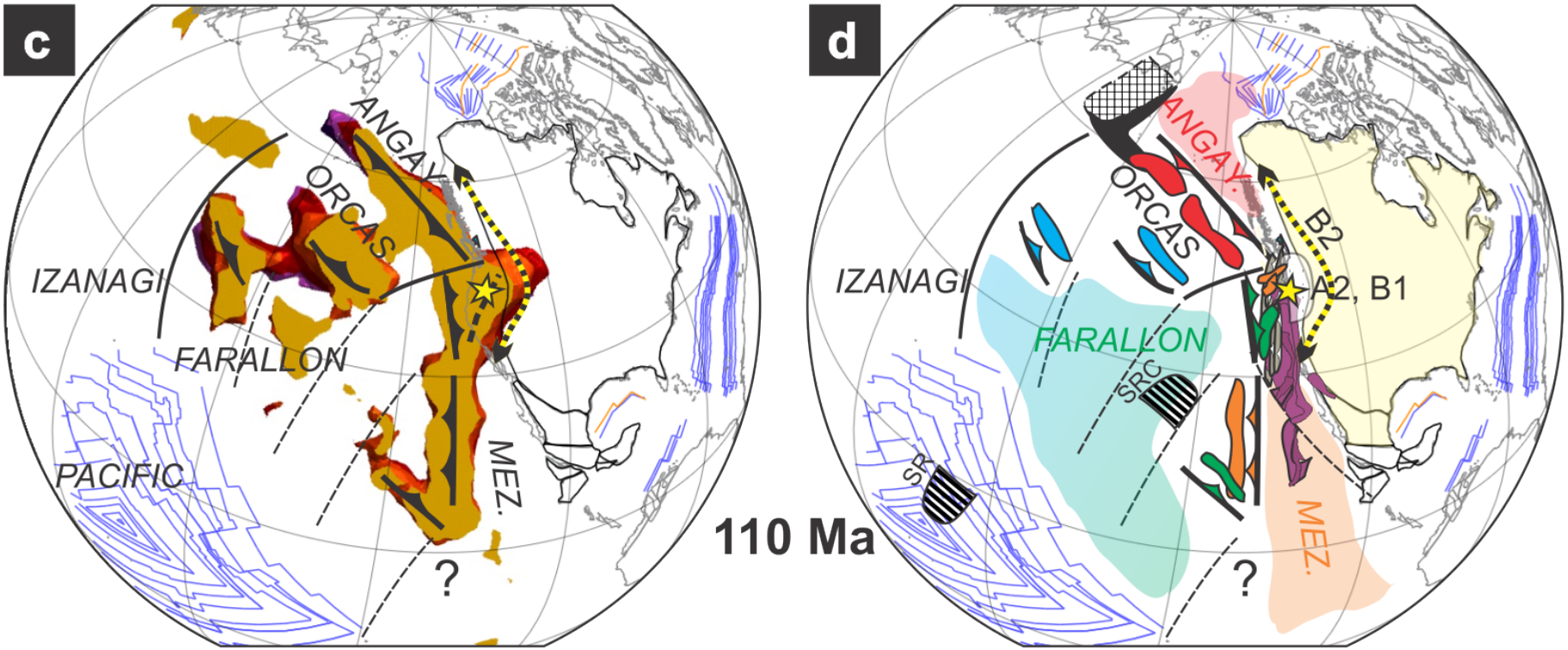


Slabs already deposited at 140 Ma, based on 10 mm/yr sinking.

Inferred terrane assemblage before override of archipelago

The Mezcalera and Angayucham oceans are gradually closing. First continent-arc collisions predicted and observed in Pacific Northwest (A1)

110 Ma: Oceanic arcs are being overridden along much of the NA margin.

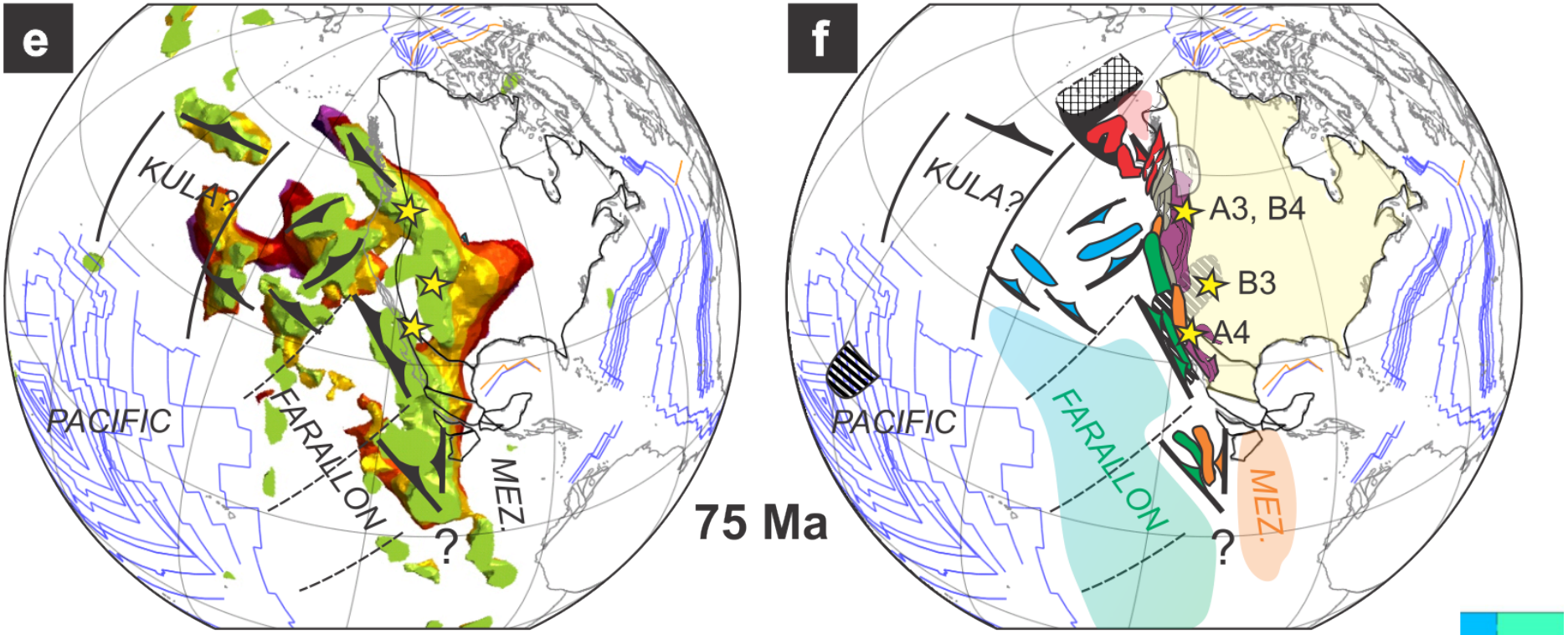


Causes Sevier and Canadian Rocky Mountain orogenies (B2).

Prolonged override of MEZ promontory → Omenica magmatic belts.

Intermontane superterrane (purple) collapsed onto NA margin.

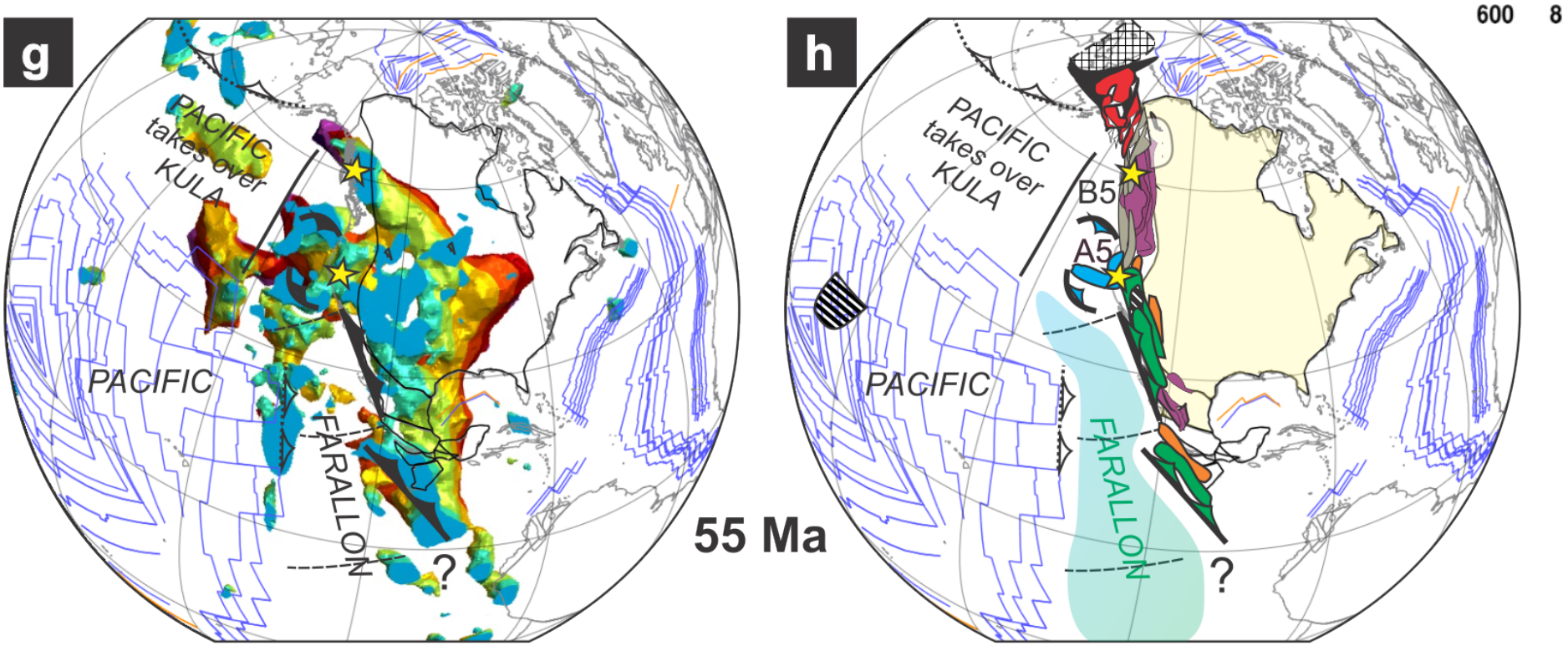
75 Ma: Coupled to the Farallon plate, accreted terranes get shuffled north.



Intermittent strong coupling of terranes to Farallon plate, due to accretion of a buoyant oceanic plateau (Shatsky Rise conjugate, B3). A corresponding slab window is clearly imaged, explains Tarahumara ignimbrite province (85±5 Ma, A4).

Buoyant plateau accretion also causes Laramide orogeny (B3).

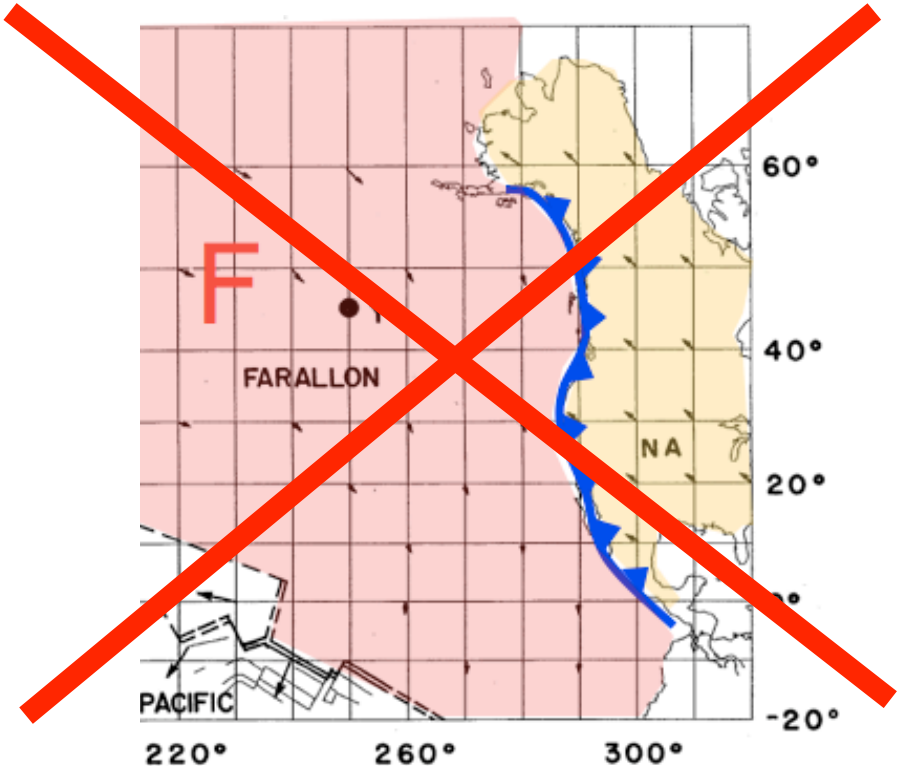
55 Ma: Archipelago override complete, last accretions along Cascadia margin.

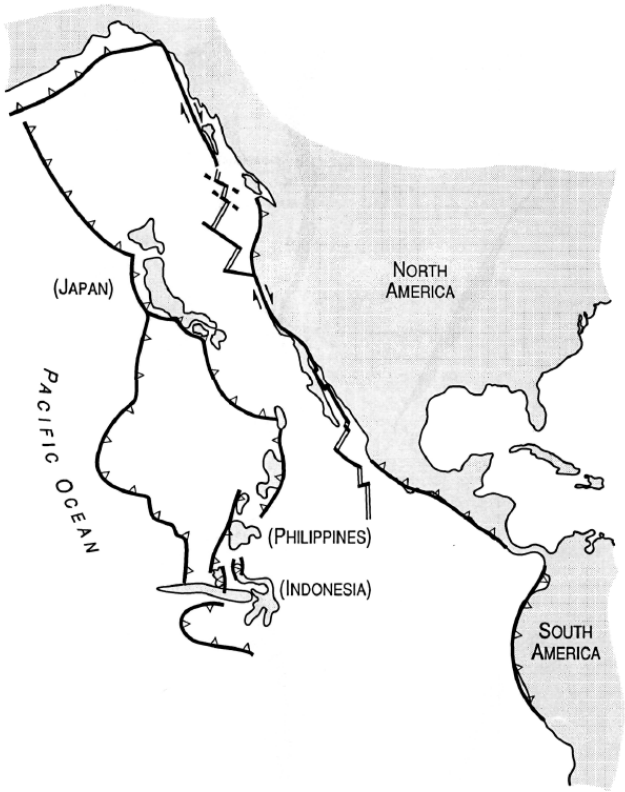


In Pacific Northwest, North Farallon trench turns continental. Accretion of associated terranes (Siletzia, Pacific Rim).

End of northward shuffle along margin. Red Angayucham terranes now make up interior Alaska. Intermontane/Insular superterranes now in B.C.

Conclusion





- Tomography and plate reconstructions predict that North America overrode a huge archipelago of island arcs between 150 and 50 Ma.
- This prediction is consistent with land geology, and causally explains the large volumes of accreted terranes of the Cordillera, and the mountain building far inland.