Imaging the Destruction of Continental Lithosphere beneath Afar

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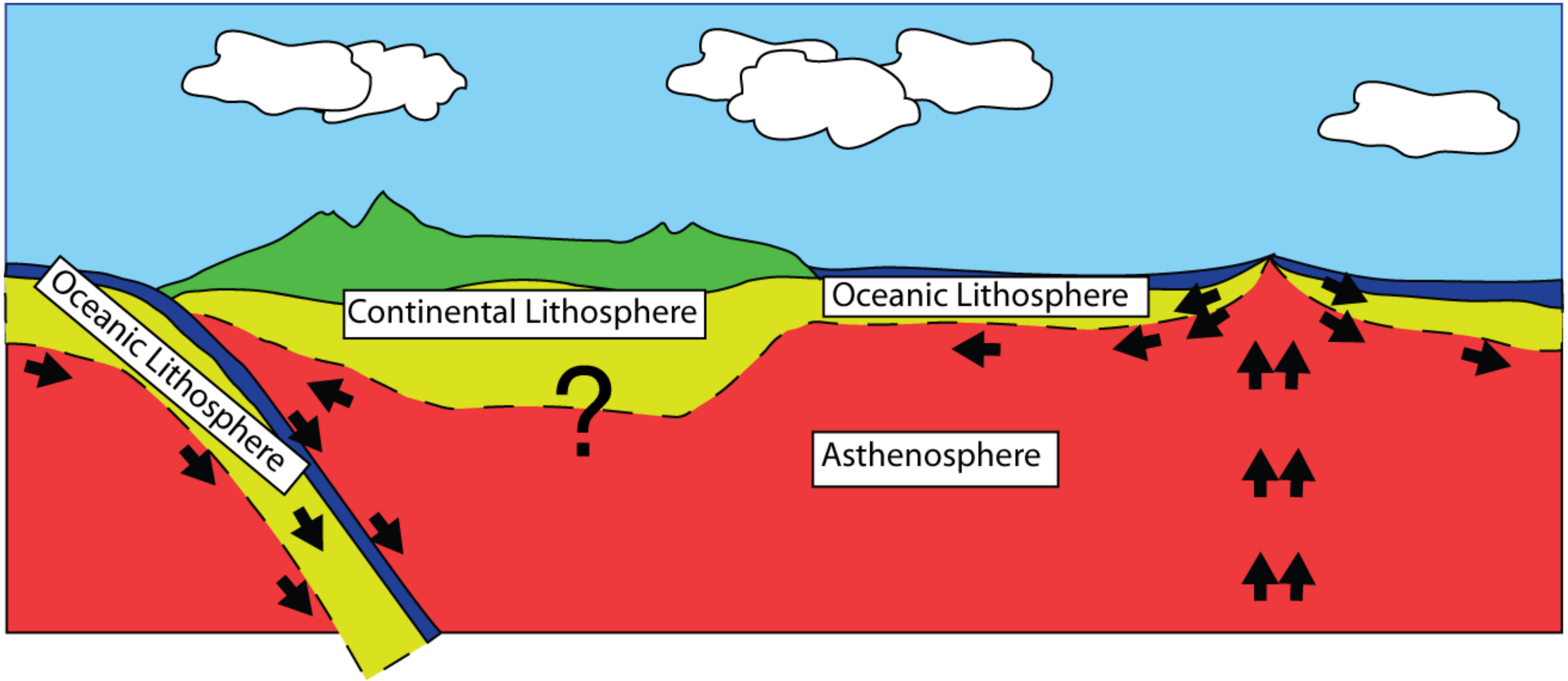
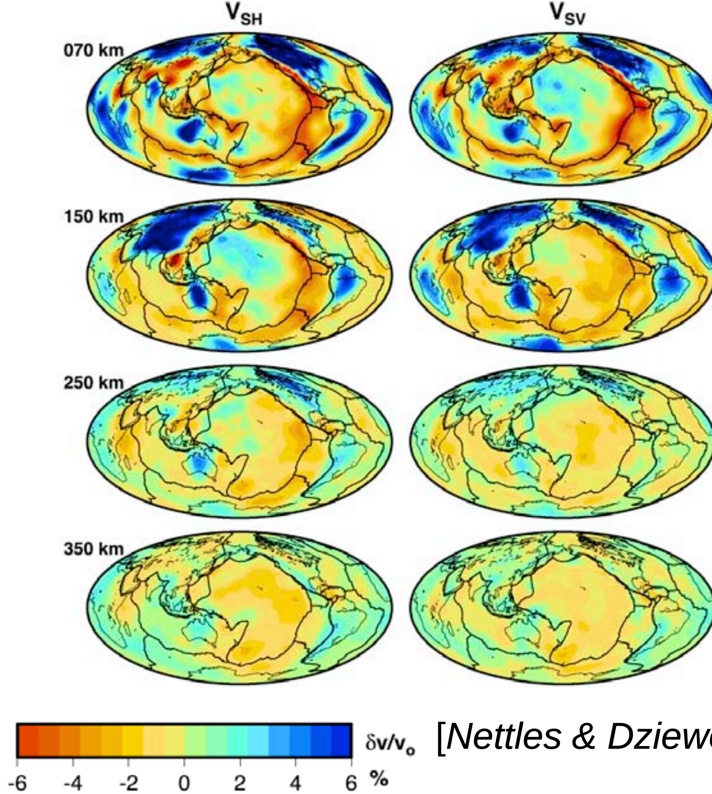
What is the lithosphere-asthenosphere boundary?



We would like to find the boundary between the rigid lithosphere and the convecting asthenosphere.

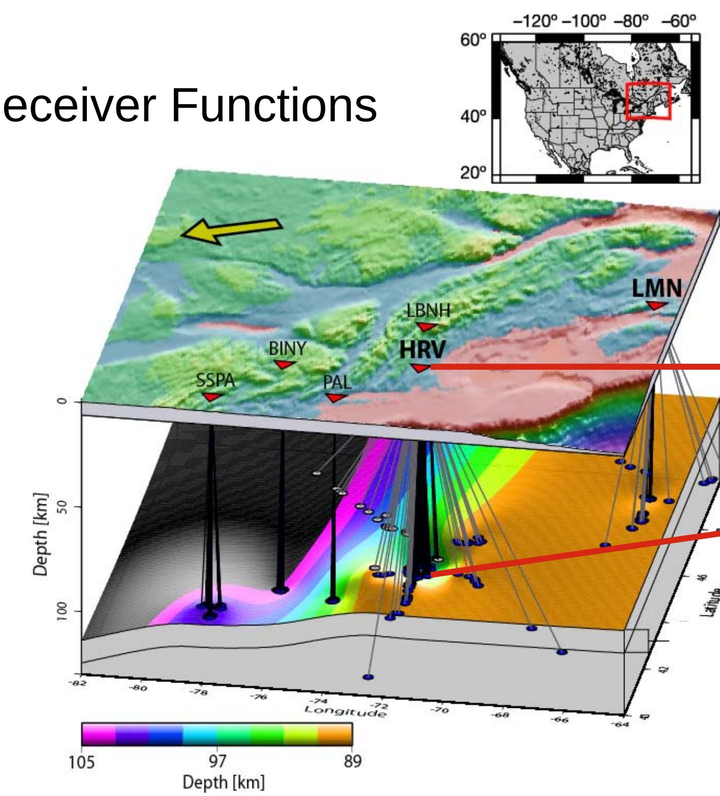
Seismic waves resolve LAB globally.

Regionally constrain character of velocity gradient, & defining mechanism.



[*Nettles & Dziewonski*, 2008]

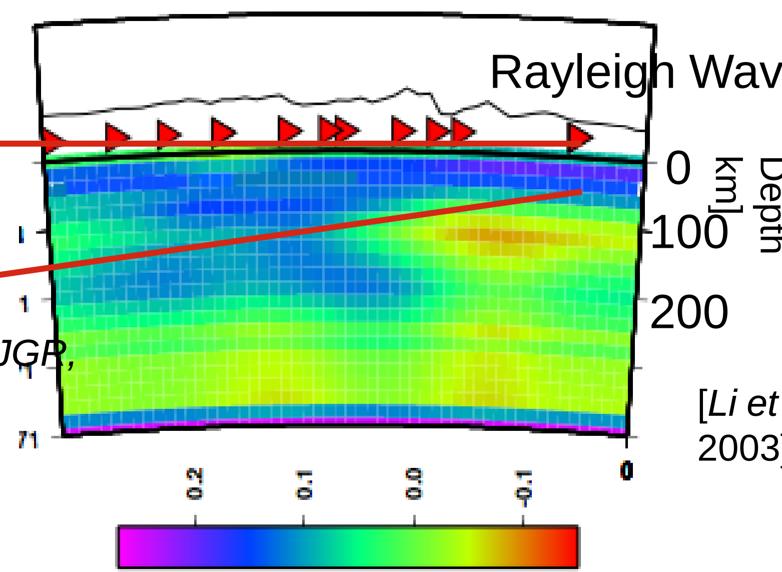
Receiver Functions



[*Rychert et al. JGR*, 2007]

Rychert et al., *Nature*, 2005]

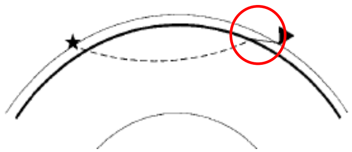
Rayleigh Waves



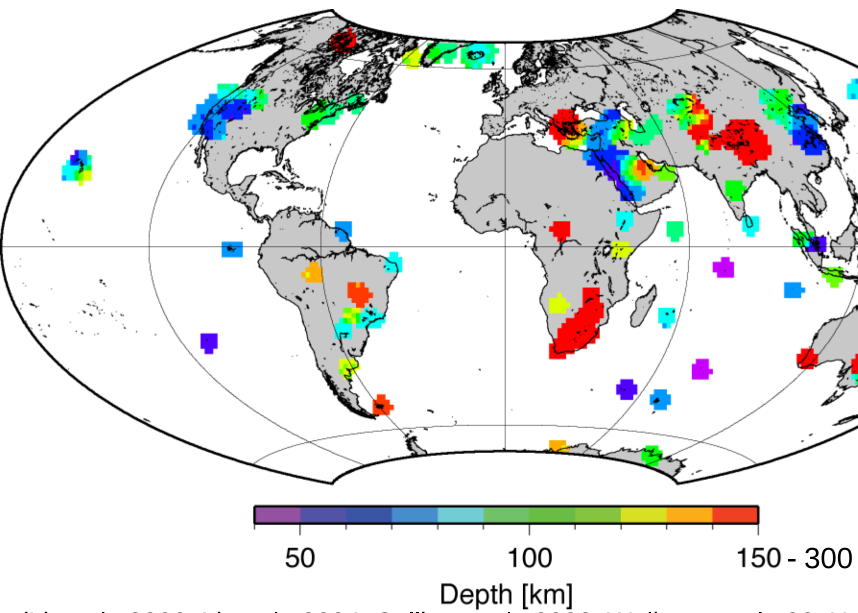
[*Li et al.*, 2003]

Globally

Receiver functions – lateral coverage limited to seismic station locations

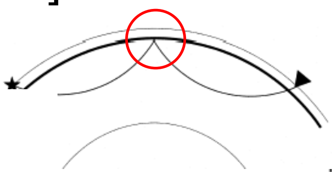


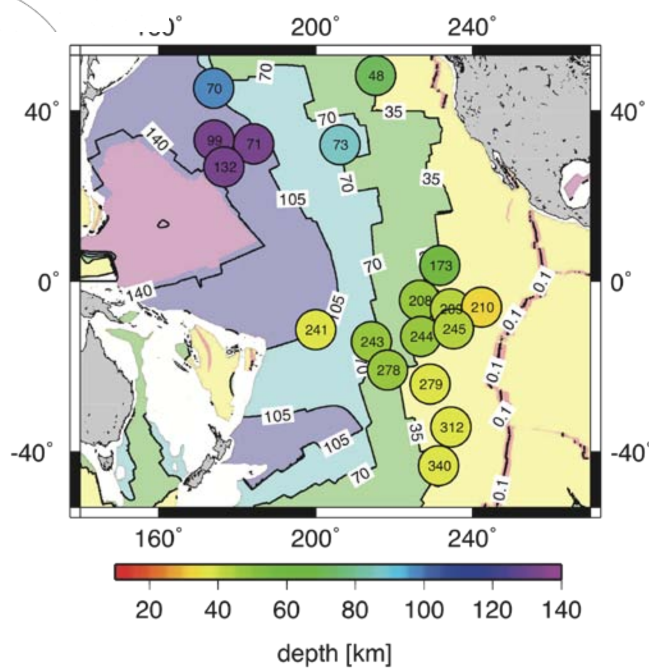
[Rychert et al., 2010]
[Fischer et al., 2010]



(Li et al., 2000; Li et al., 2004; Collins et al., 2002; Wolbern et al., 06; Heit et al., 2007; Li et al., 2007; Rychert et al., 2005; Rychert et al., 2007; Snyder, 2008; Kumar et al., 2005; Sodoudi et al., 2006; Ozacar et al., 2008; Angus et al., 2006; Mohsen et al., 2006; Hansen et al., 07; Kumar et al., 2007; Wittlinger and Farra, 2007; Hansen et al., 2009; Sodoudi et al., 2009; Kumar et al., 2005; Oreshin et al., 2002; Kumar et al., 2006; Sodoudi et al., 2006; Chen et al., 2006; Chen et al., 2008; Chen, 2009; Kawakatsu et al., 2009)

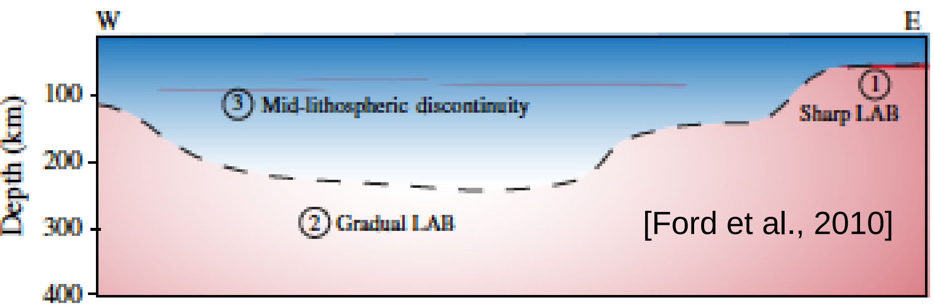
SS bounces in locations where station coverage is sparse.



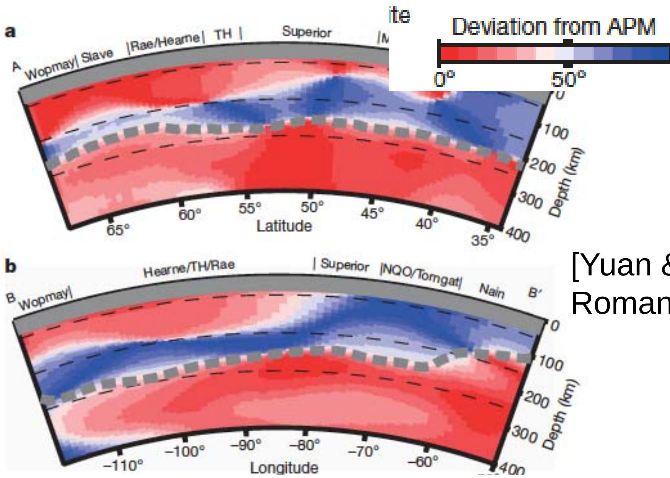


[Rychert & Shearer, 2011]

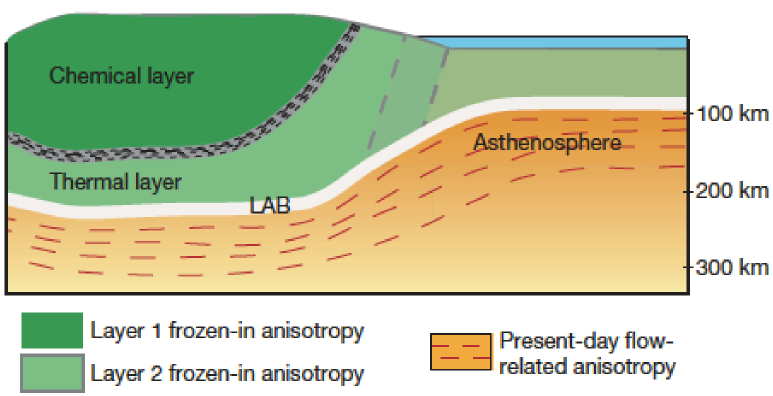
Complications…

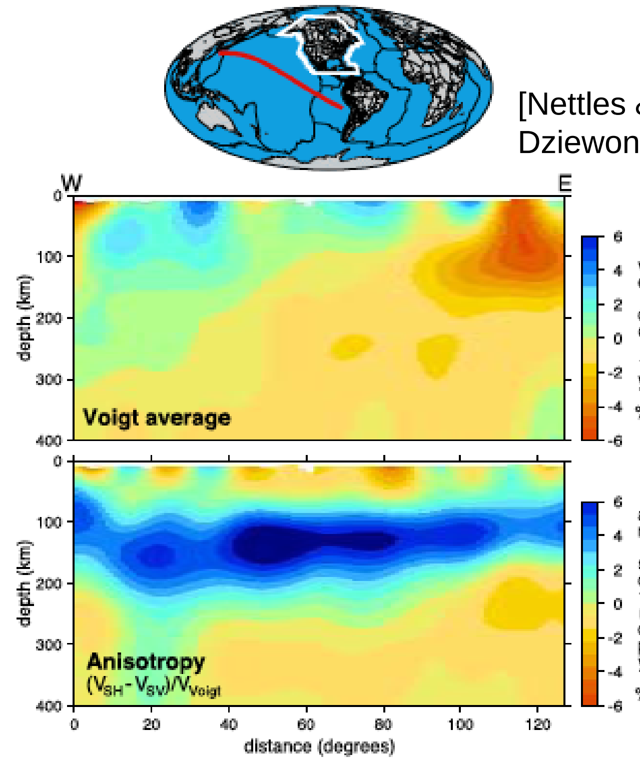


[Ford et al., 2010]



[Yuan & Romanowicz, 2010]





[Nettles & Dziewonski, 2008]

[Bostock, 1999]

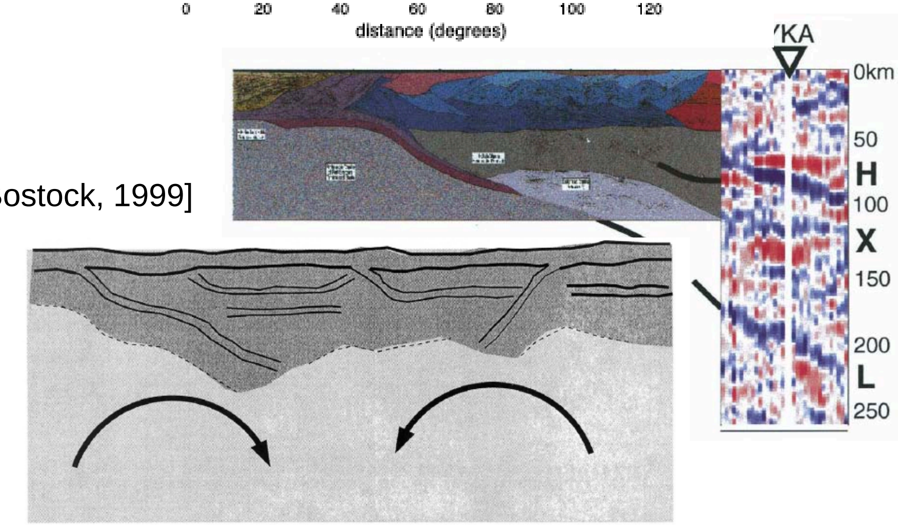


Fig. 4. Schematic diagram, loosely based on information in Fig. 2, depicting continental lithosphere as a juxtaposition of blocks stabilized through shallow subduction and brought together through continental collision.

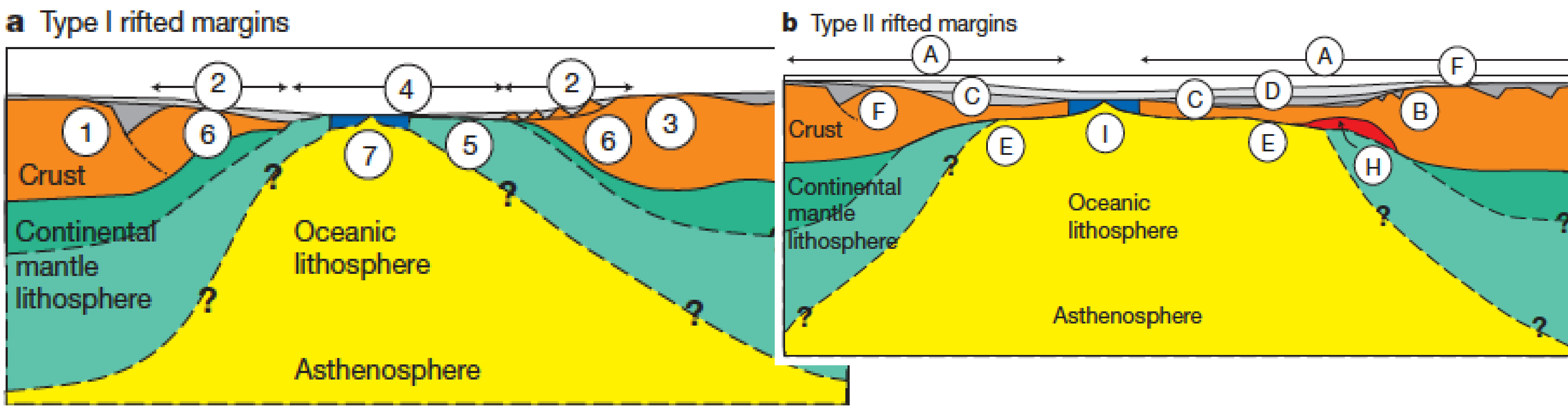
Afar triple junction –

Detailed resolution of the lithosphere-asthenosphere boundary at transition of tectonic environments

Motivation -

How is continental lithosphere destroyed?

How does the depth and character of the lithosphere-asthenosphere boundary vary at across a rift?



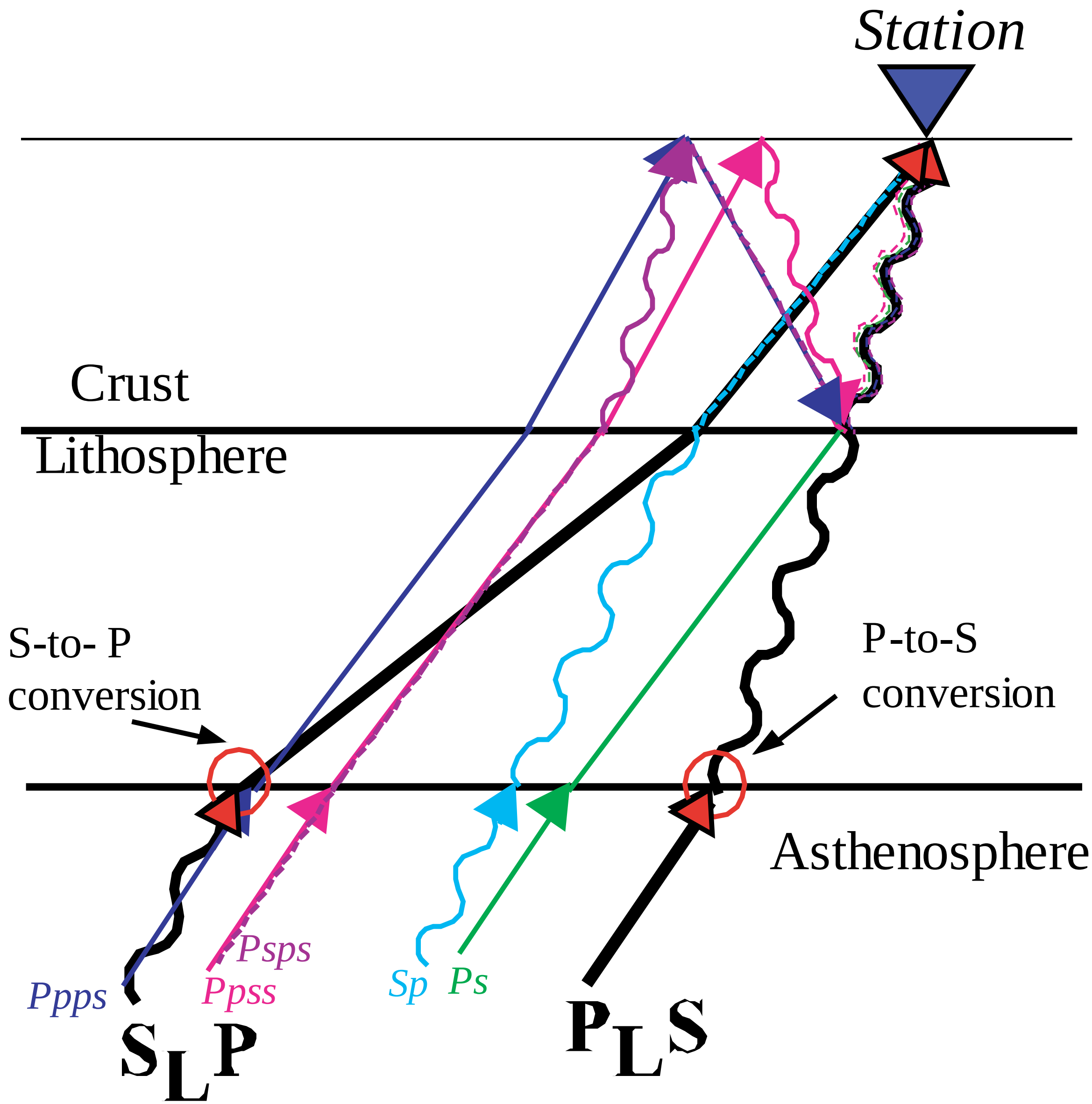
Huismans & Beaumont, Nature, 2011

Method

1) Rotate recorded waveform to P and S components.

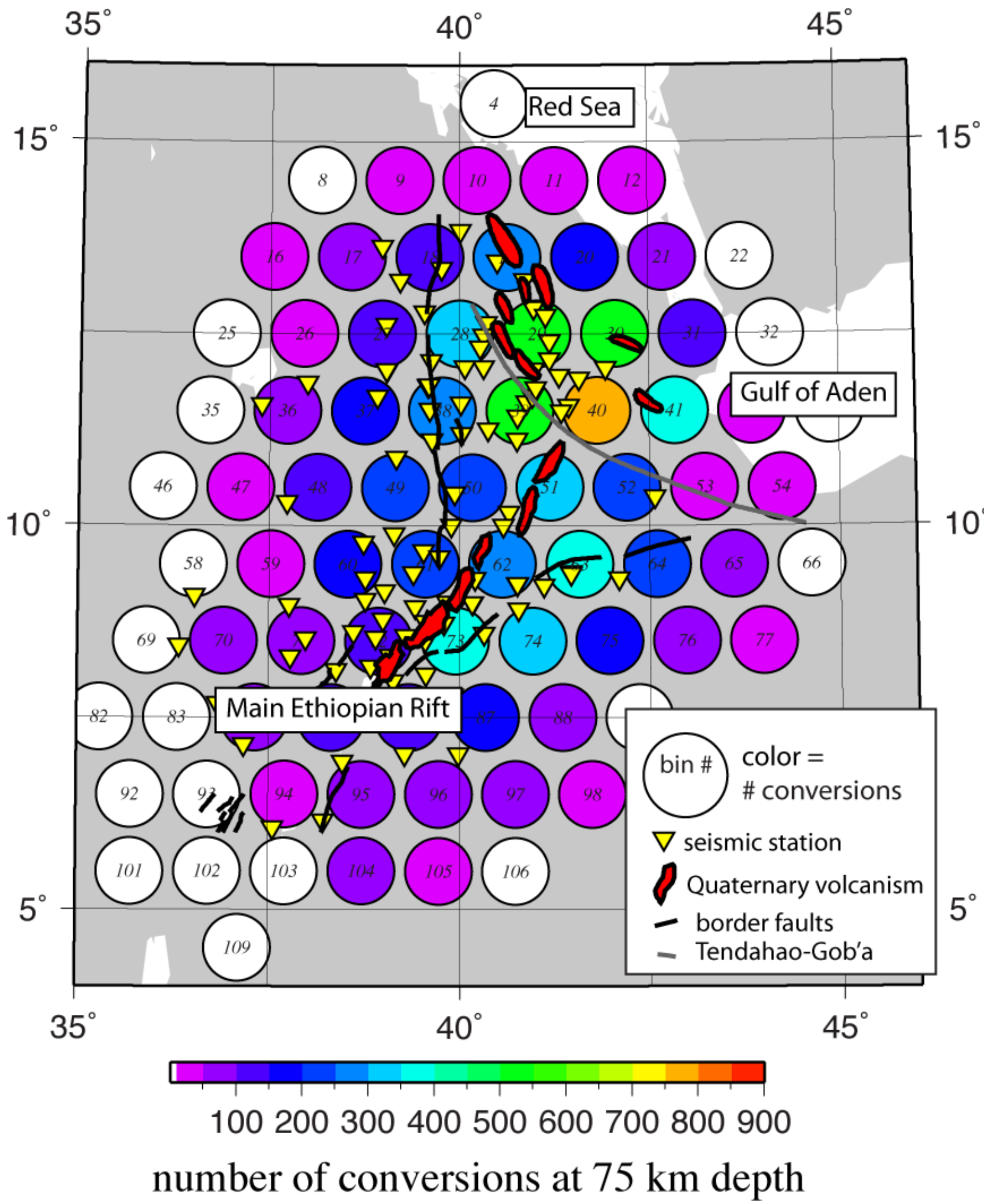
2a) Bin data by conversion point, simultaneously deconvolve and migrate to depth in 1-D.

2b) Extended multi-taper receiver function technique and 3-D migration.



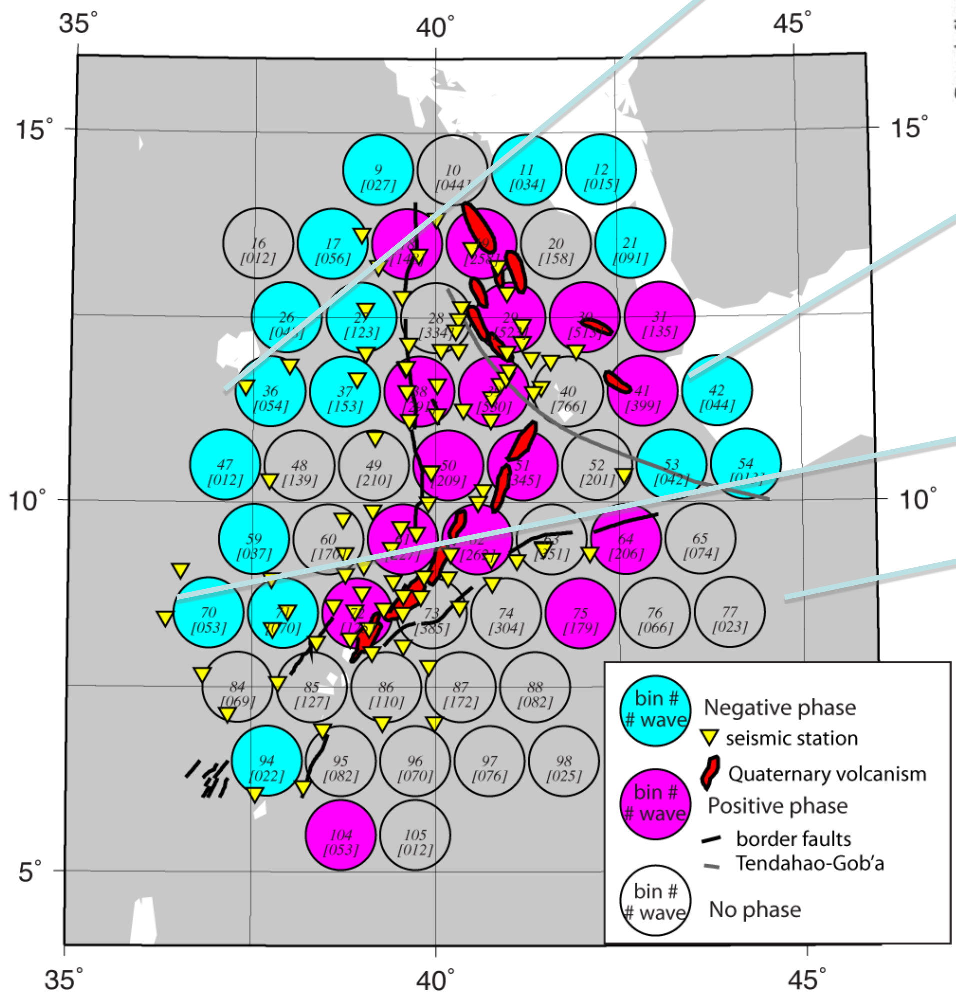
Bin by conversion point.

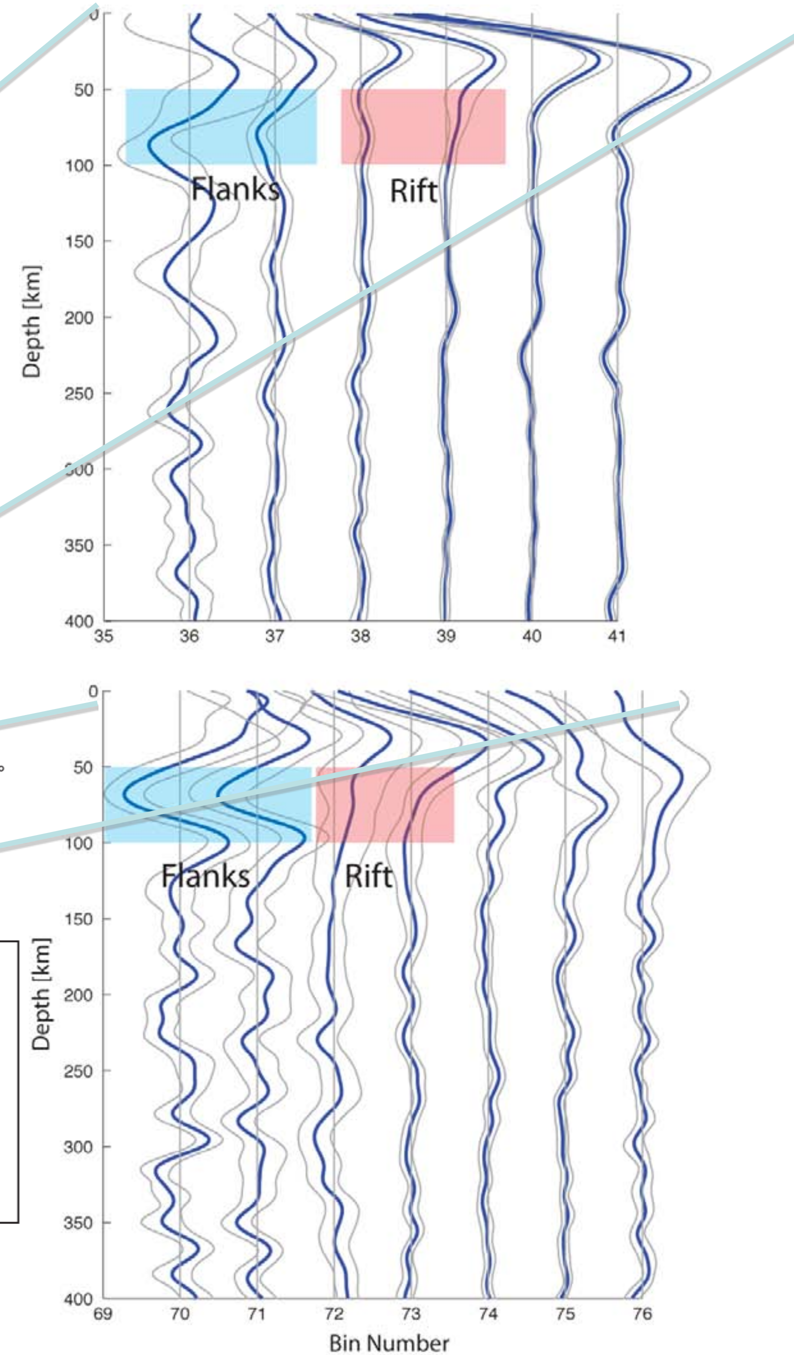
Bin radius = ¾ degree, 75 km depth.



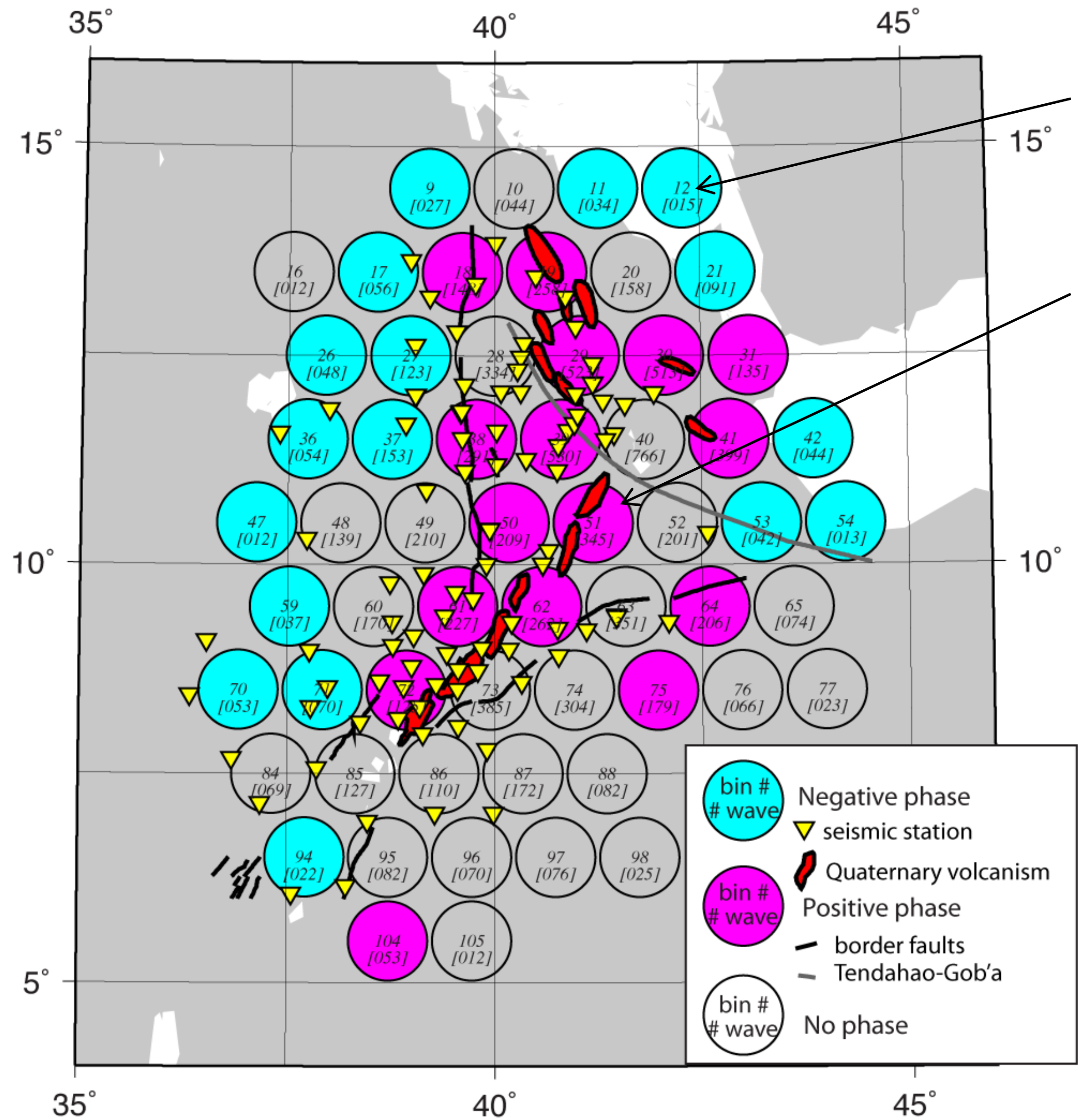
Afar triple junction, 75 km depth

Strong variation in waveform character from flank to rift.





Afar triple junction, 75 km depth



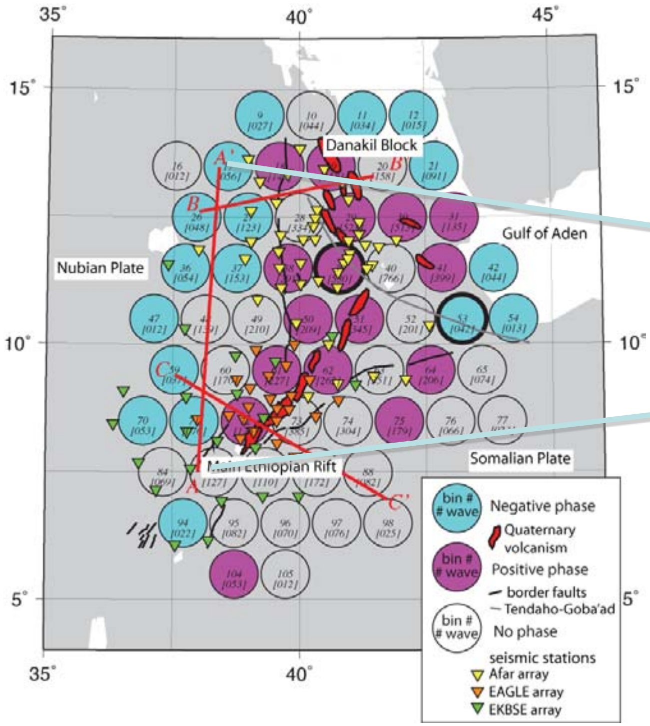
Velocity decreases with depth beneath the flank.

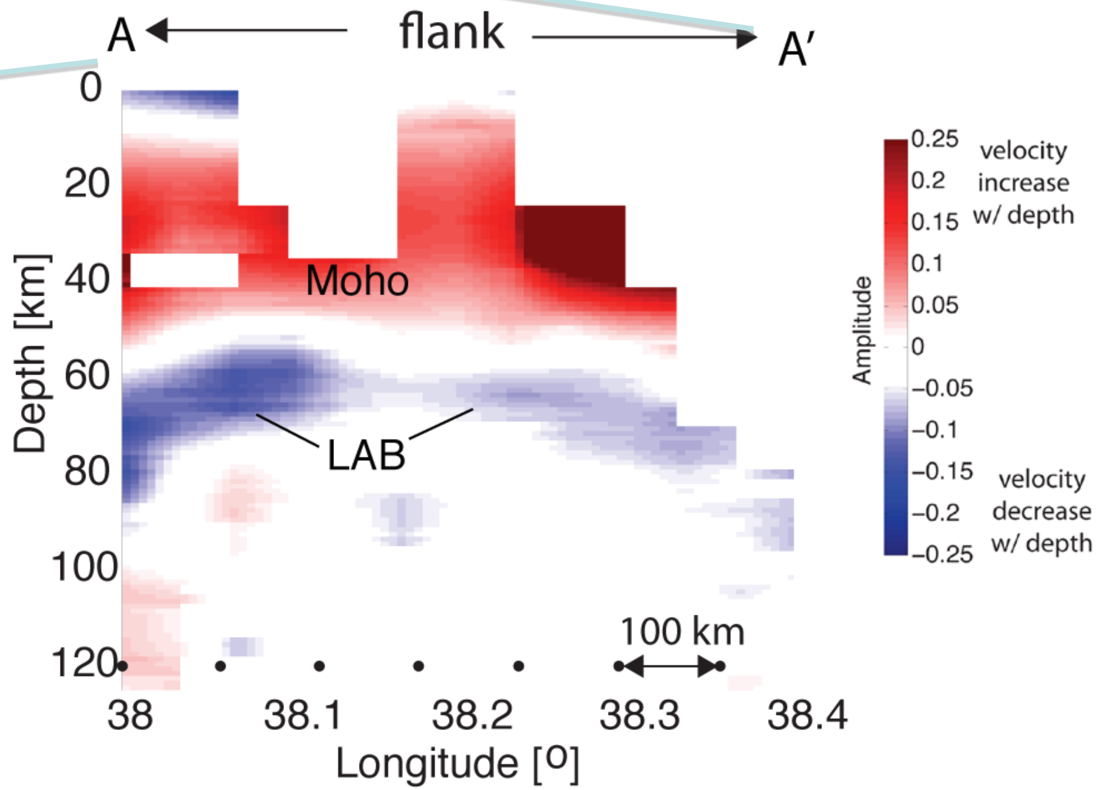
Velocity increases beneath the rift.

[*Rychert et al., submitted*]

Flank cross section

Results from the migrated extended multitaper method



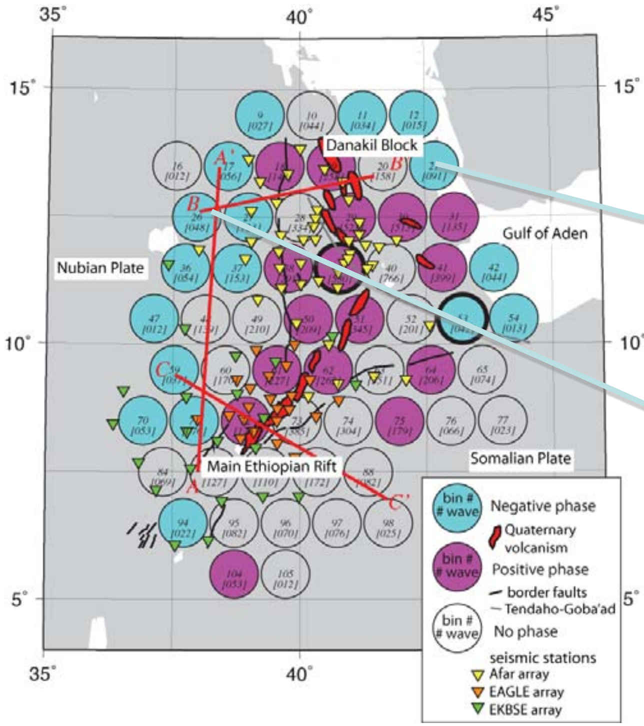


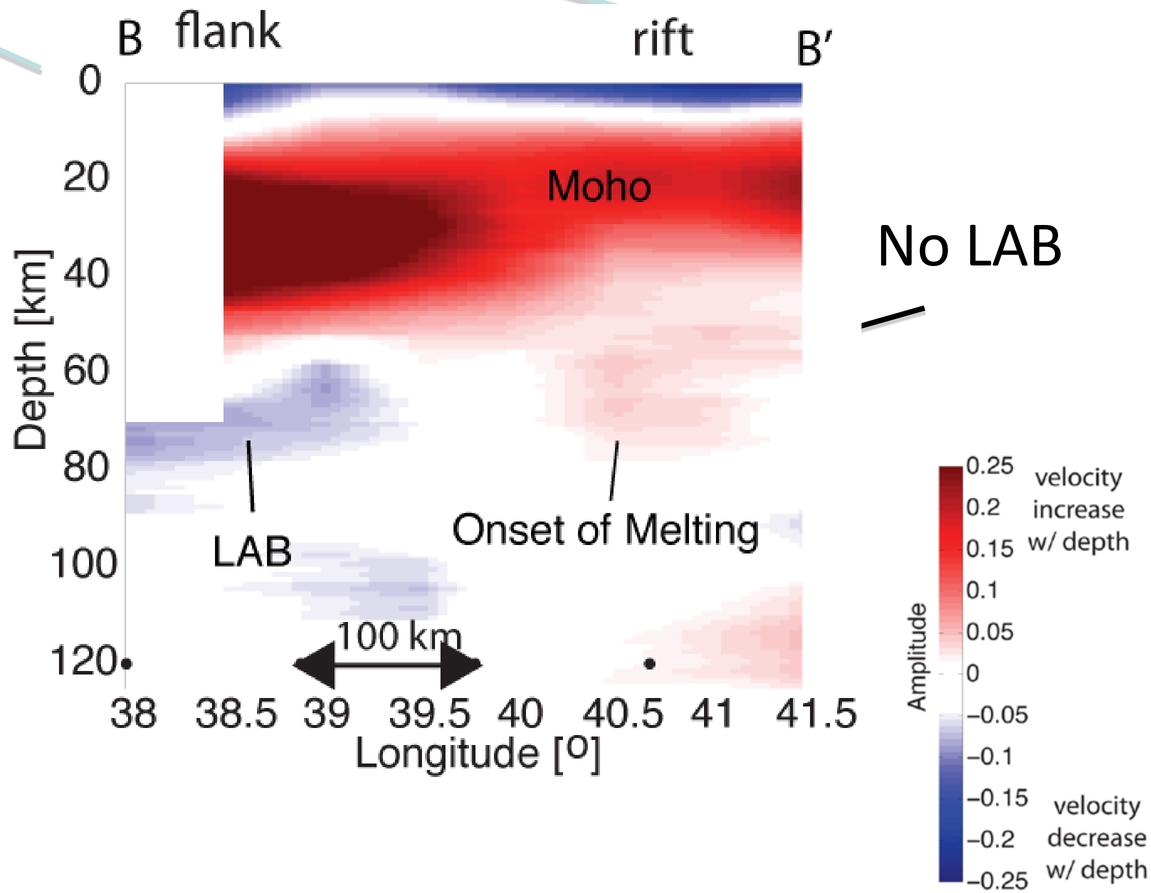
Strong LAB beneath flank, shallows beneath flood basalts

Strong velocity decrease likely requires a mechanism such as melting in the asthenosphere.

Flank to rift cross section

Results from the migrated extended multitaper method





No LAB beneath flank.

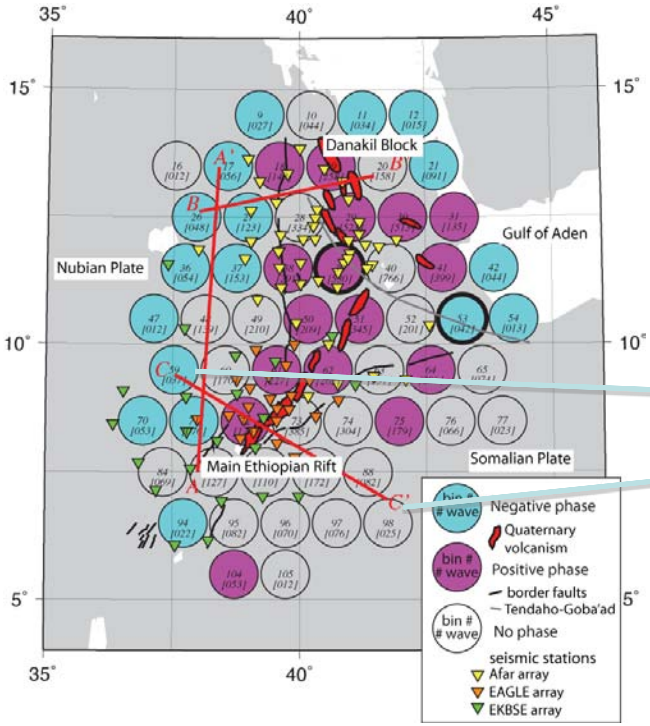
No LAB beneath rift.

Sharp transition implies rigidity of the lid.

[*Rychert et al.*, submitted]

Flank to rift cross section

Results from the migrated extended multitaper method



beneath flank.

No LAB
beneath rift.

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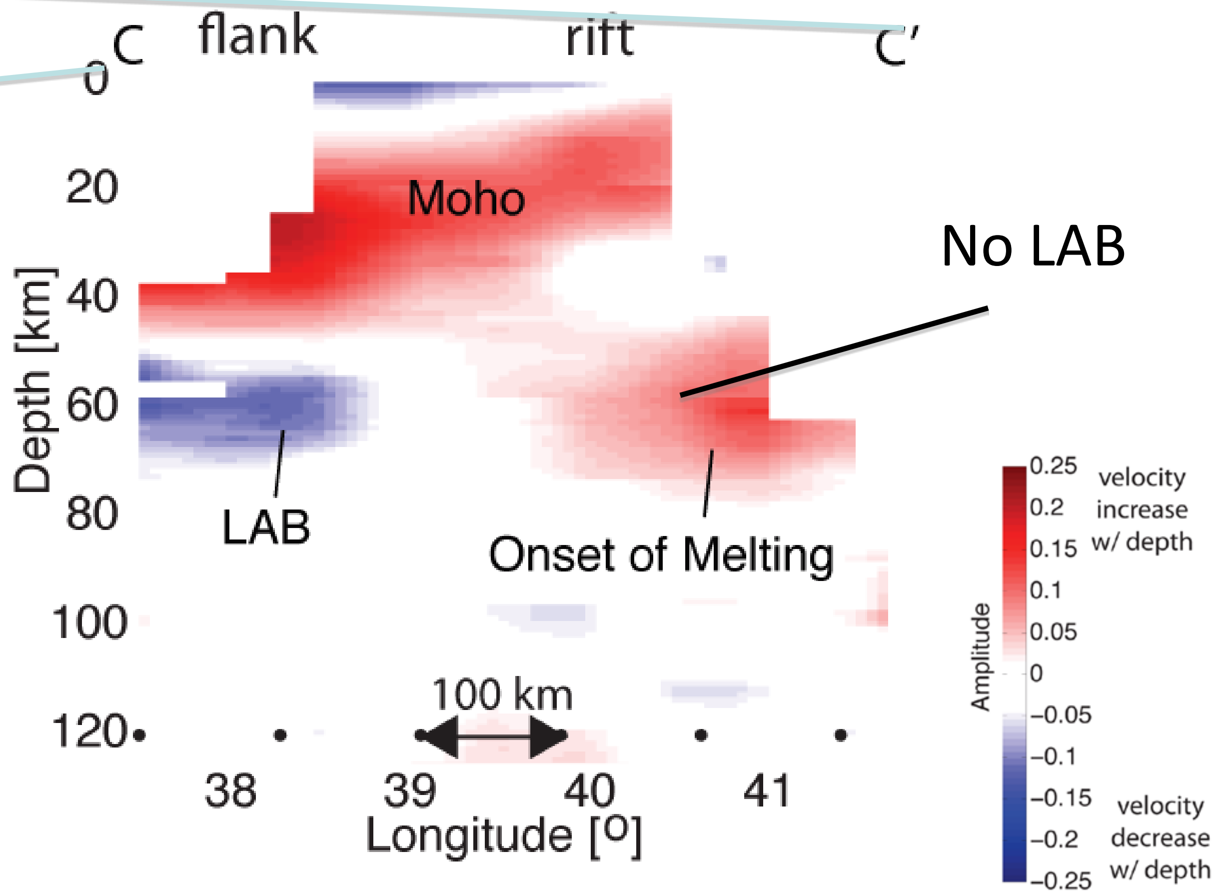
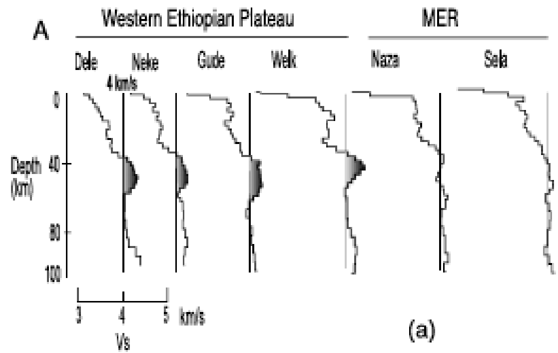
implies rigidity
of the lid.



[*Rychert et al.*, submitted]

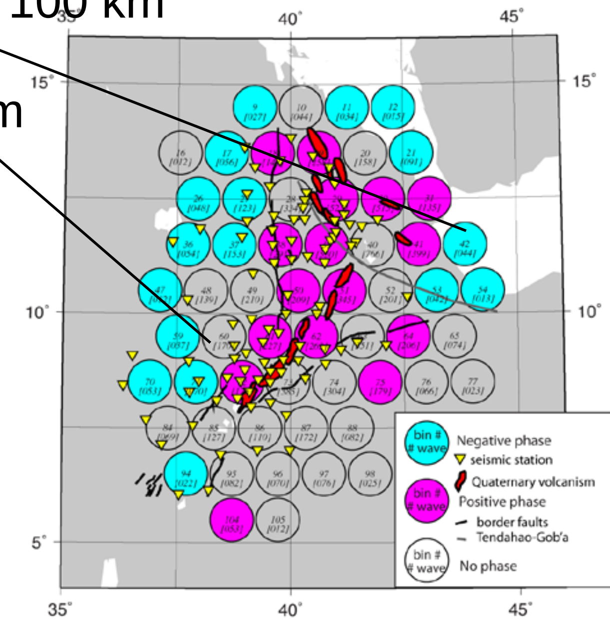
Good agreement with previous seismic results.

Sp receiver functions [Hansen et al., 2009]



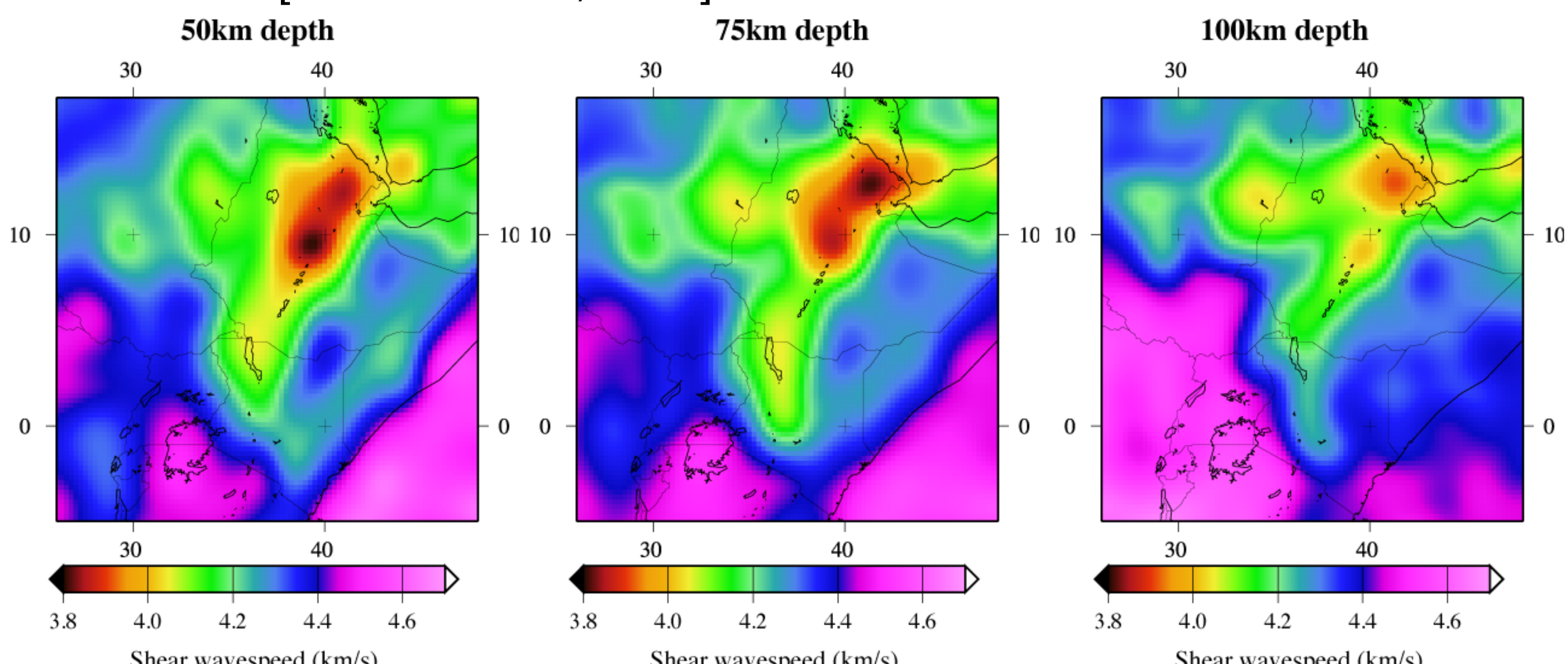
30 km or possibly 100 km

80 km

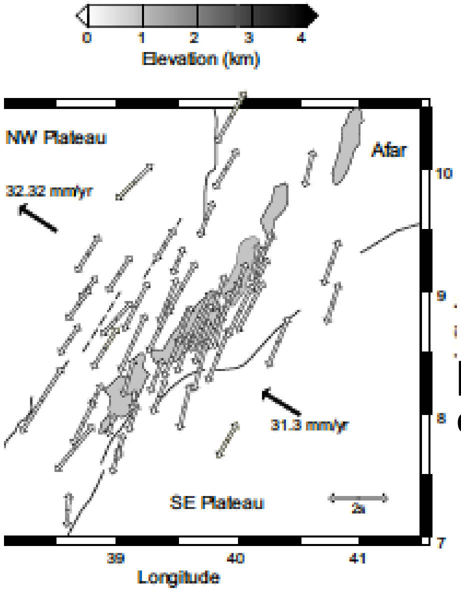


Joint Ps receiver function – surface waves 70-80 km thick lid vs. no lid beneath rift [Dugda et al., 2007].

Surface waves [Fishwick et al., 2010].



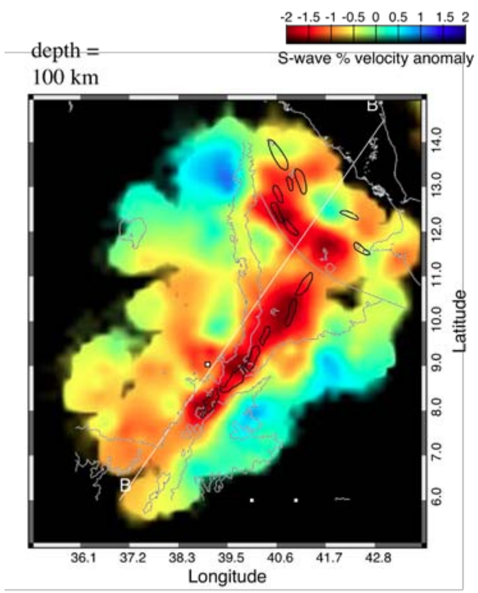
Previous seismic results

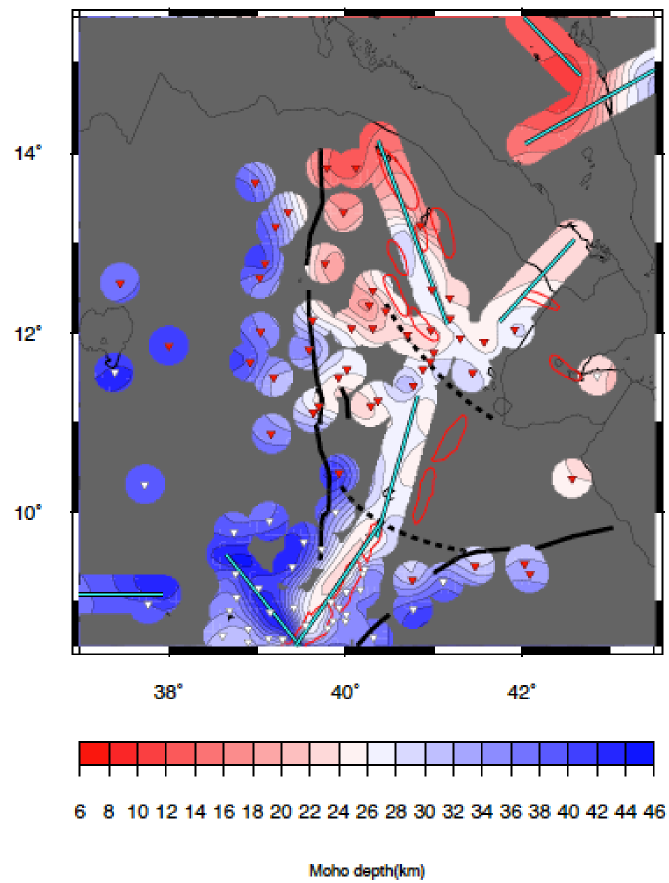


SKS & surface waves – aligned melting in upper 75 km.

[Kendall et al., 2005; Bastow et al,. 2010]

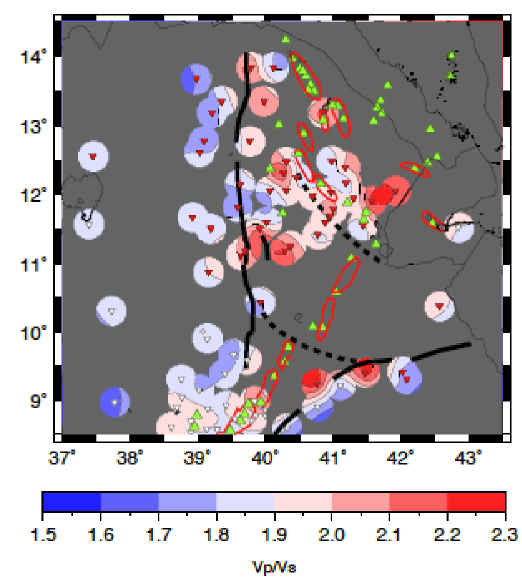
Body wave velocity anomalies beneath rift





P-to-S: Moho shallows, Vp/Vs high beneath rift

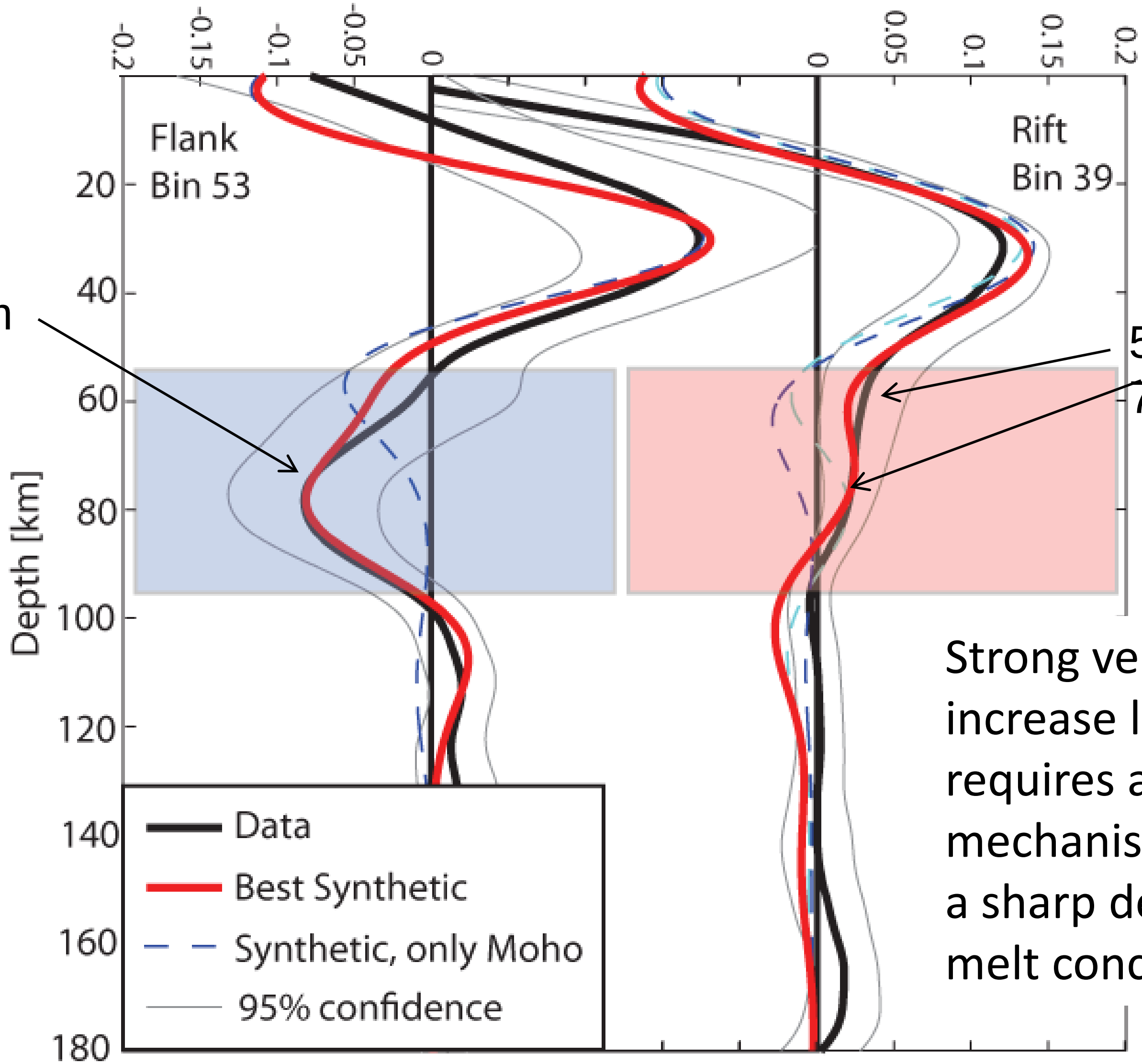
[Hammond et al., 2011]



Synthetic Waveform Modeling

11 %↓ @ 77 km

Strong velocity decrease likely requires a mechanism such as melting in the asthenosphere.

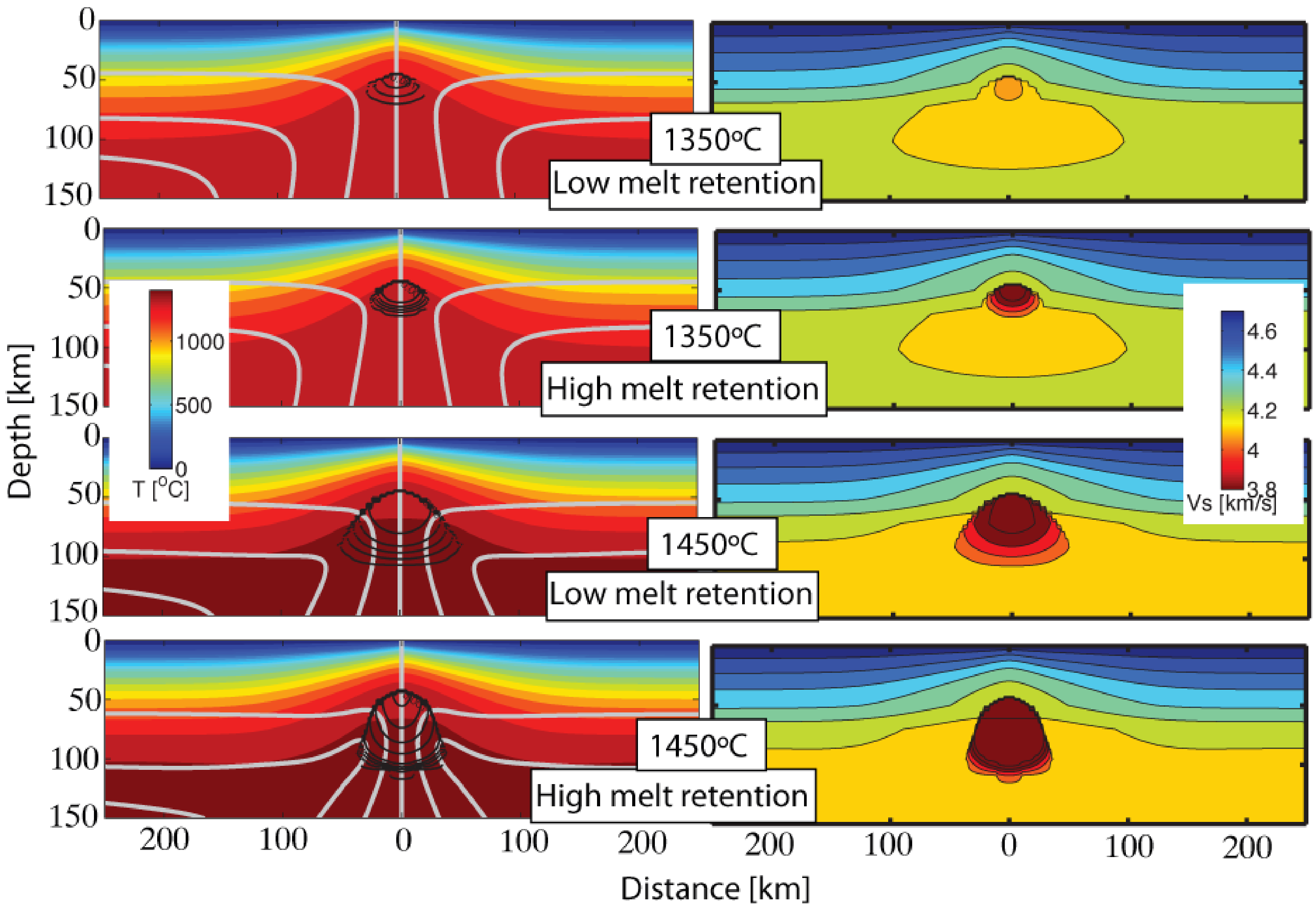


5 % ↑@ 41 km

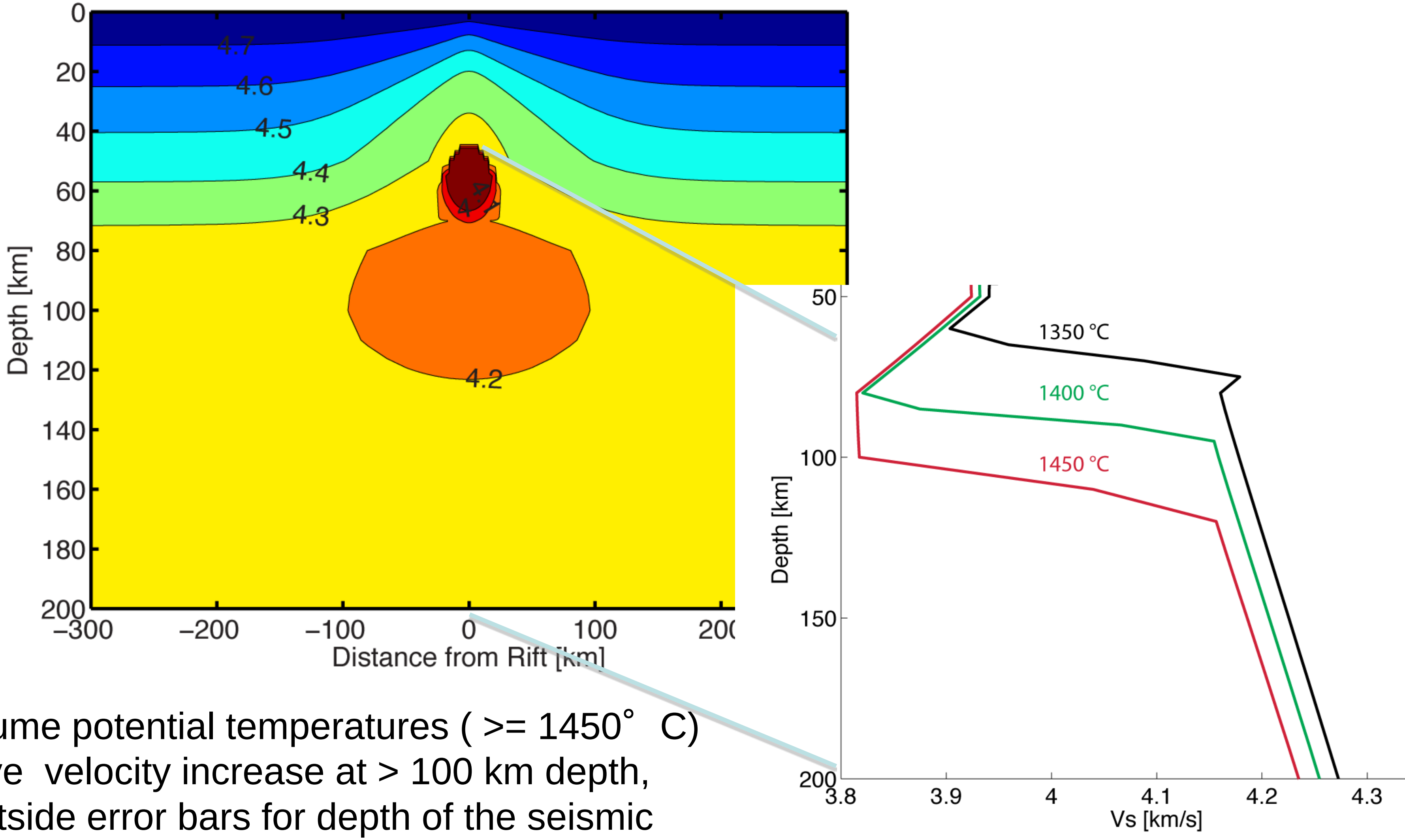
7 % ↑@ 62 km

Strong velocity increase likely requires a mechanism such as a sharp decrease in melt concentration.

Geodynamic Modeling



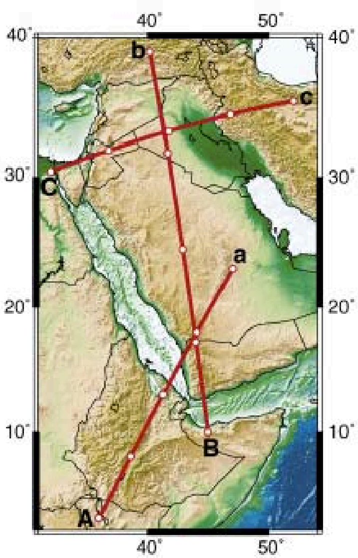
Geodynamic models with high melt retention and Tp = 1350 – 1400° C match both the depth (65-85 km) and the magnitude (~8%) of the observed seismic discontinuity.

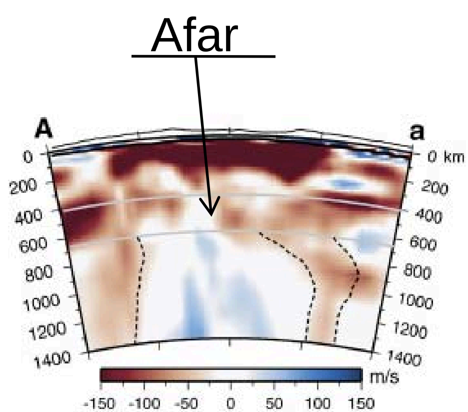


Plume potential temperatures (>= 1450° C) give velocity increase at > 100 km depth, outside error bars for depth of the seismic discontinuity.

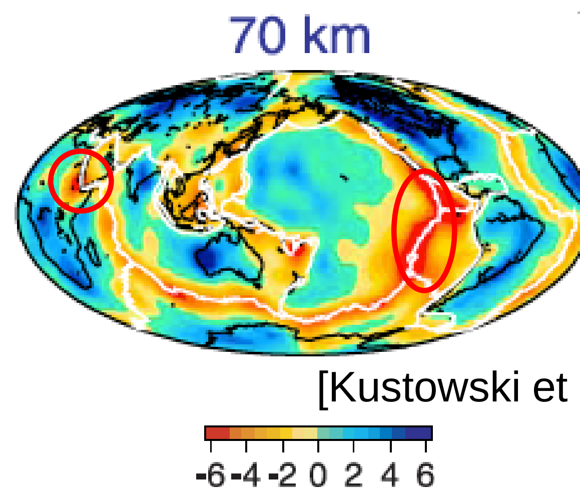
Other Supporting Evidence

- Africa has moved ~700 km away from the location where a plume caused flood basalt volcanism ~35 Ma [Silver et al., 1998].
- Although interpreted as a thermal anomaly, the range of potential temperatures from geochemistry (1370 - 1490° C)[Rooney et al., 2011] agrees with our predicted range (1350 – 1400° C), i.e., not significantly hotter than normal mantle.
- Depth of melting consistent with geochemical estimates (70 – 90 km) [Furman, 2007].





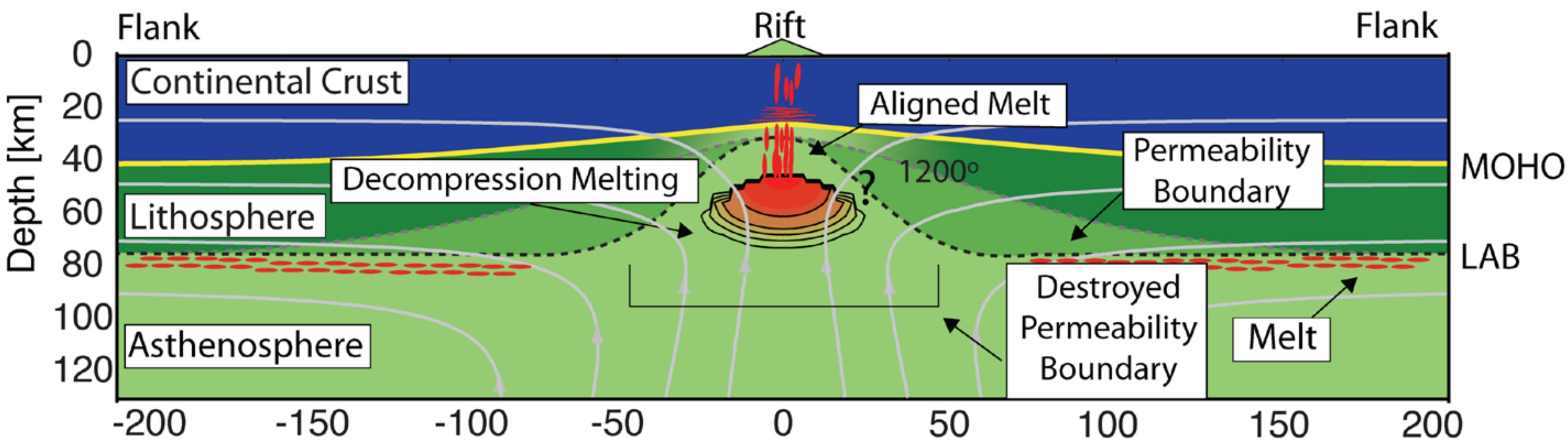
[Chang & van der Lee, 2011]



[Kustowski et al., 2008]

- No plume visible beneath Afar in joint body wave surface wave tomography.
- Channelized flow from a low viscosity asthenosphere may provide slightly warmer material, but certainly no plume [Toomey et al., 2002; Ebinger & Sleep 1998].

Conclusions



- A sharp rigid lid is imaged on the flank of the Afar rift at ~75 km depth. The transition from flank to rift is abrupt.
- The sub-crustal lithosphere beneath the rift has been destroyed.
- A significant velocity increase imaged beneath the rift is consistent with geodynamic predictions for the onset of decompression melting.
- Its depth is shallow, indicating no significant plume influence today.

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