Mantle structures and their origins

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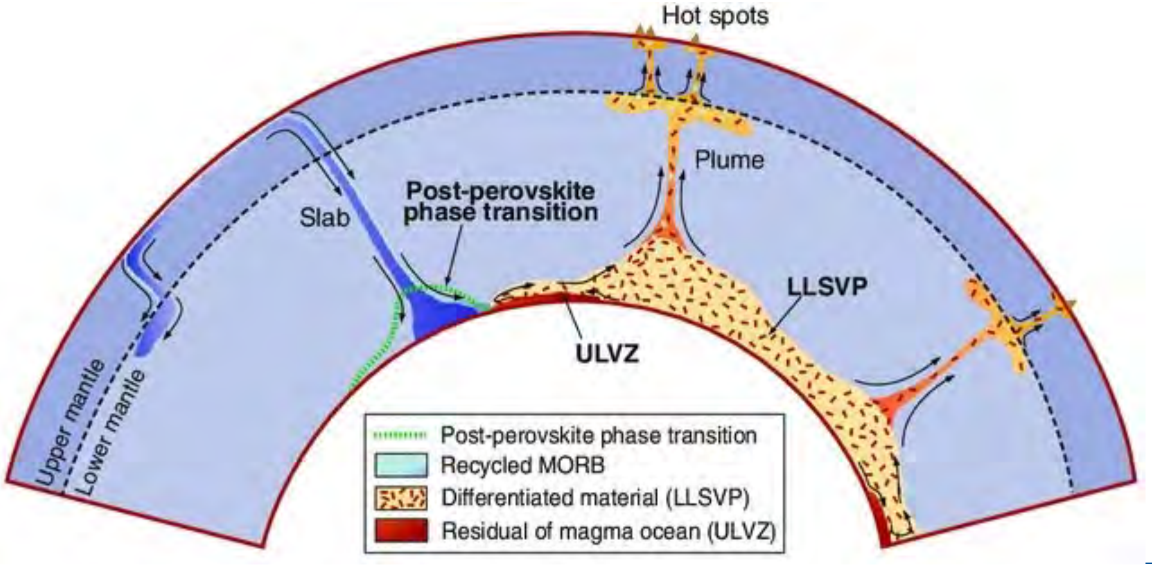

Figure from Deschamps, Li & Tackley, 2015

Sendai, Summer 2017

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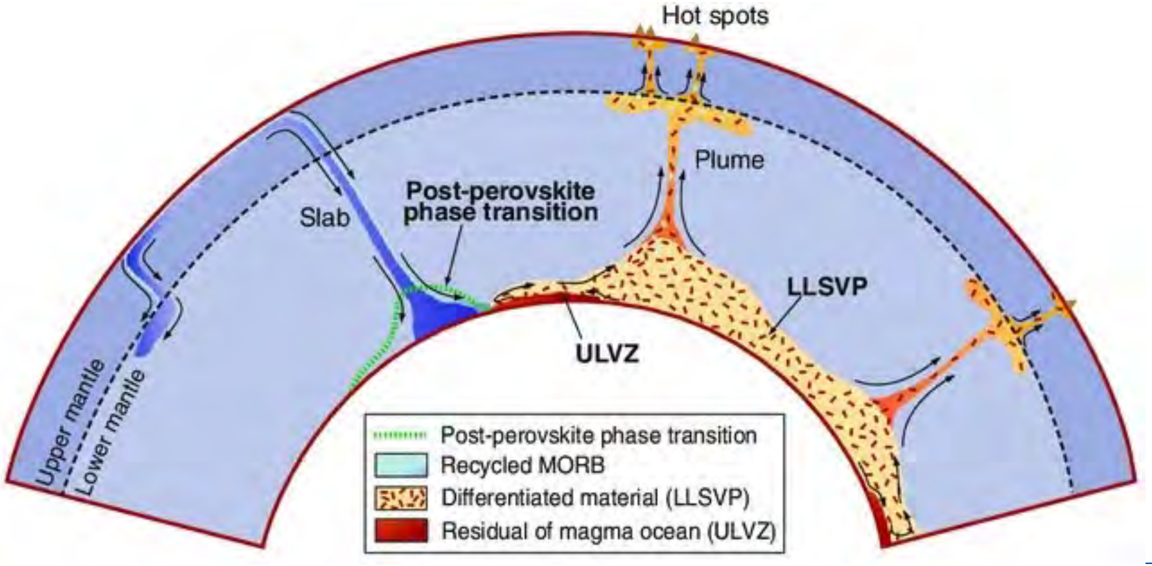
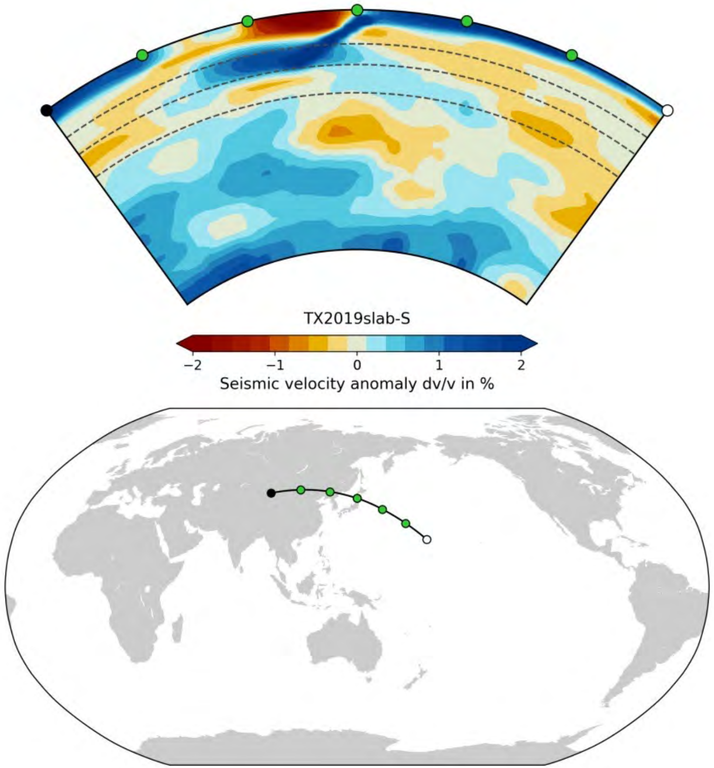
HELMHOLTZ

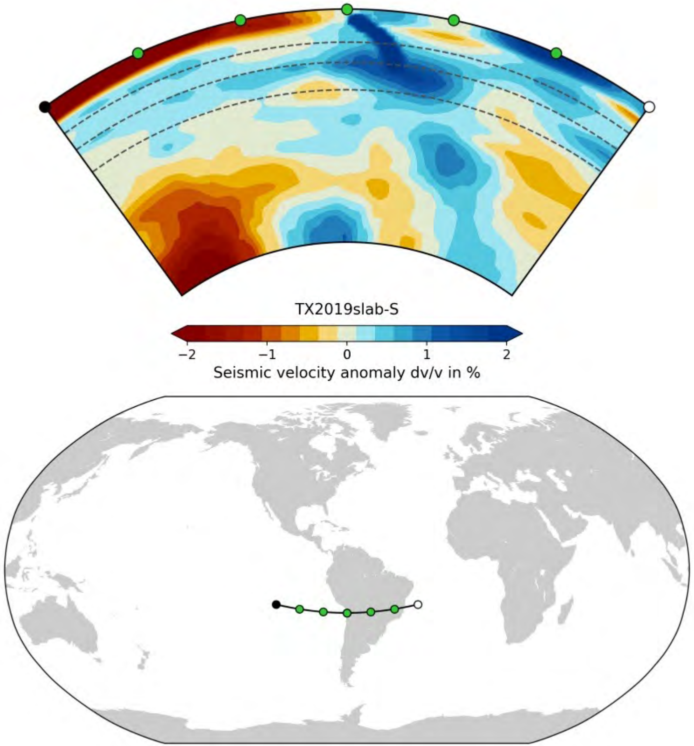
- Mantle contains thermal and chemical structure
- Convection creates thermal structure; erases chemical structure through mixing
- Melting separates materials and causes chemical structure
- Large uncertainties on mantle rheology



Example for stagnating slab: Japan

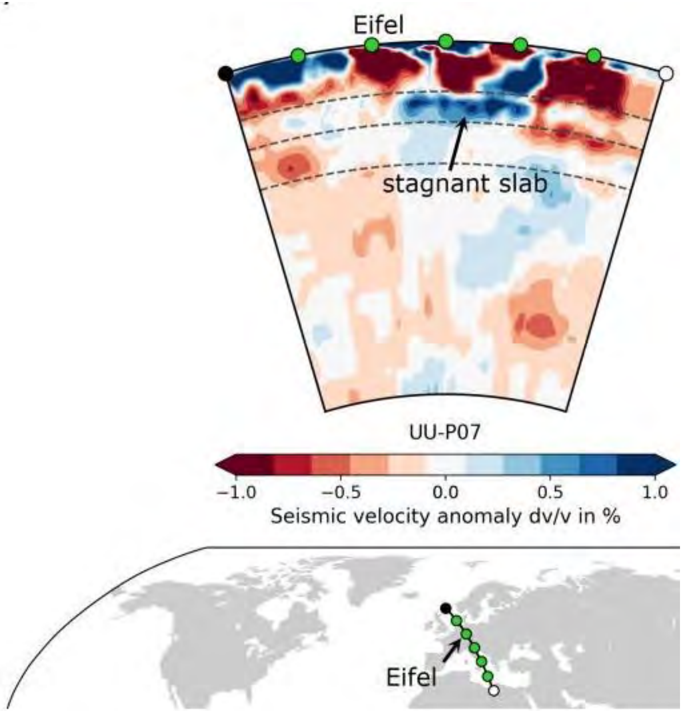


Example for penetrating slab: South America

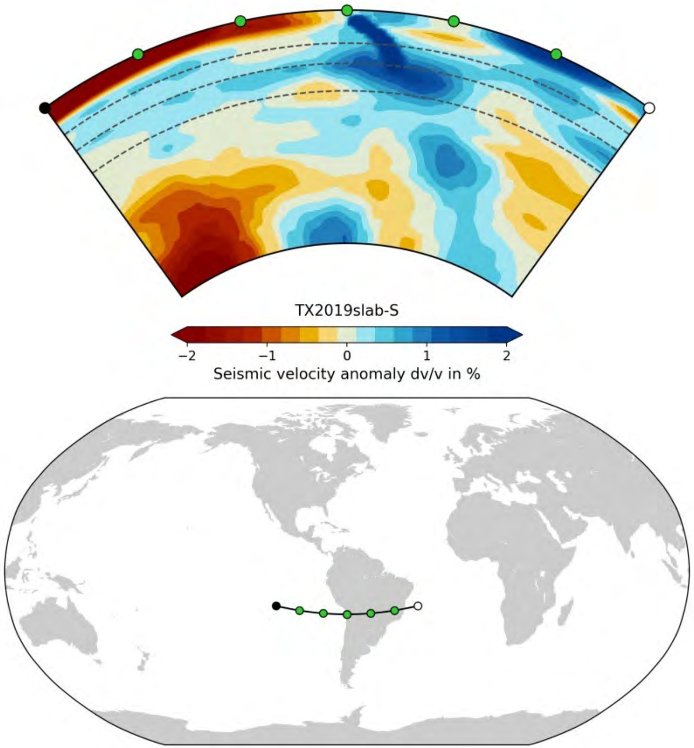


Cross sections from SubMachine (Hosseini et al.) https://www.earth.ox.ac.uk/~smachine

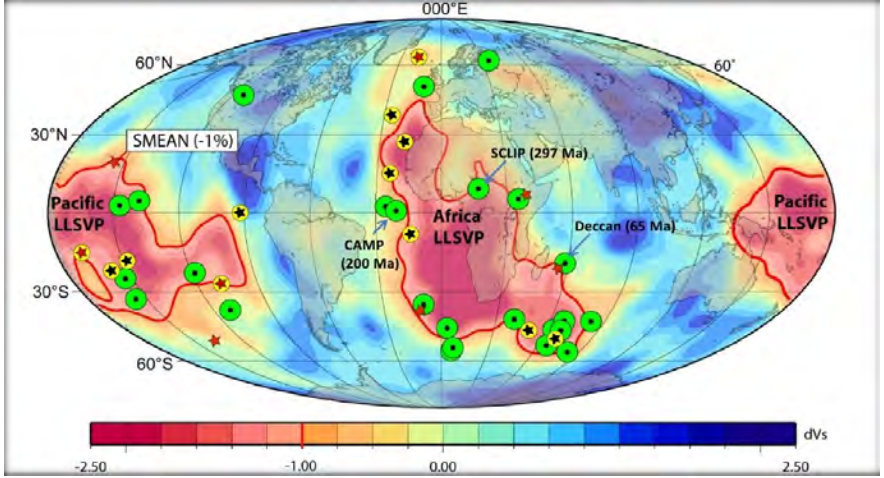
Example for stagnating slab: Europe



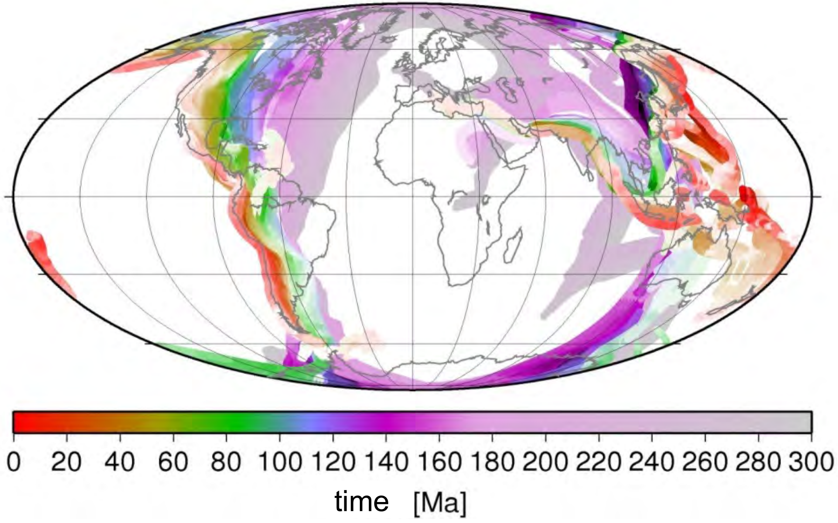
Example for penetrating slab: South America



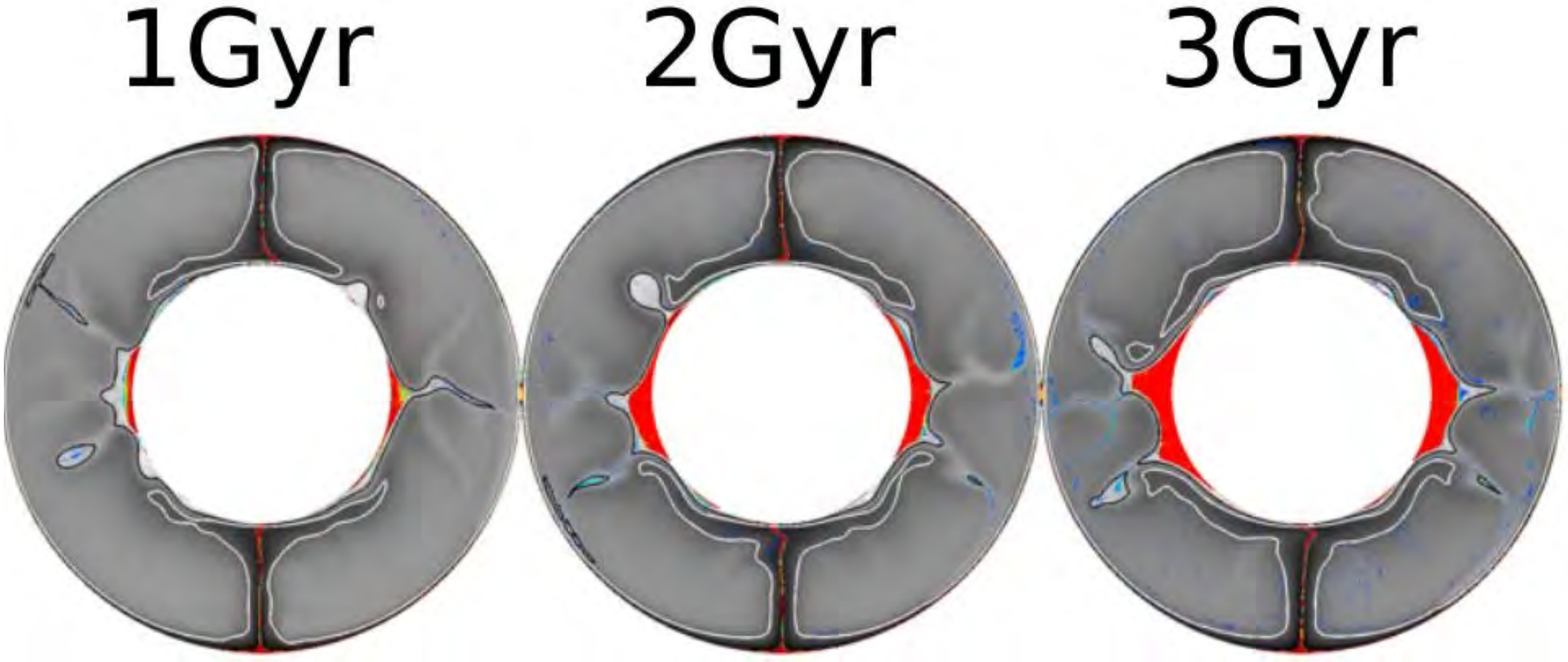
→ s-wavespeed anomalies in lowermost mantle,
→ reconstructed LIPs (green) → likely deep hotspots (stars) → after Torsvik et al. (2006)

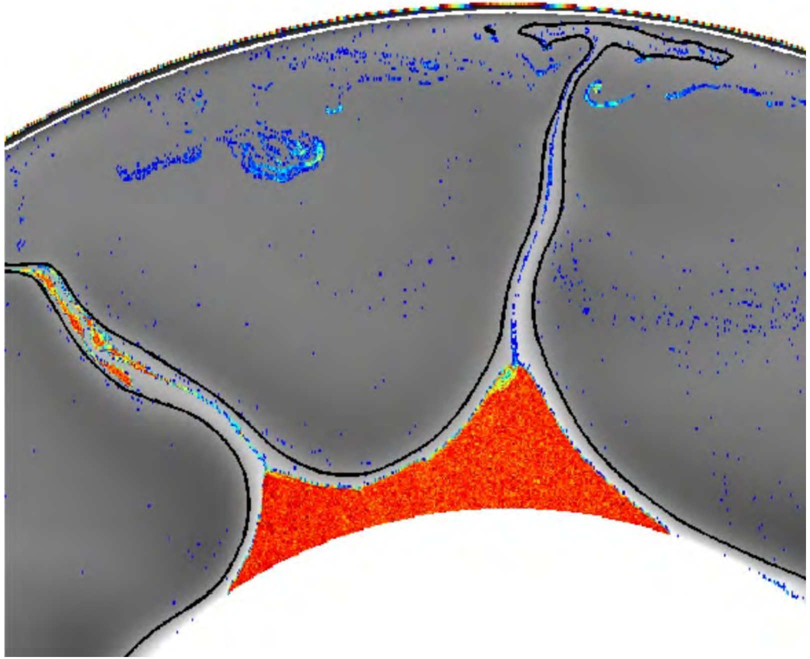


Subduction locations and amounts (color intensity) from a global plate reconstruction (see Steinberger and Torsvik, 2012, for details)

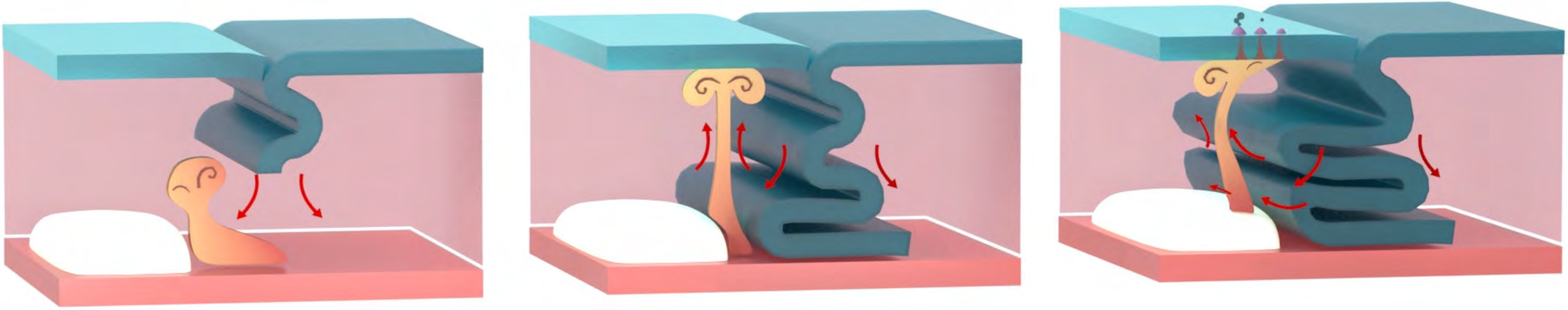


From Mulyukova et al., JGR: Piles from subducted slabs accumulating over Gyrs

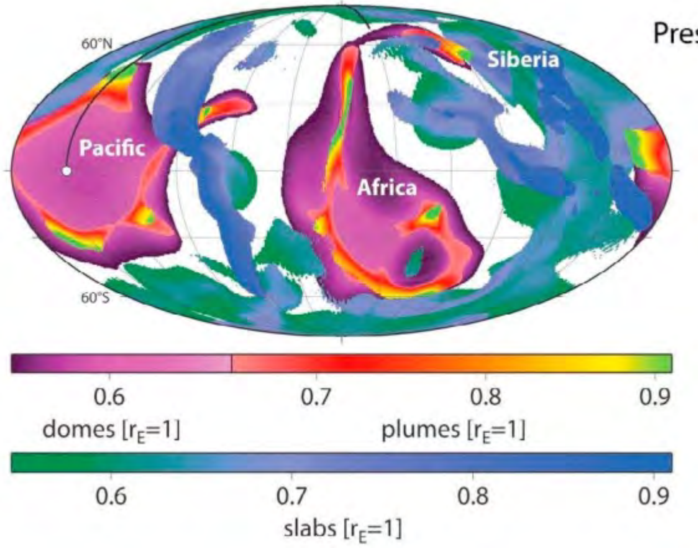


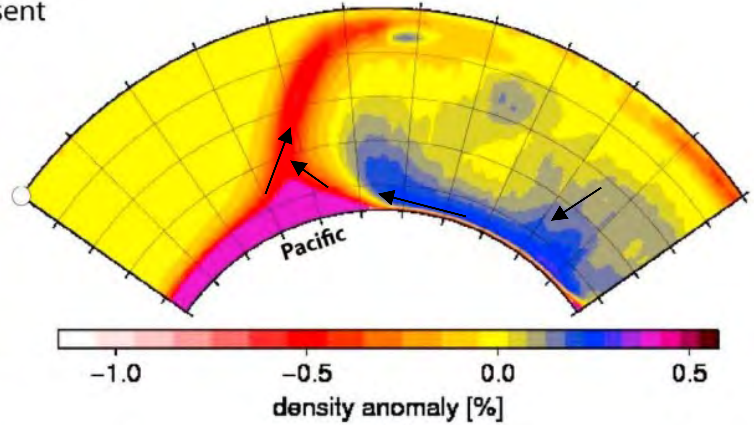


- Zoom-in on one of the piles
- plumes forming at cusps near margins
- plumes entraining pile materials



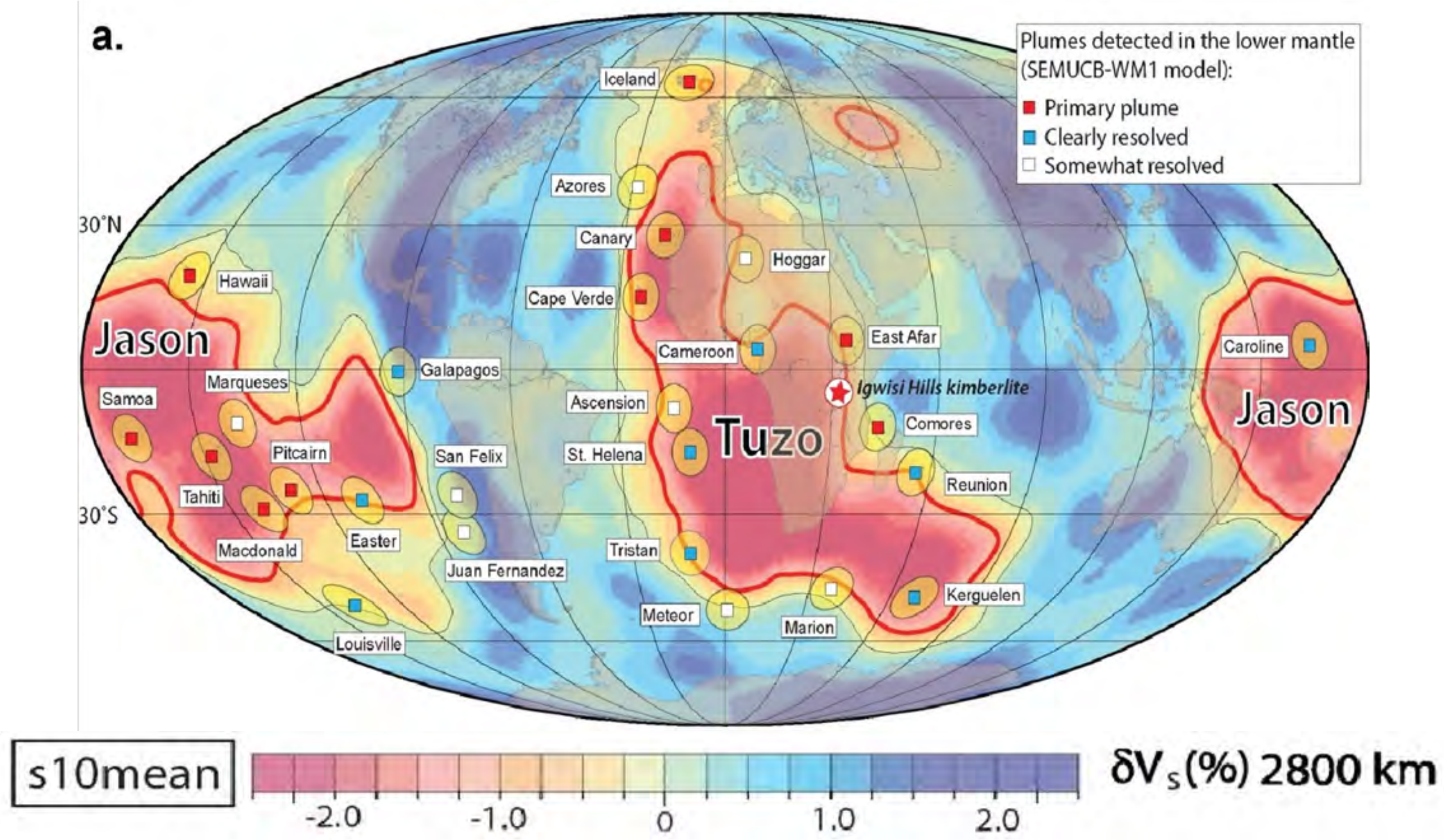
Present





“Hawaii plume” after
Steinberger and Torsvik (2012)

Hotspots located near margins of Large Low Shear Velocity Provinces (LLSVPs) "Jason" and "Tuzo"



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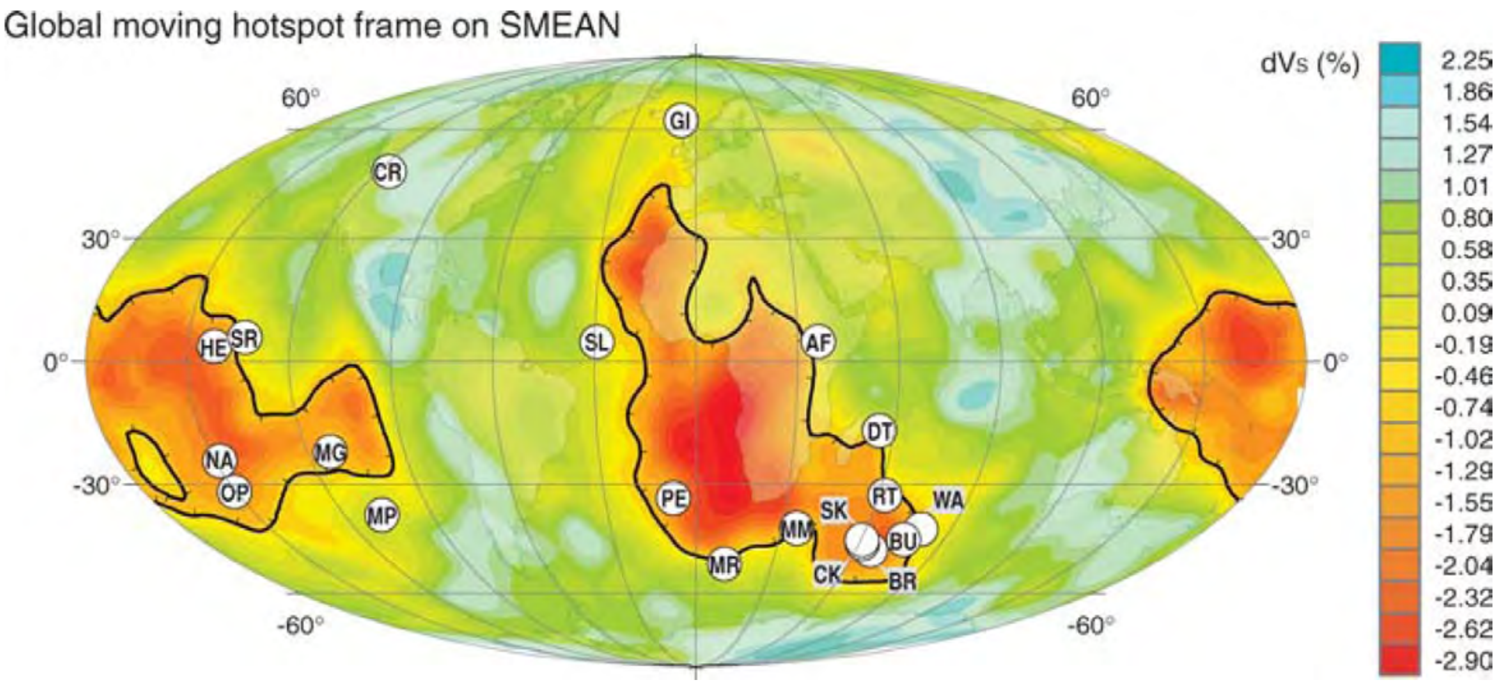
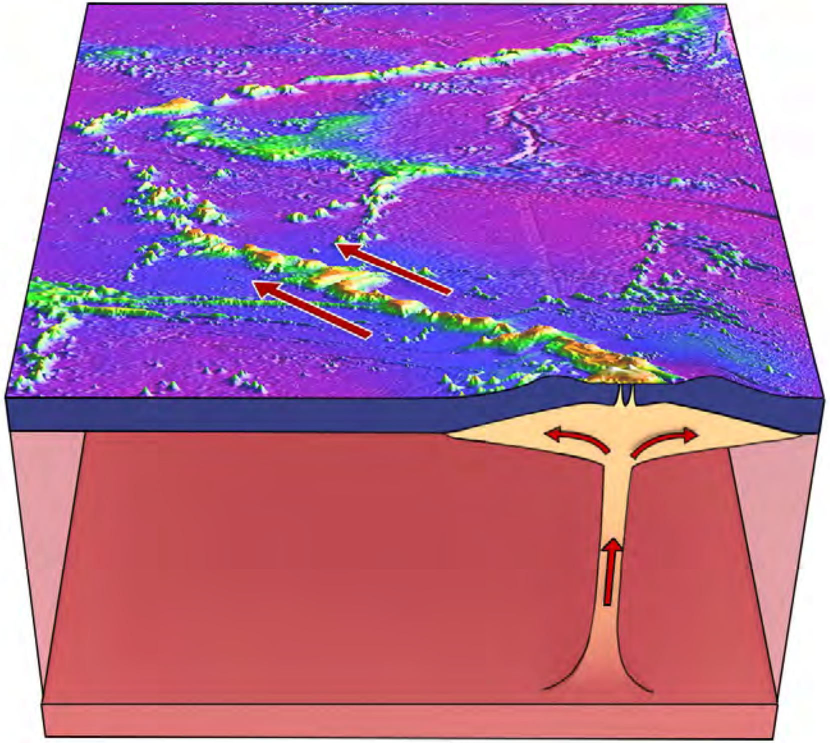
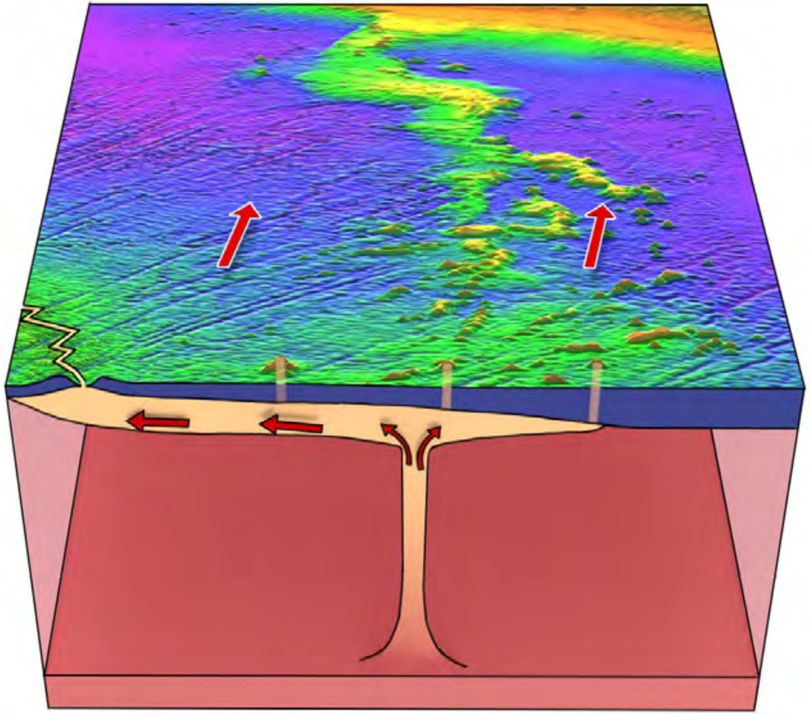
- Same is true also for reconstructed LIP locations
- Indicates spatial stability of LLSVPs back to at least 200 Myr, perhaps longer

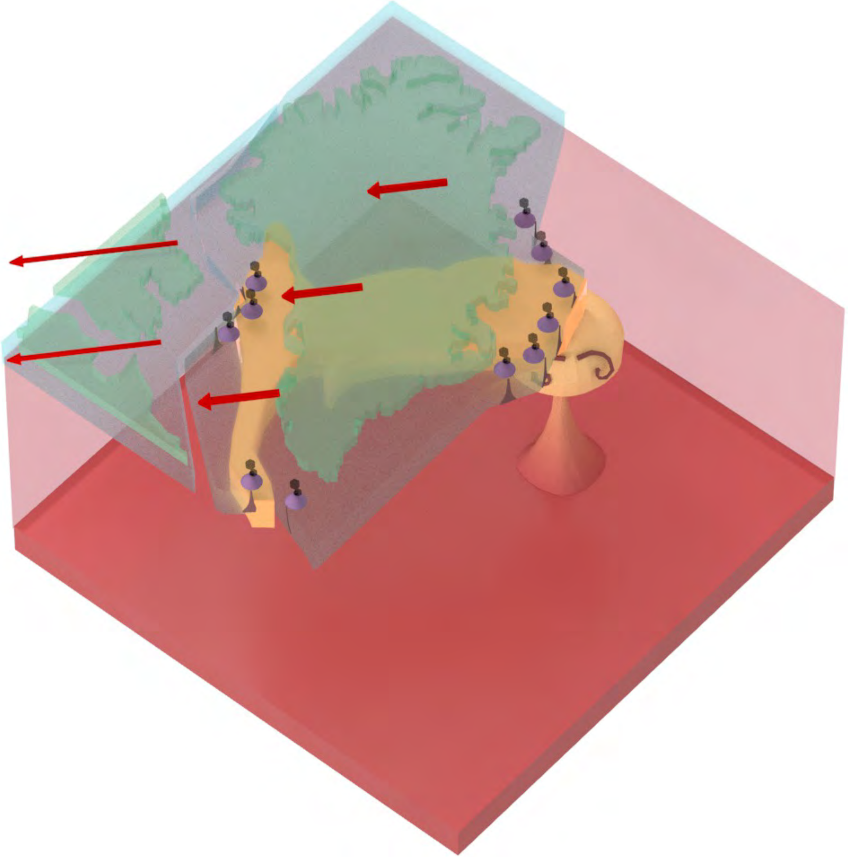


Plume-Lithosphere interaction
– intraplate: Hotspot track and swell:

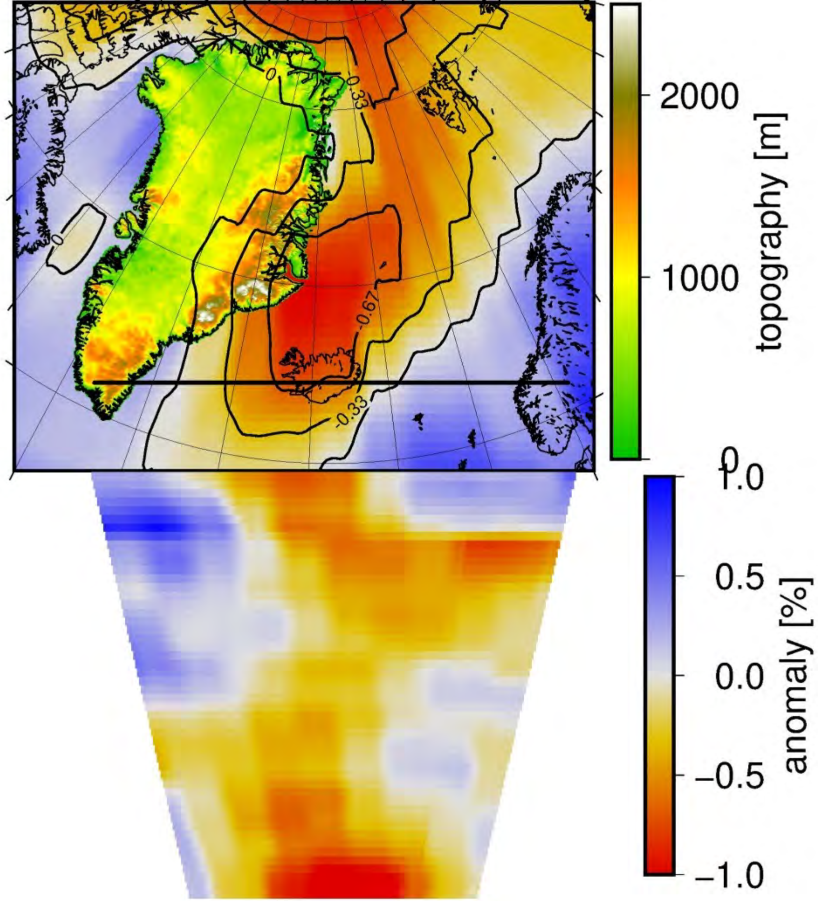


- Interaction with ridge
(Gassmöller et al., G-Cubed, 2016)

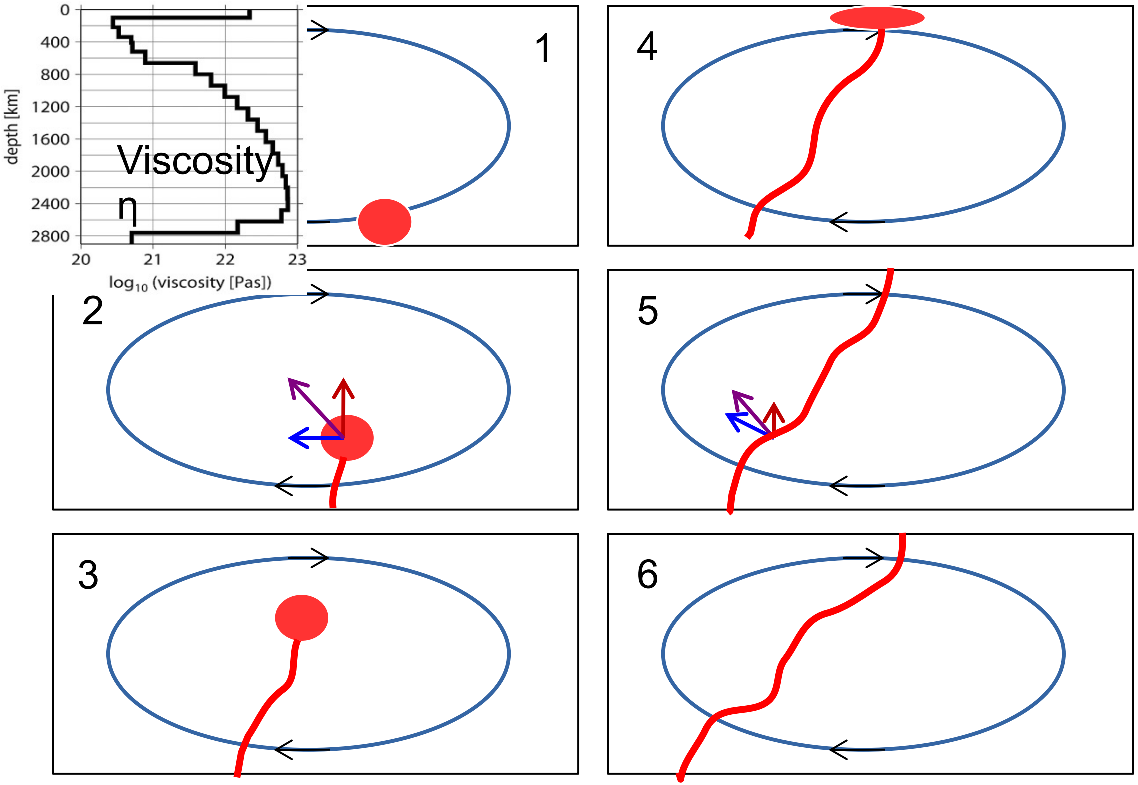




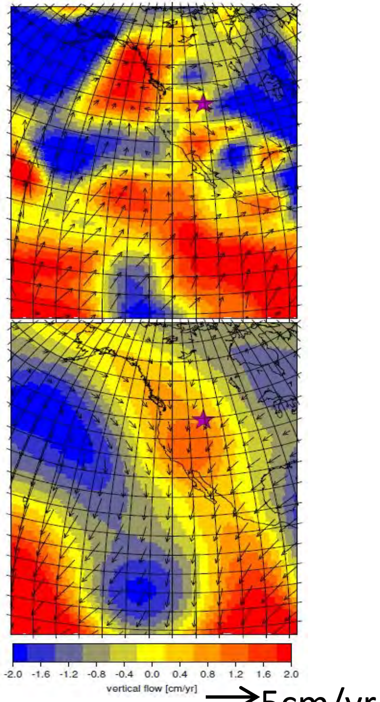
Interaction with moving lithosphere of variable thickness (Steinberger et al., NGeo, 2019)



TX2019slab-S (Lu et al., 2019)



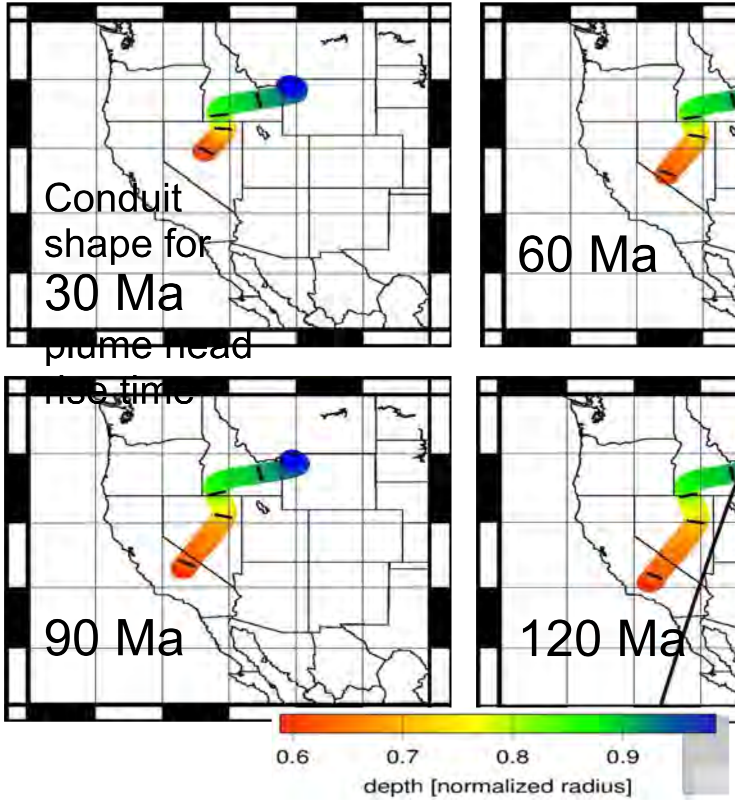
Upper mantle flow (650 km

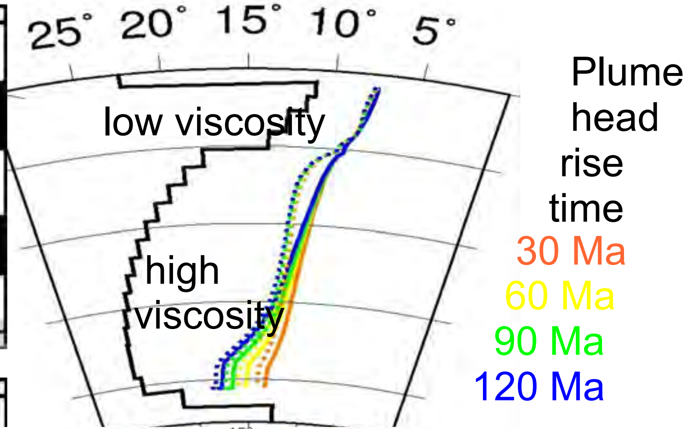


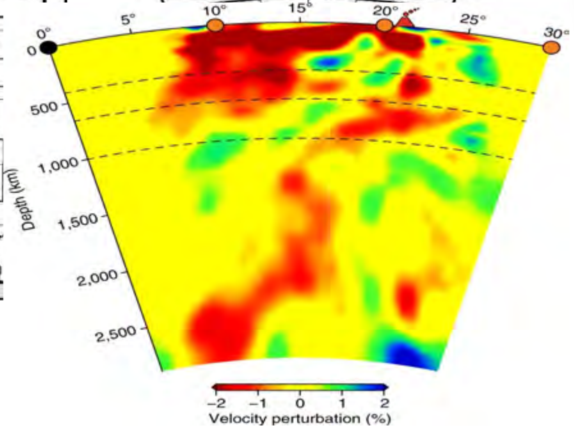
Lower mantle flow (2600 km depth)

Plume head rises ($v_{rise} \sim 1/\eta$)
gets advected by large-scale flow
(density anomalies from tomography)
How fast?
→ vary total rise time (prescribed)

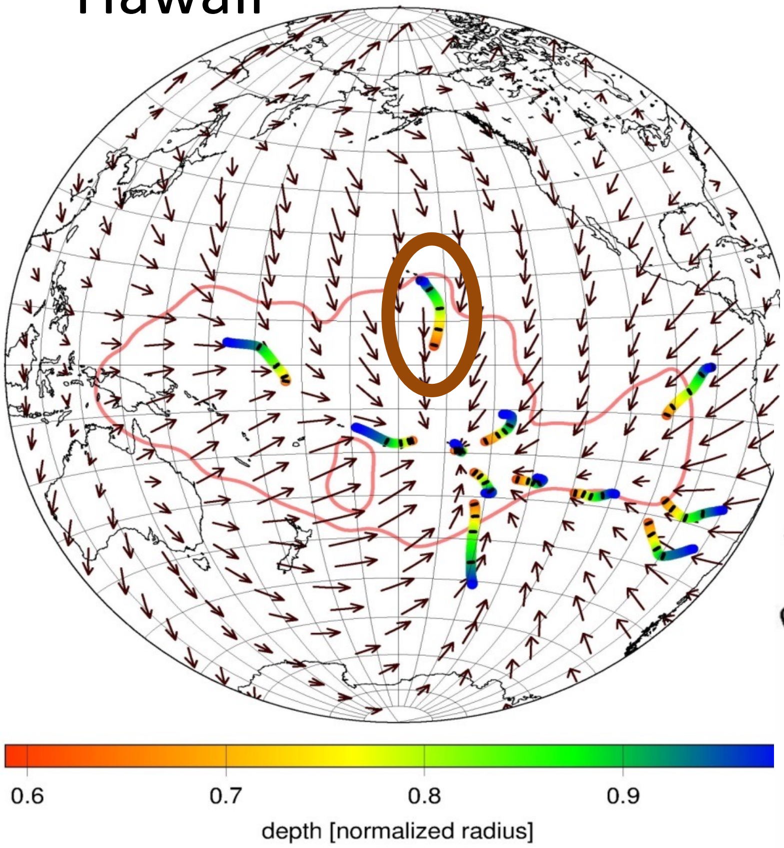
Plume conduit also rises
(but less fast) +
gets advected by large-scale flow


Conduit shape for 30 Ma plume head rise time
60 Ma
90 Ma
120 Ma
0.6
0.7
0.8
0.9
depth [normalized radius]

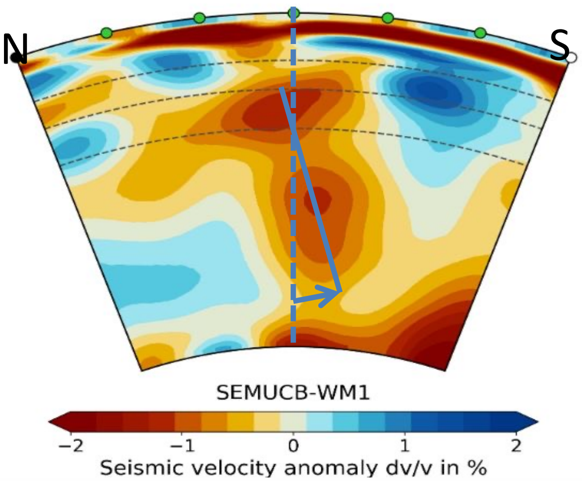

25°
20°
15°
10°
5°
low viscosity
high viscosity
Plume head rise time
30 Ma
60 Ma
90 Ma
120 Ma


0°
5°
10°
15°
20°
25°
30°
0
500
1,000
1,500
2,000
2,500
Depth (km)
−2
−1
0
1
2
Velocity perturbation (%)

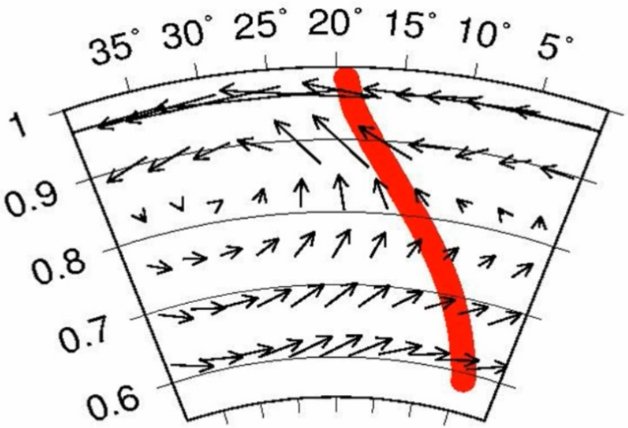
Hawaii



0.6
0.7
0.8
0.9
depth [normalized radius]

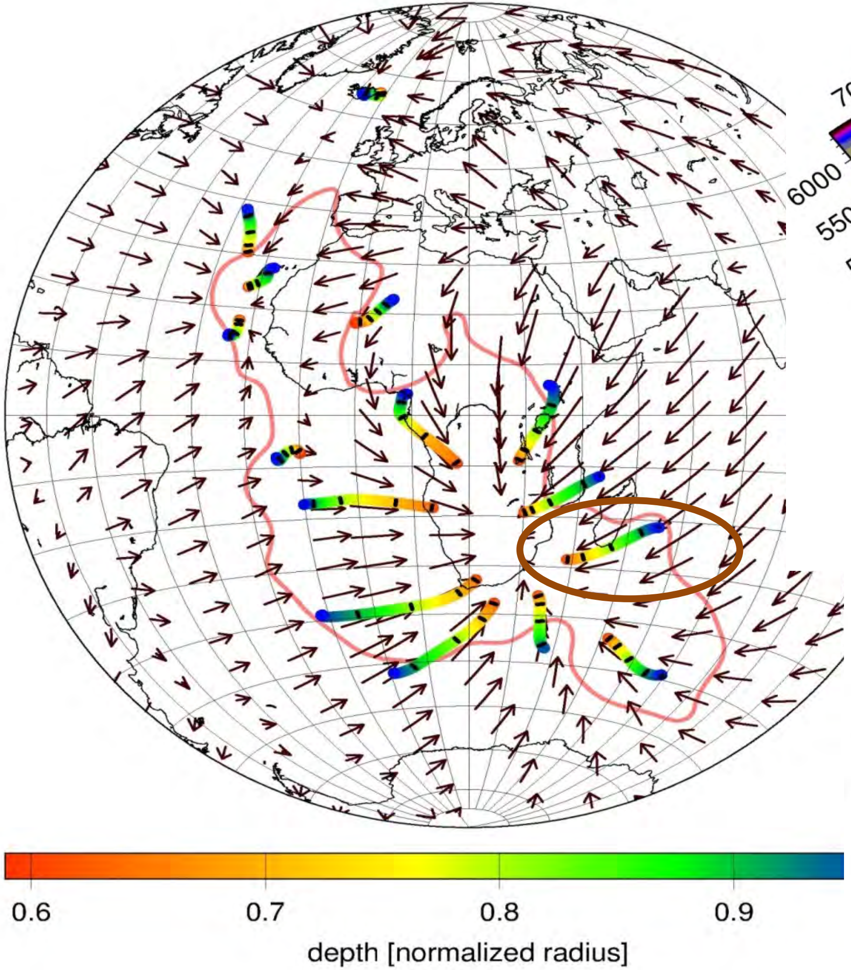


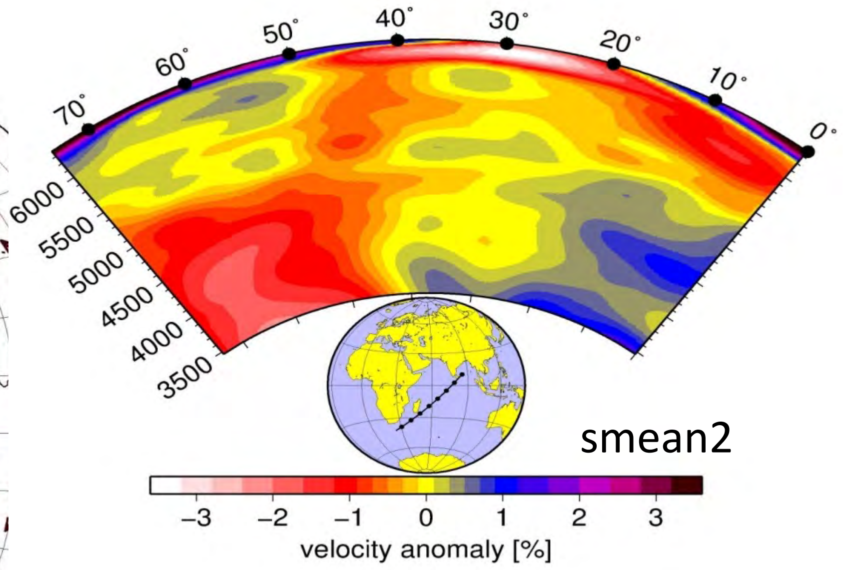
N
S
SEMUCB-WM1
−2
−1
0
1
2
Seismic velocity anomaly dv/v in %

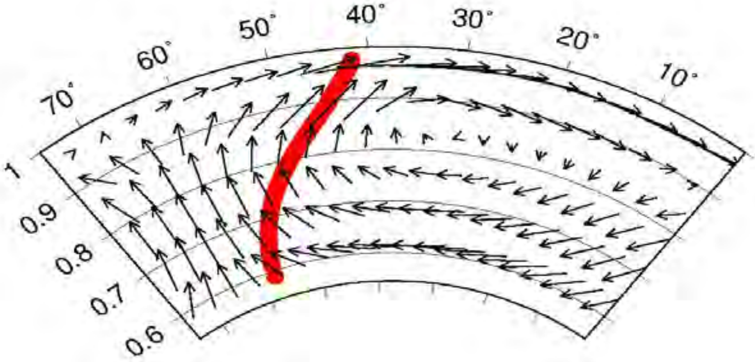


35°
30°
25°
20°
15°
10°
5°
1
0.9
0.8
0.7
0.6

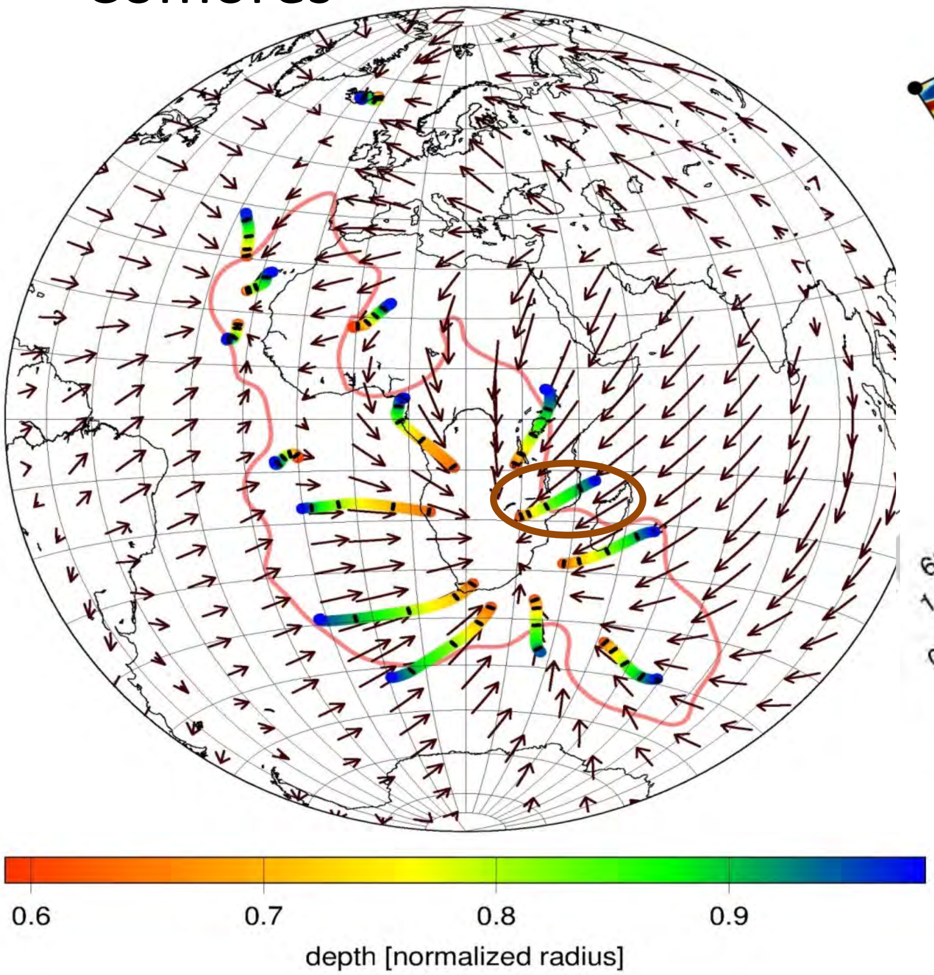
La Reunion


0.6
0.7
0.8
0.9
depth [normalized radius]

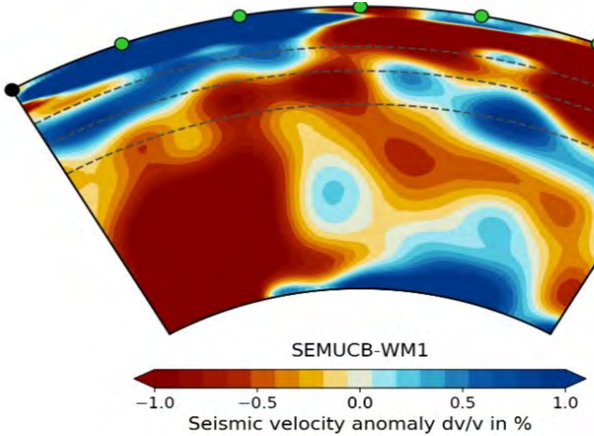

70°
60°
50°
40°
30°
20°
10°
0°
6000
5500
5000
4500
4000
3500
smean2
−3
−2
−1
0
1
2
3
velocity anomaly [%]


70°
60°
50°
40°
30°
20°
10°
1
0.9
0.8
0.7
0.6

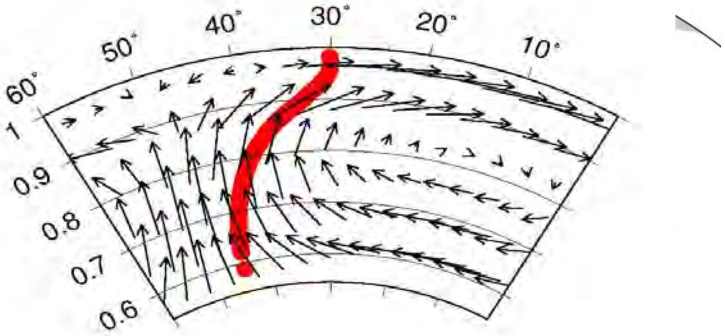
Comores



0.6
0.7
0.8
0.9
depth [normalized radius]

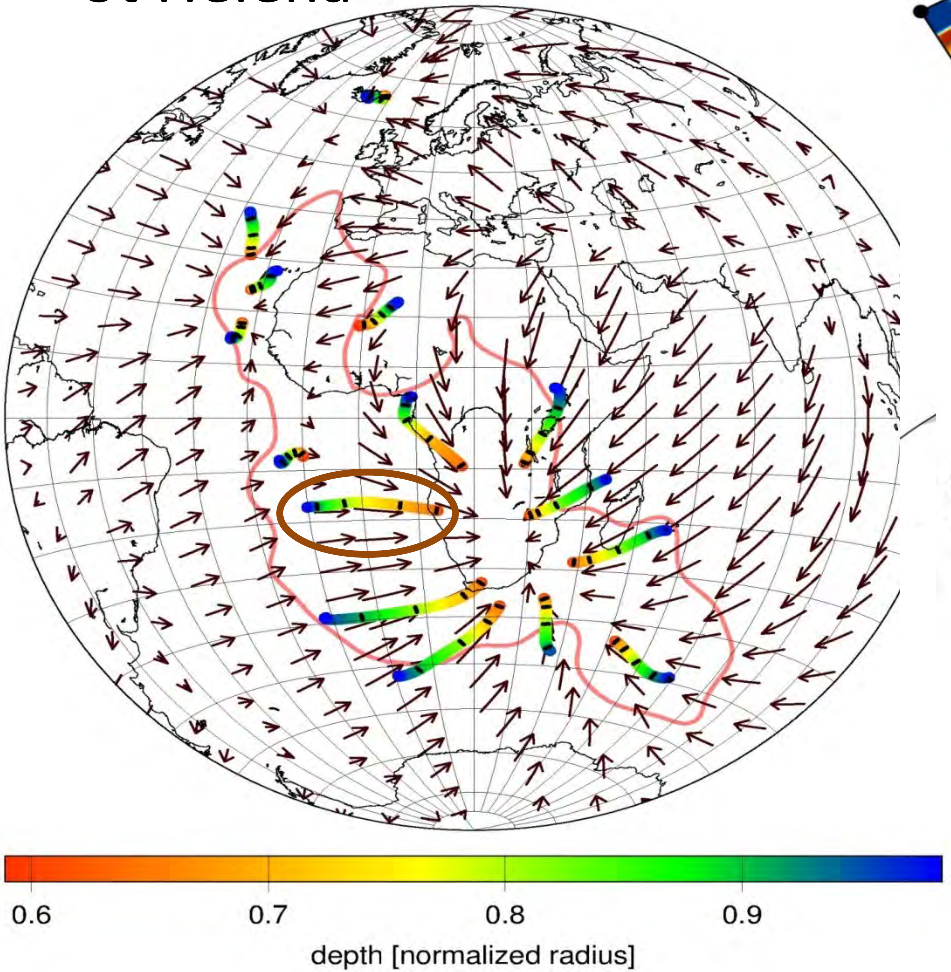


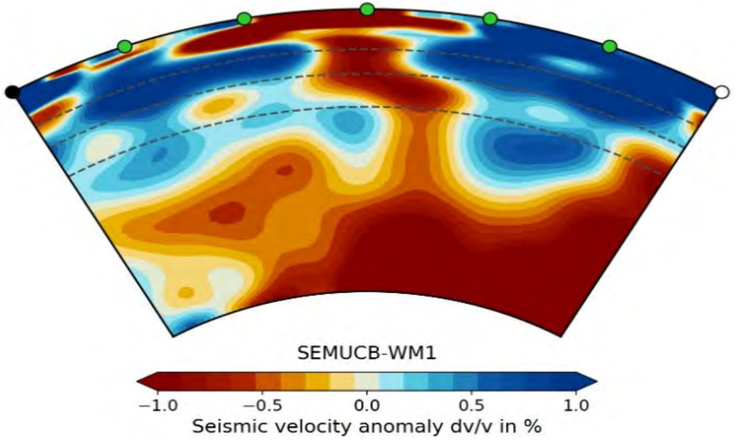
SEMUCB-WM1
−1.0
−0.5
0.0
0.5
1.0
Seismic velocity anomaly dv/v in %

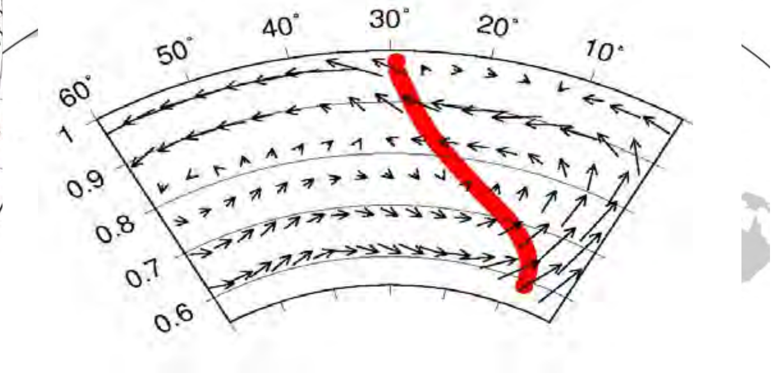


60°
50°
40°
30°
20°
10°
1
0.9
0.8
0.7
0.6

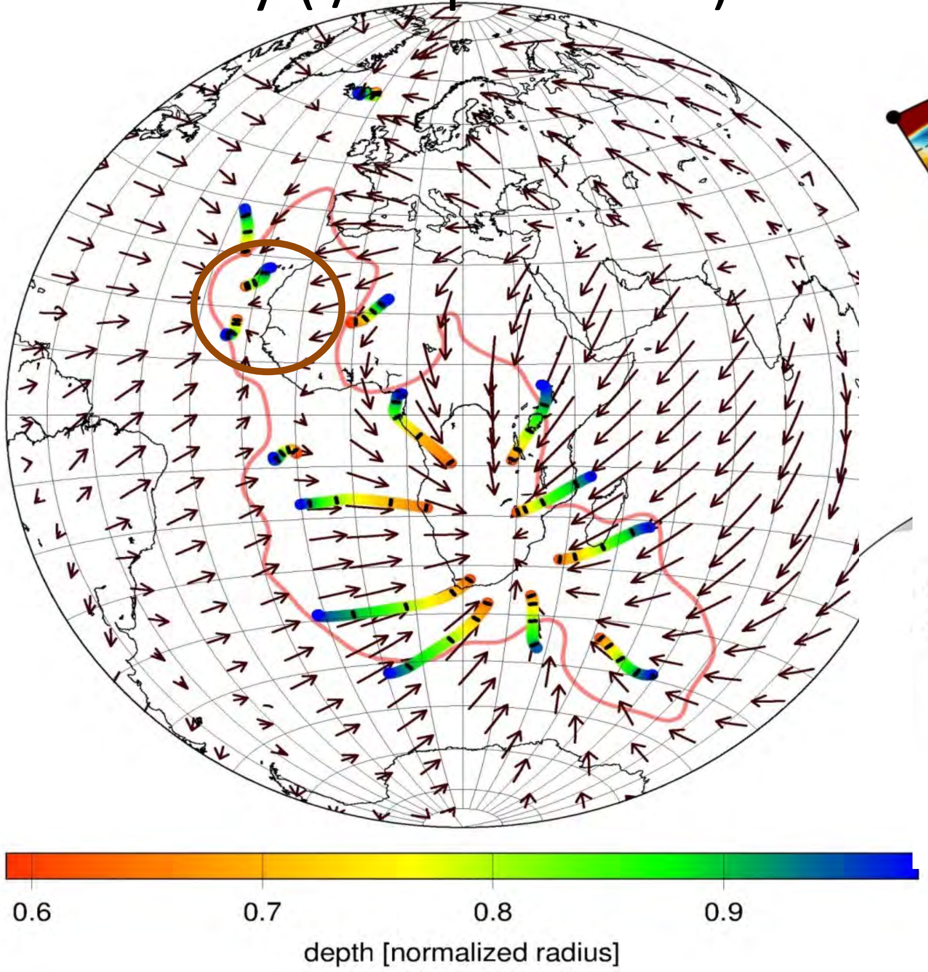
St Helena

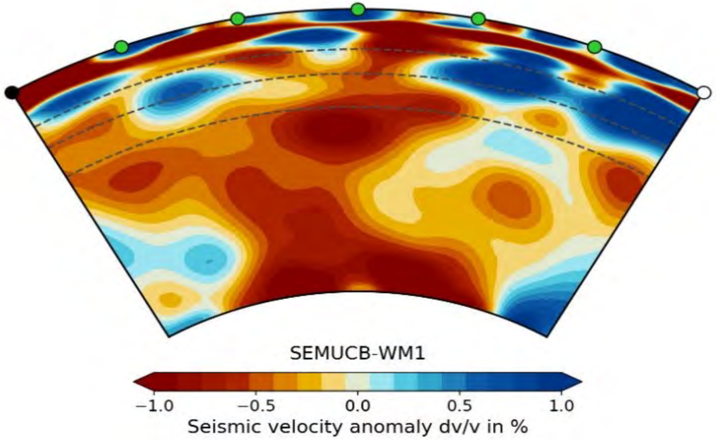

0.6
0.7
0.8
0.9
depth [normalized radius]

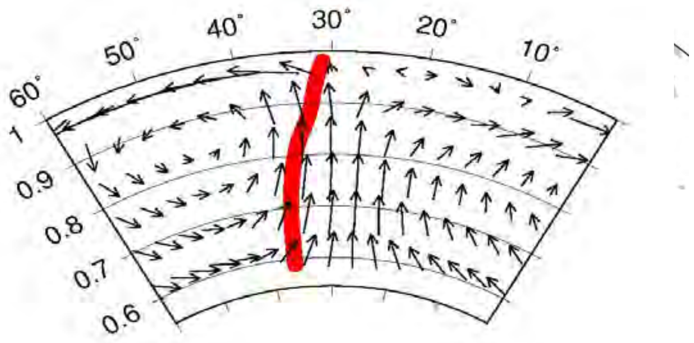

SEMUCB-WM1
−1.0
−0.5
0.0
0.5
1.0
Seismic velocity anomaly dv/v in %


50°
40°
30°
20°
10°
60°
1
0.9
0.8
0.7
0.6

Canary (/ Cape Verde)

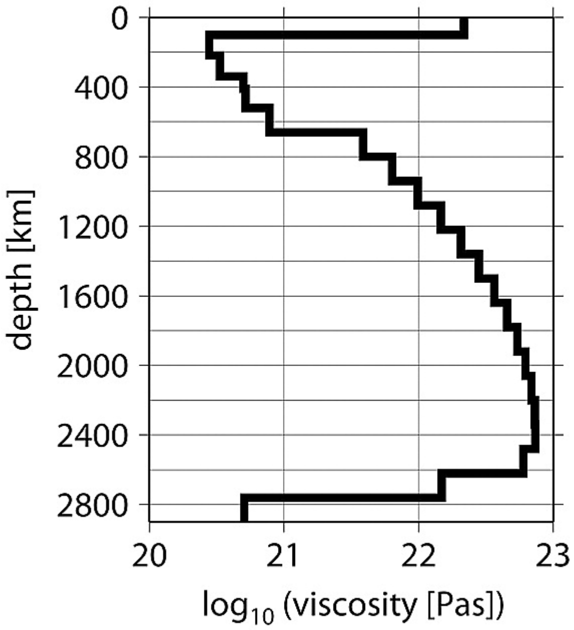






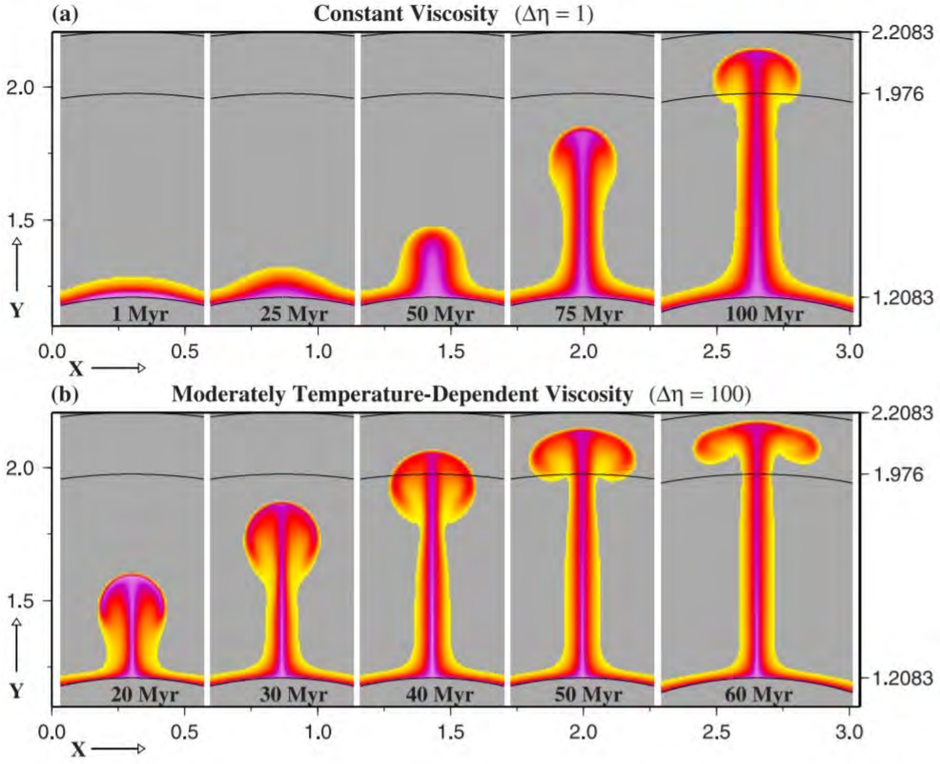
Radial viscosity:

- Postglacial rebound
- Geoid modelling
- Slow motion of hotspots



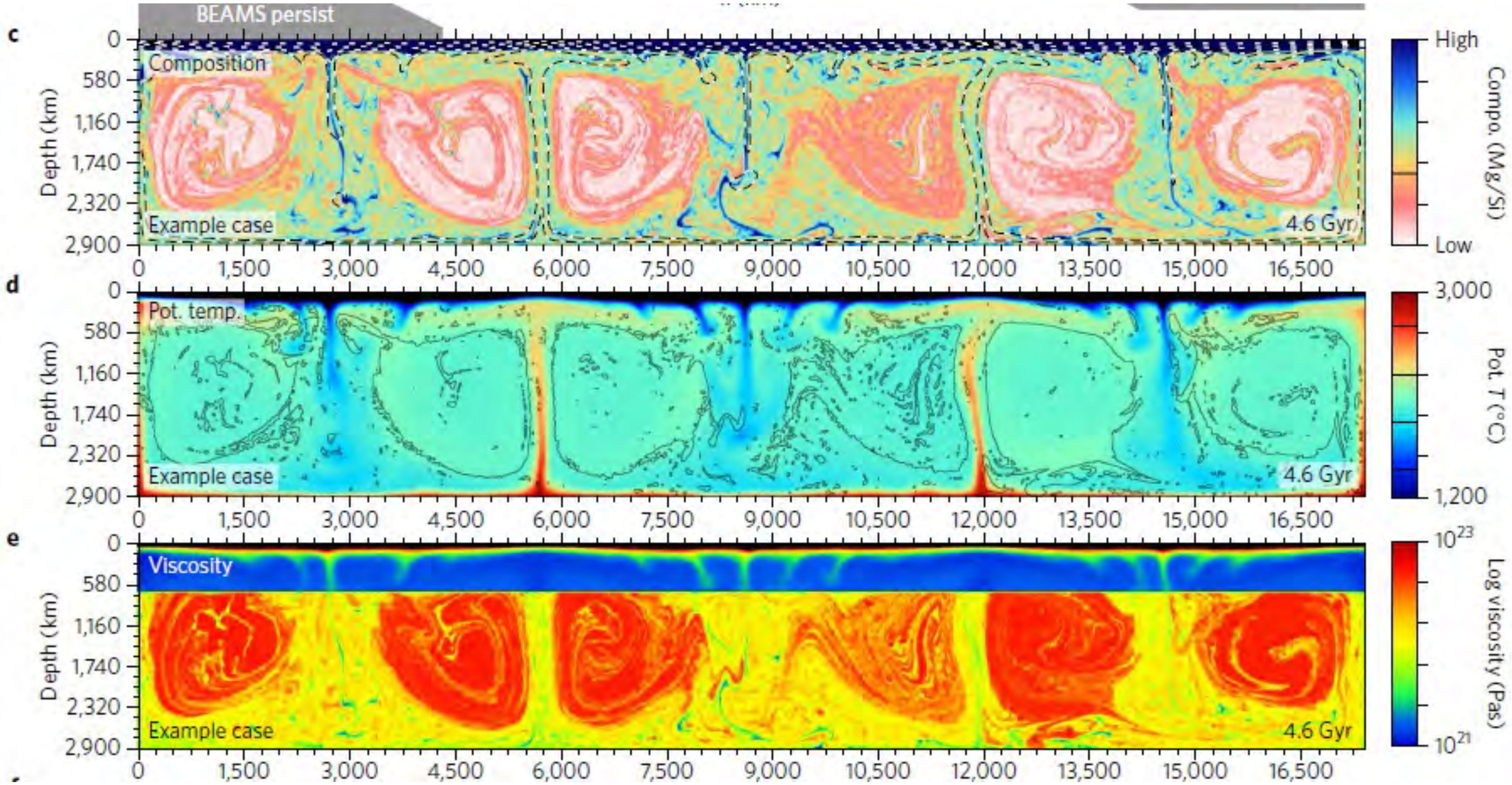
Steinberger & Calderwood (2006)

Temperature dependent viscosity
Causing narrow plume conduits



Lin and van Keken (2006)

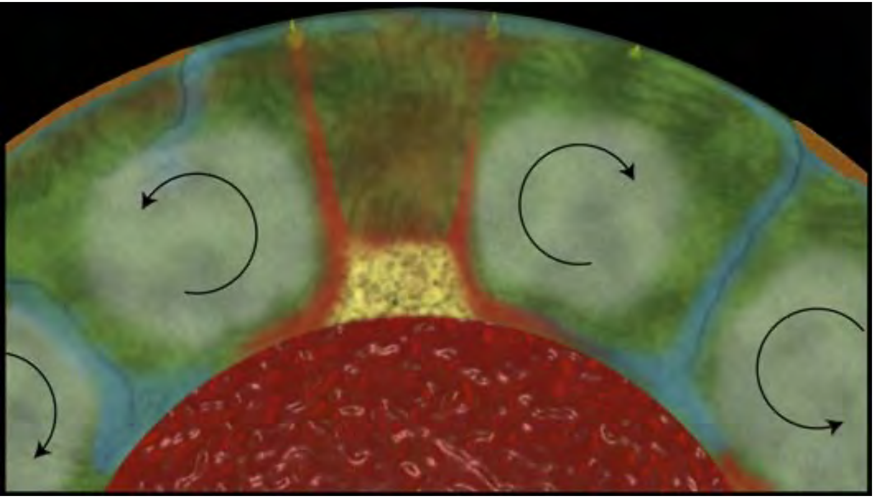
Composition dependent viscosity: bridgmanite-enriched ancient mantle structures

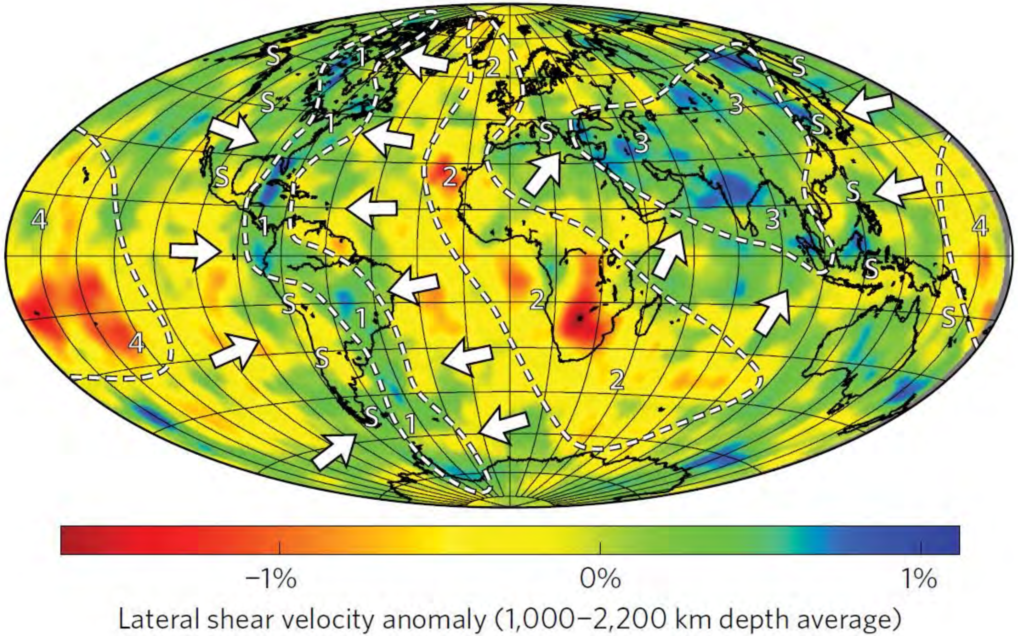


Ballmer et al., NGeo, 2017

Cartoon view of BEAMS

Suggested distribution:
Between dashed lines, below arrows





Ballmer et al., NGeo, 2017

Integrated strain dependent viscosity
LBF=Load-bearing framework

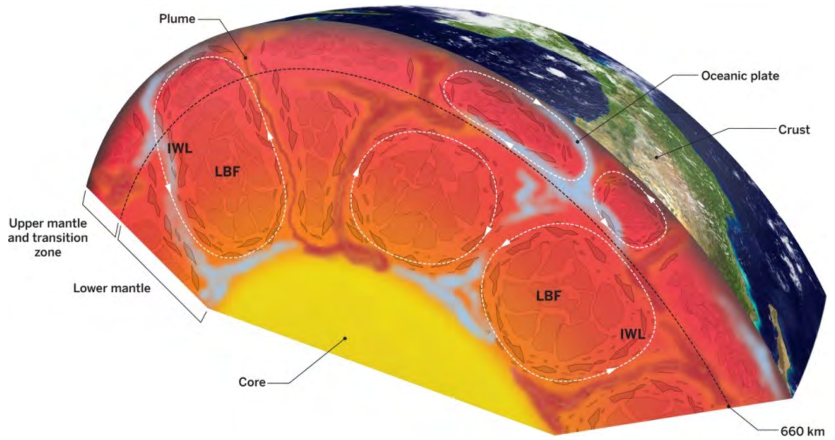


ILLUSTRATION: C. BICKEL/*SCIENCE*
Illustrating Girard et al., Science, 2016

- Where Bridgmanite is interconnected, mantle is stronger.
- However, strong shear may lead to interconnection of weaker Magnesiowustite

Summary

- Thermal structure created through convection: slabs going down, plumes coming up.
- Chemical structure: Crust generated through melting. Accumulated in piles on base of mantle? Entrained in plumes?
- Ancient (primordial) structure in piles? In BEAMS?
- Complicated rheology: Viscosity depth dependent, temperature-composition- strain(rate), strain history dependent?