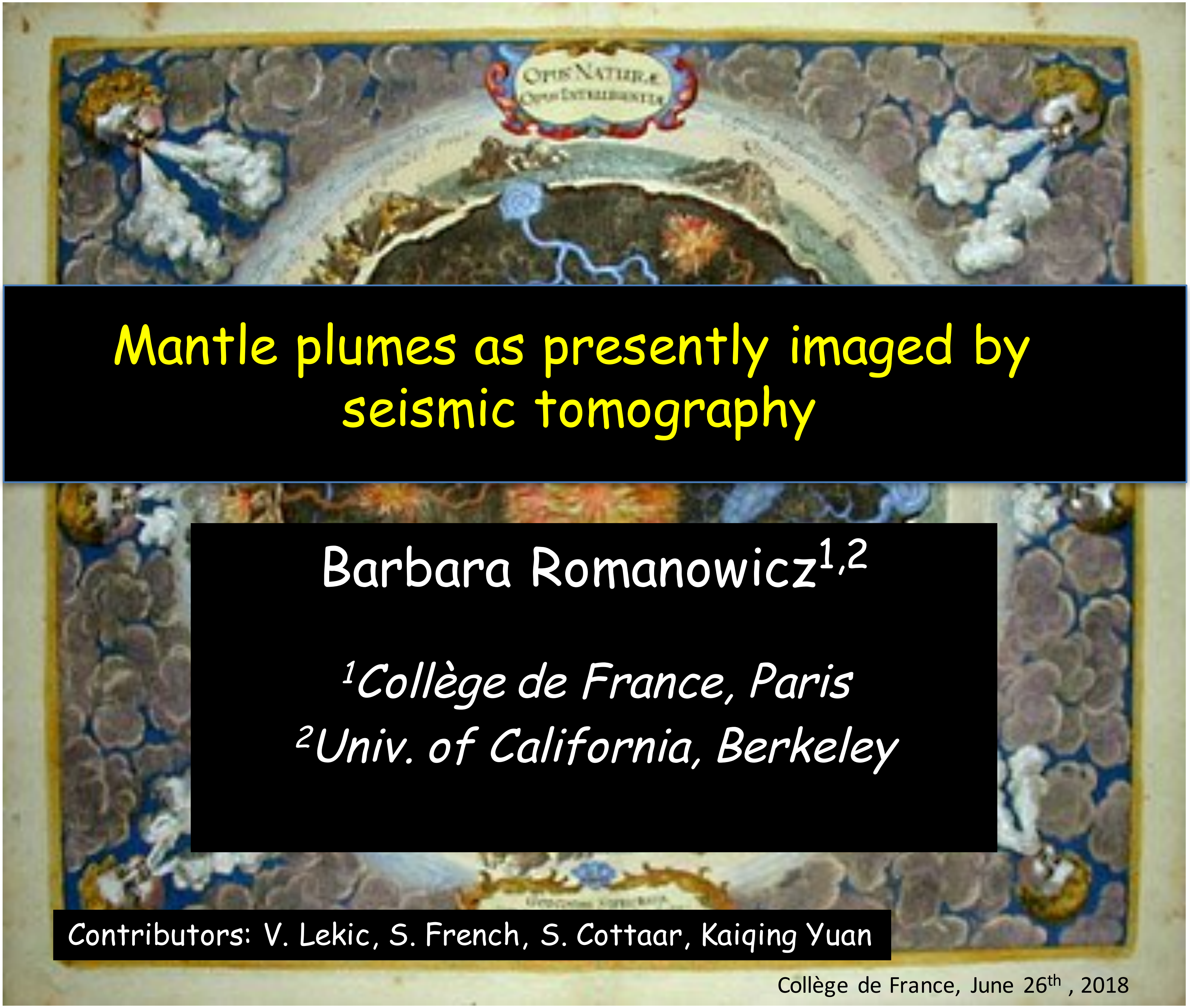


Mantle plumes as presently imaged by seismic tomography

Barbara Romanowicz[1,2]

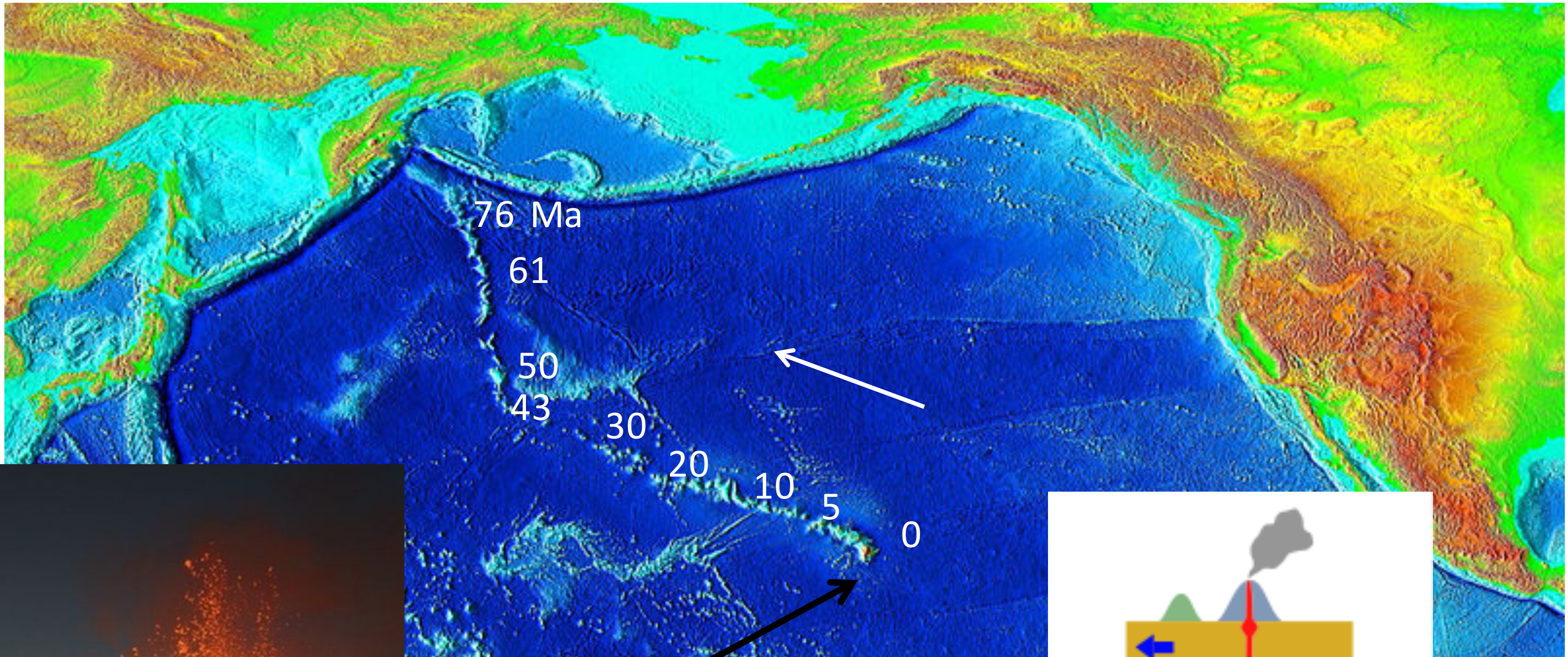
[1]Collège de France, Paris

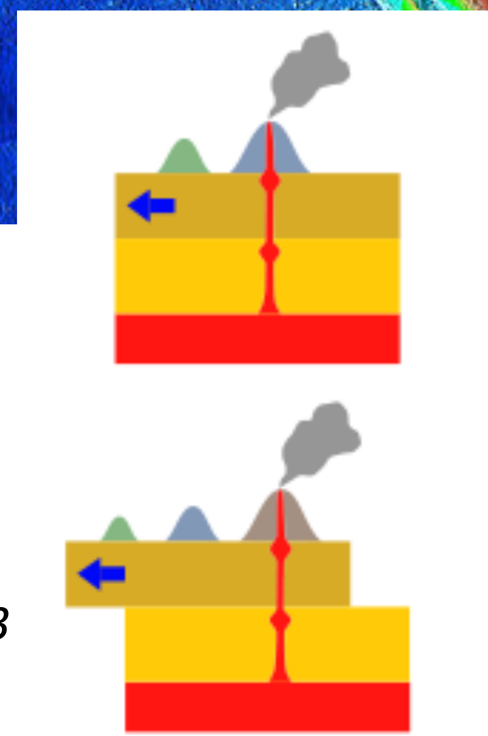
[2]Univ. of California, Berkeley

Contributors: V. Lekic, S. French, S. Cottaar, Kaiqing Yuan

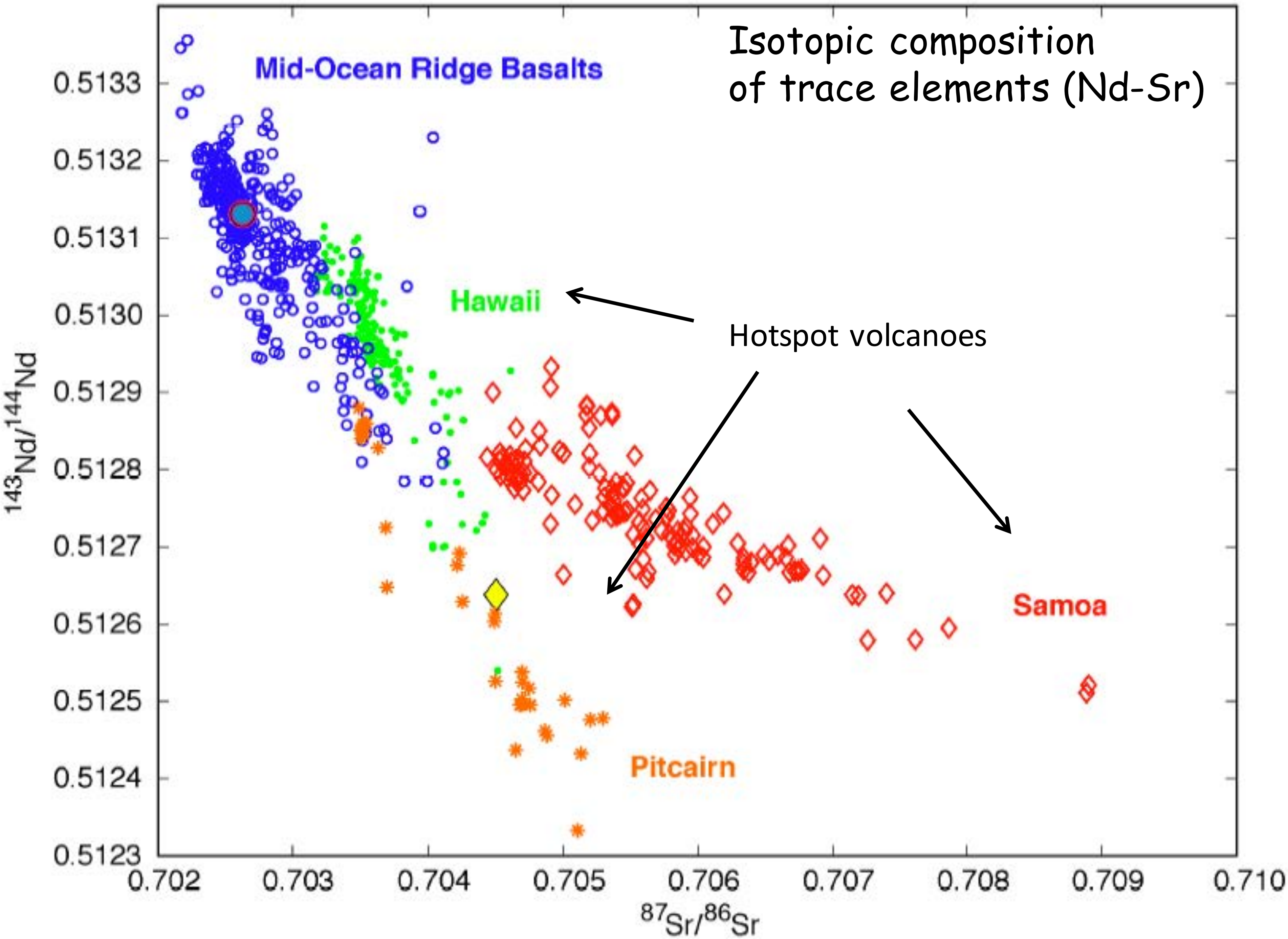
Collège de France, June 26th , 2018

Hot spots and mantle plumes

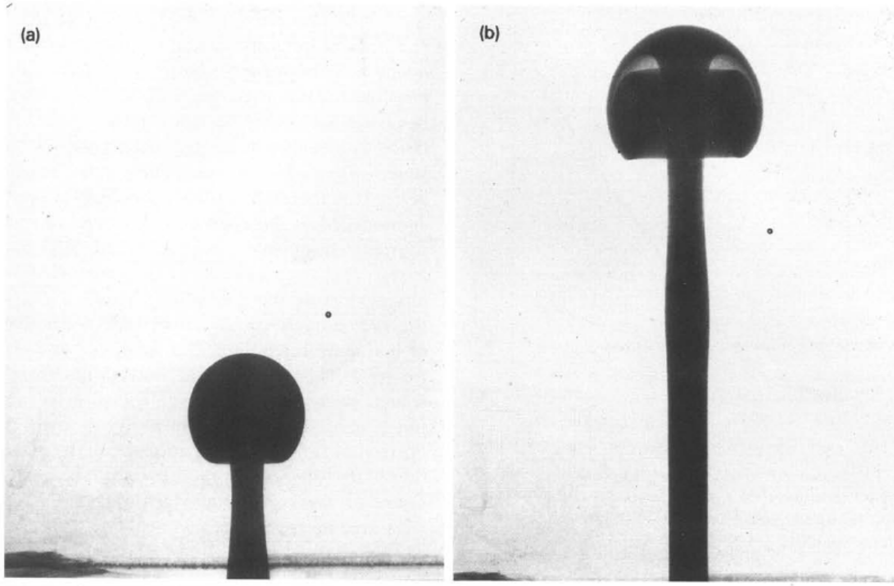




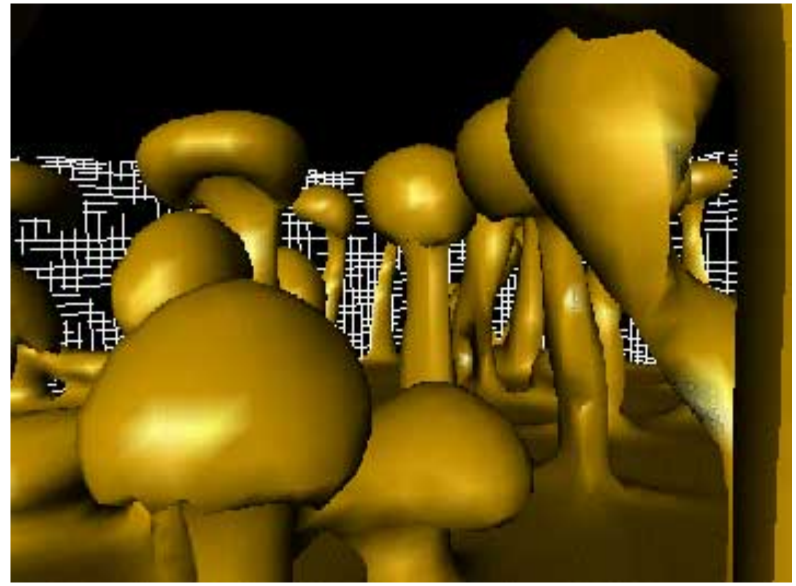
T. Wilson, 1963
Morgan, 1971

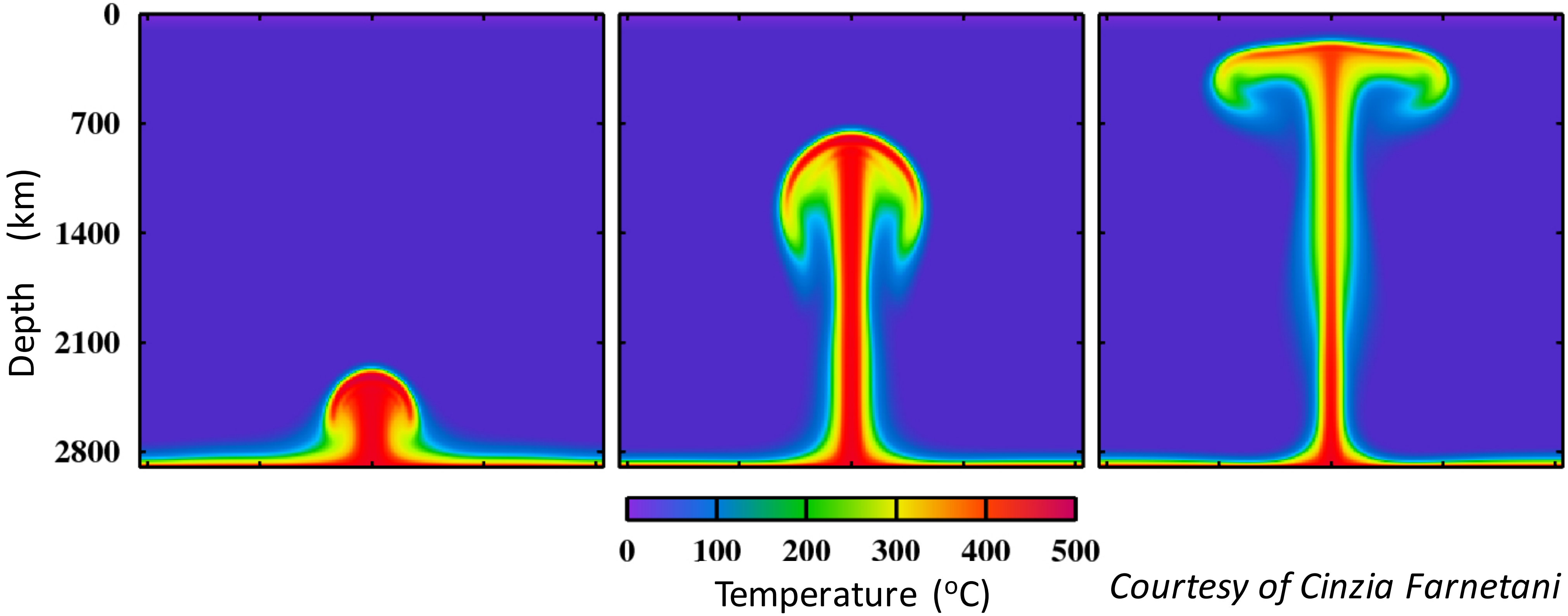


Workman, 2005

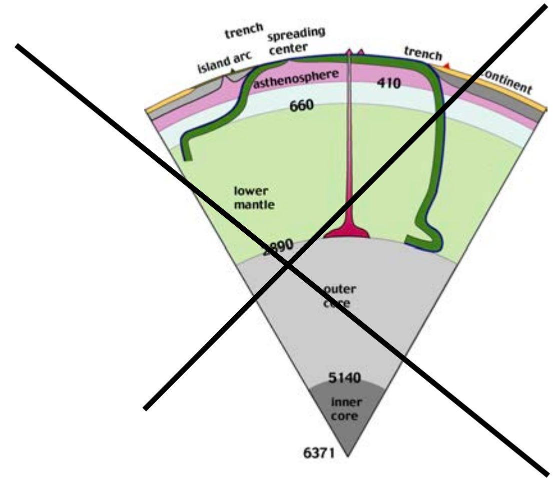


Griffiths and Campbell, 1990





Courtesy of Cinzia Farnetani

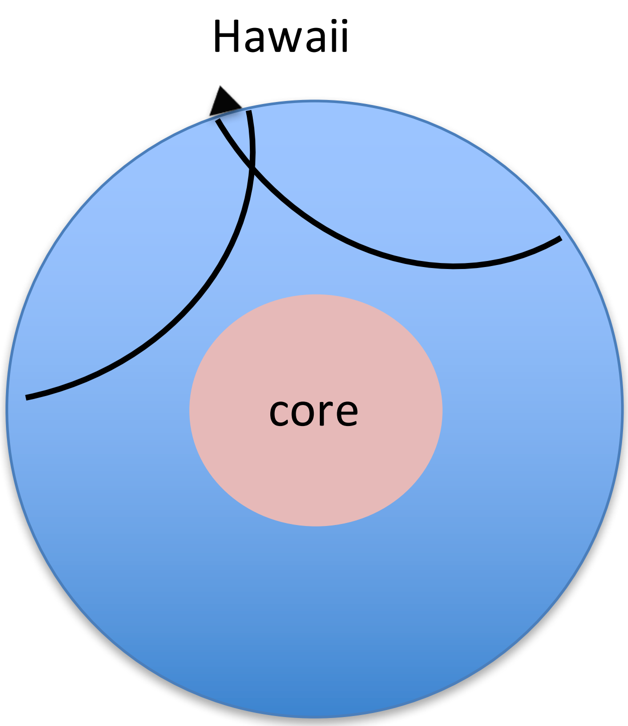


- Mantle Plumes exist!!

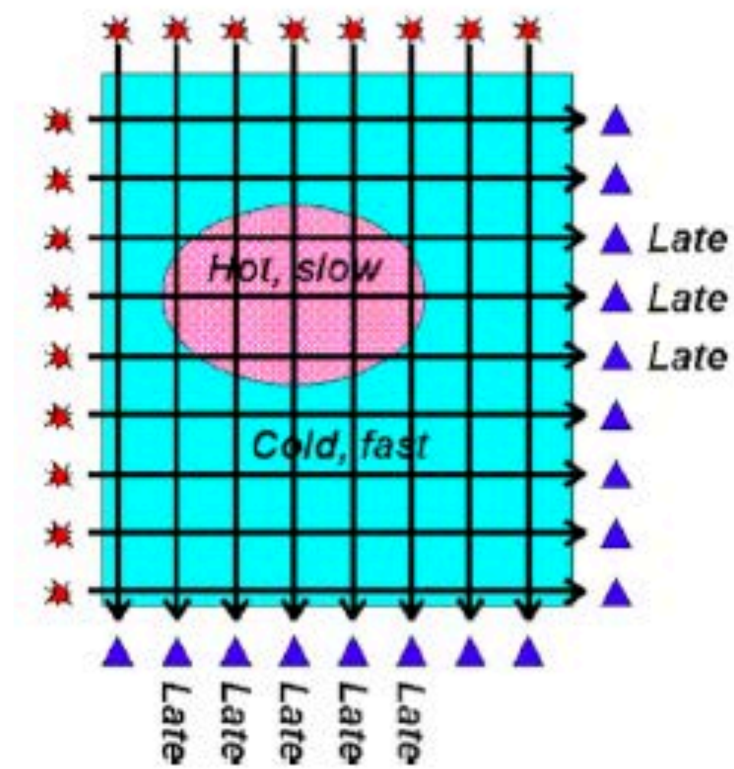
- As currently resolved by global seismic tomography:
  - Rooted at the core-mantle boundary
  - Clustered within the large low shear velocity provinces of the lower mantle
  - Not purely thermal
    - Thermo-chemical or
    - Partially molten and/or involve a non-Newtonian rheology for the lower mantle

- Their morphology highlights the more vigorous convection in the upper 1000 km of the mantle and a very sluggish lower mantle

Imaging mantle plumes: Challenge nr 1

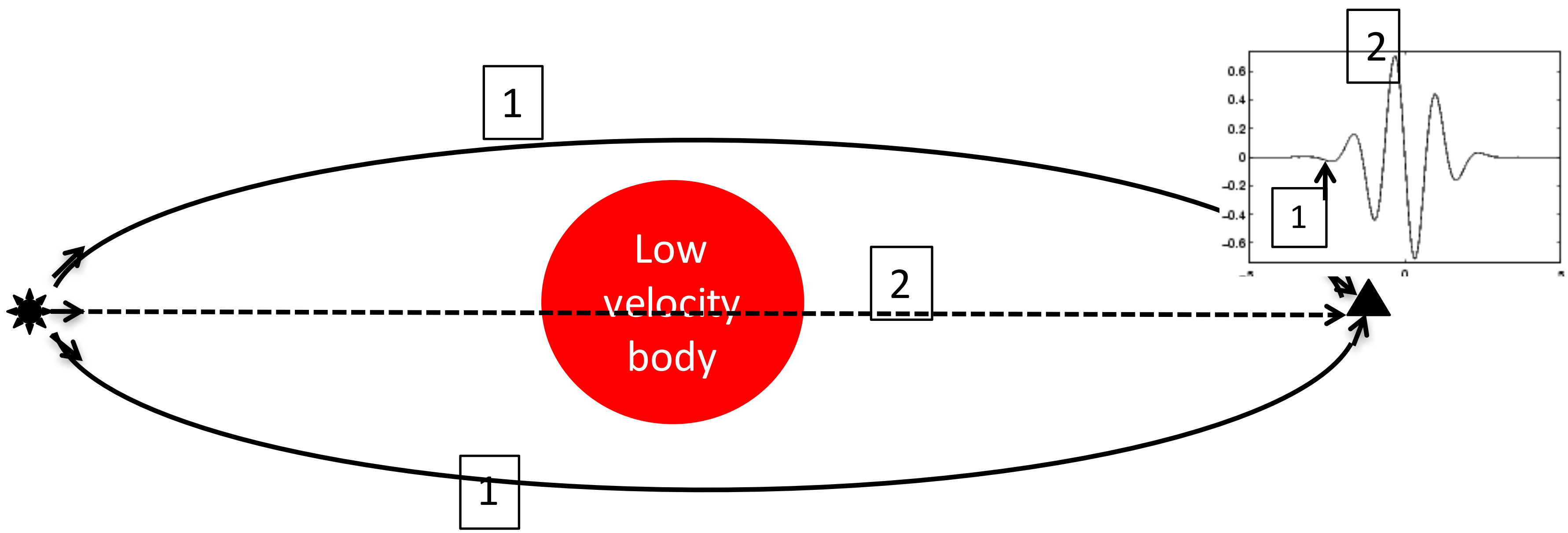


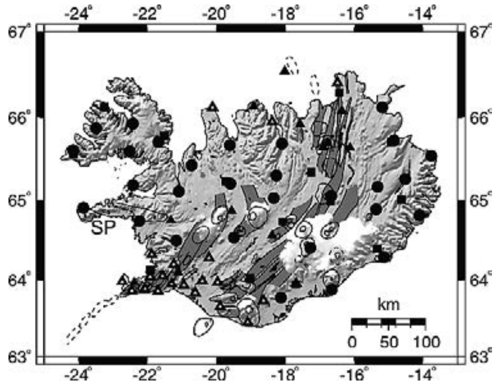
Principle of travel time tomography



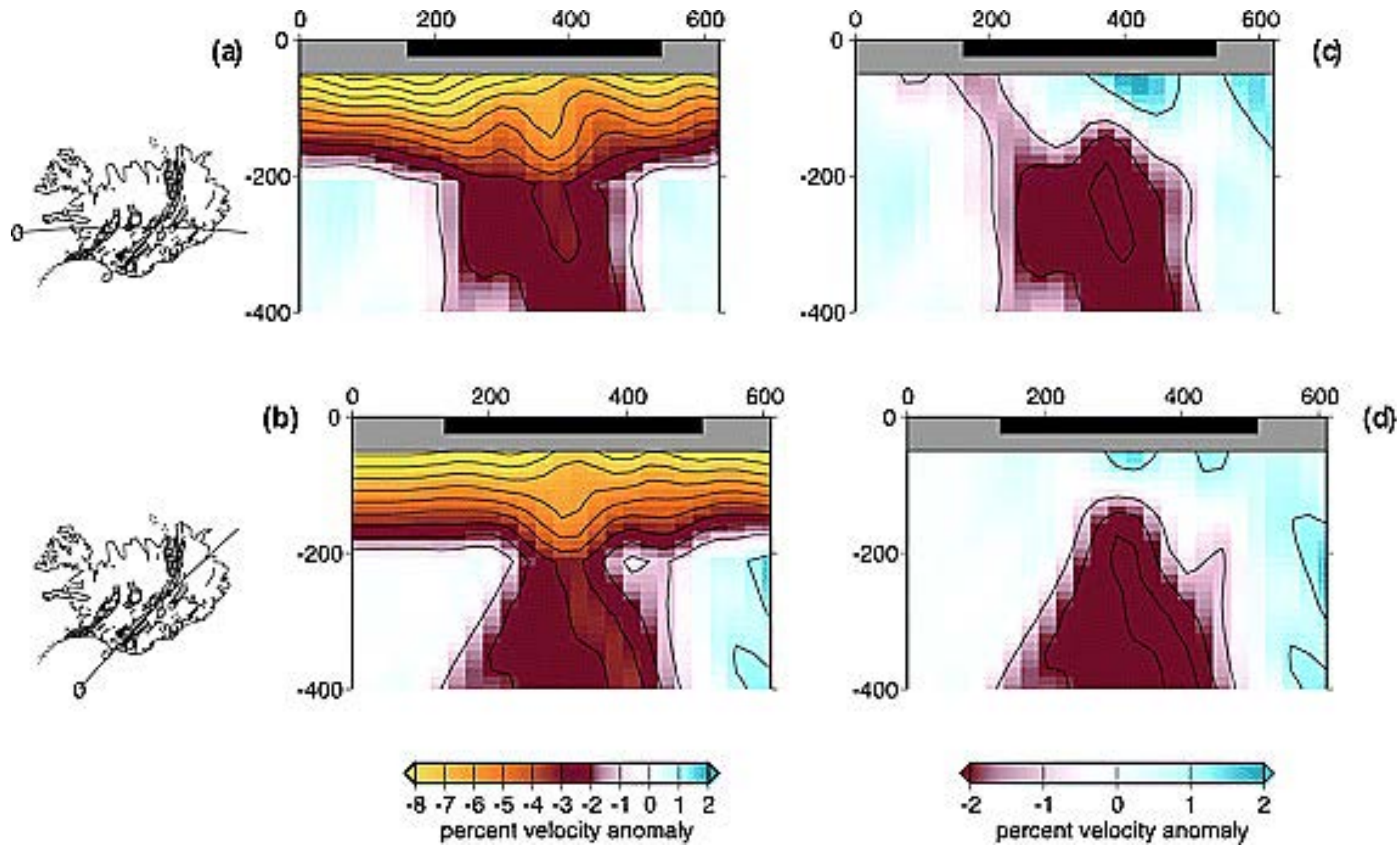
Imaging mantle plumes: Challenge nr 2

Low velocity regions of relatively small size are hidden from view when considering only first arriving waves





Iceland Hotspot and Plume

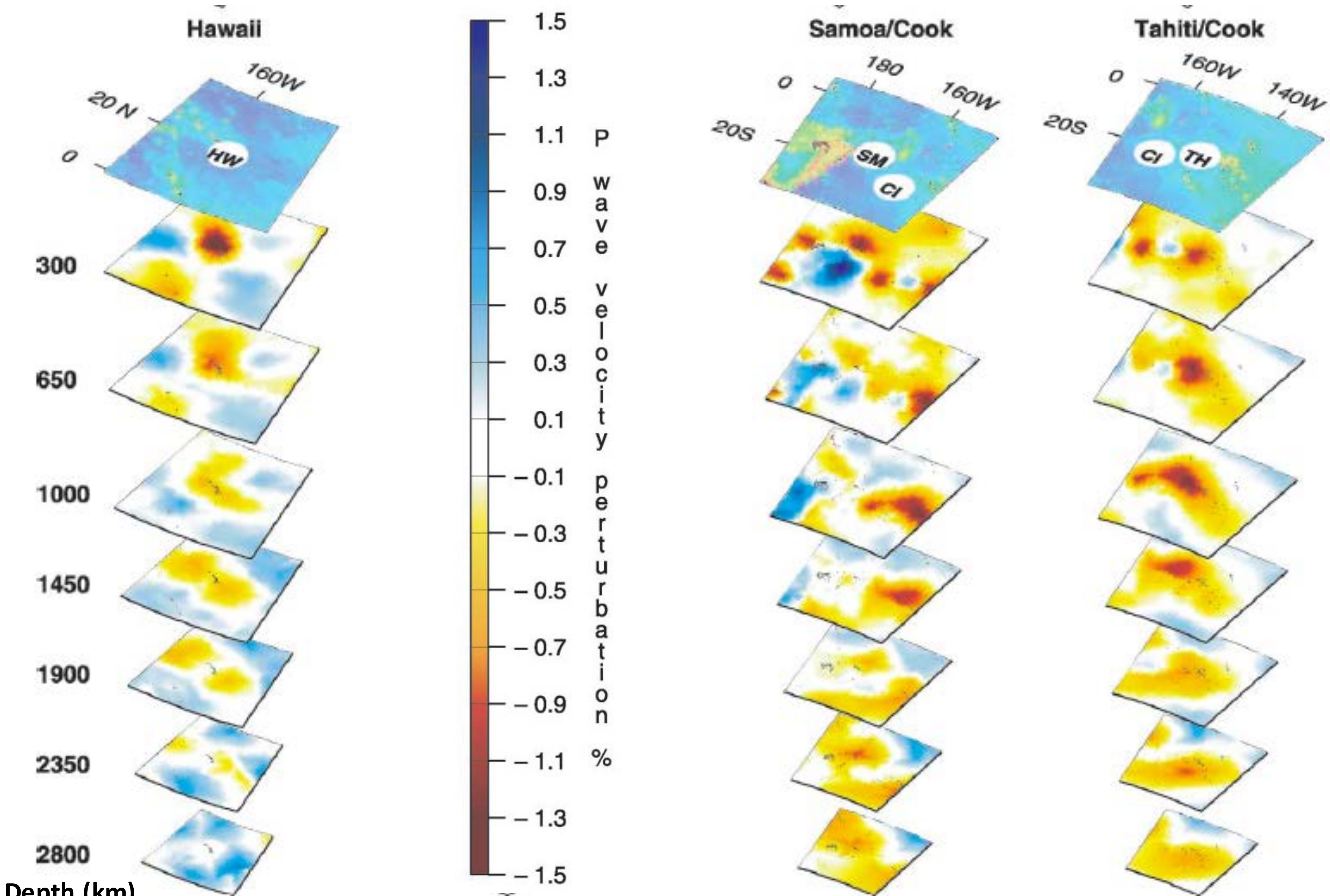


Absolute w/r 4.5 km/s

Relative velocities

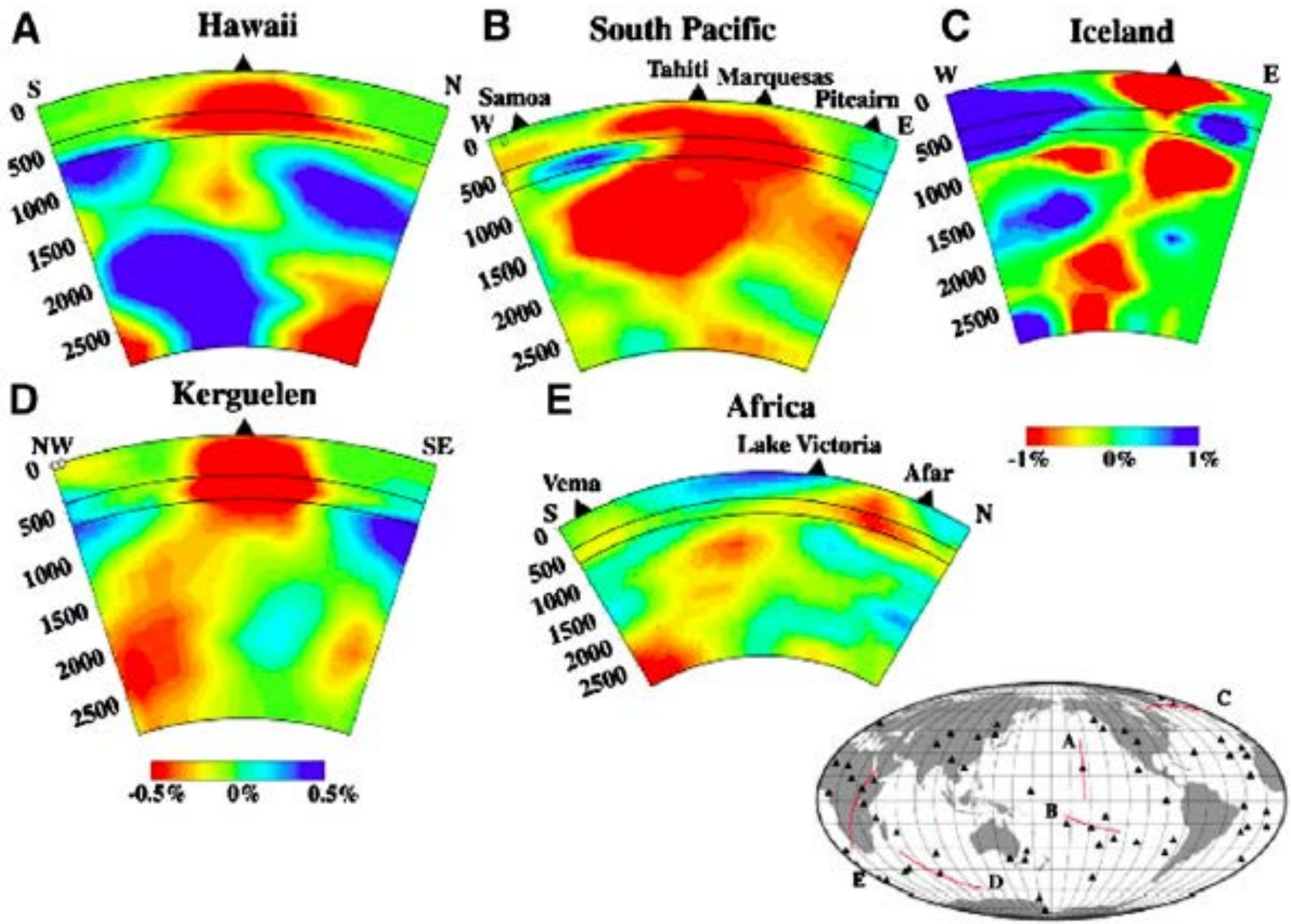
R. Allen, Nolet, Morgan et al., 2002

P wave travel time tomography



Montelli , Nolet, Dahlen et al., 2004, Science

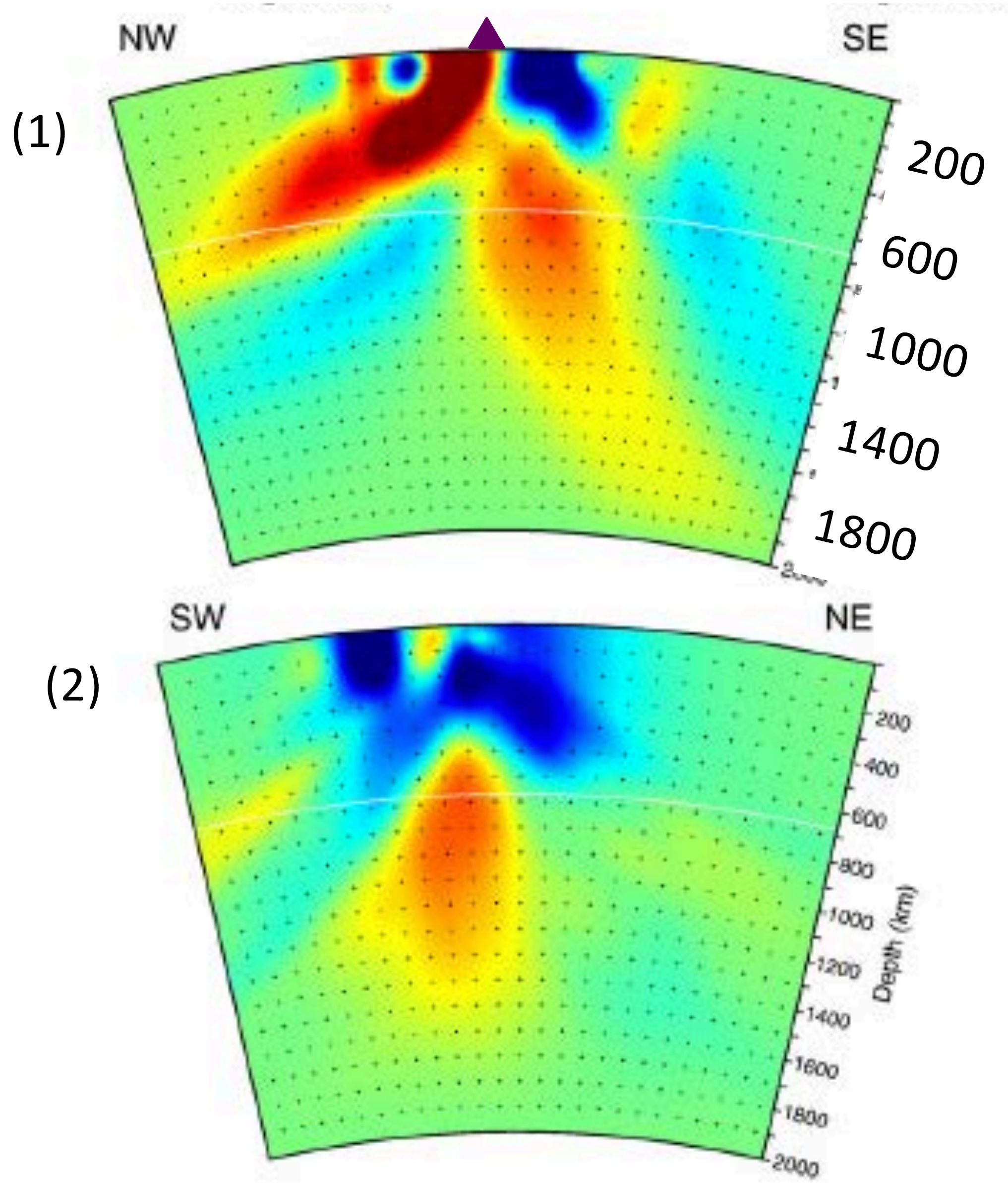
P wave travel time tomography

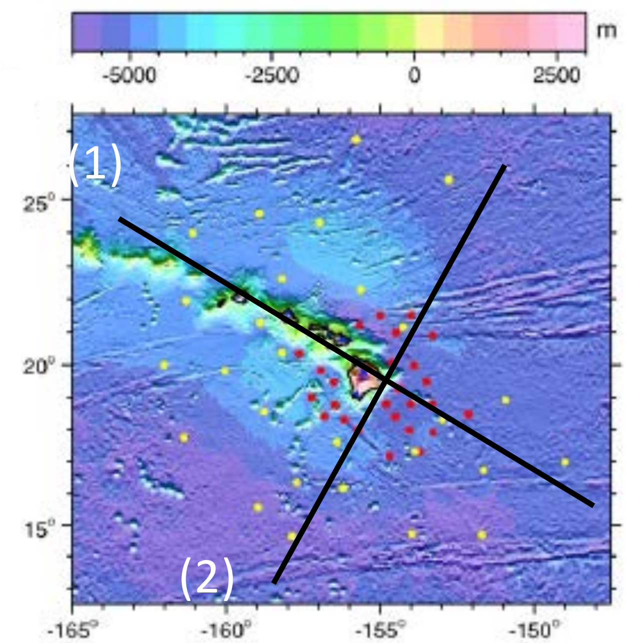


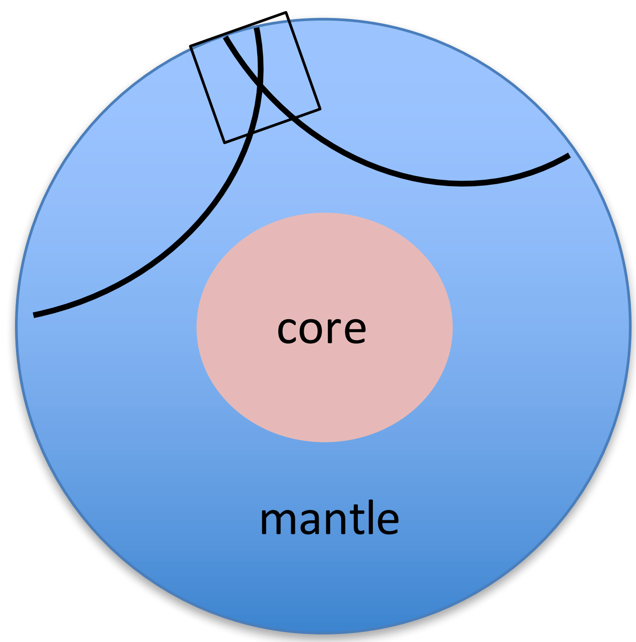
Nolet, Allen and Zhao., 2005

P wave travel time tomography

Hawaiian "plume"

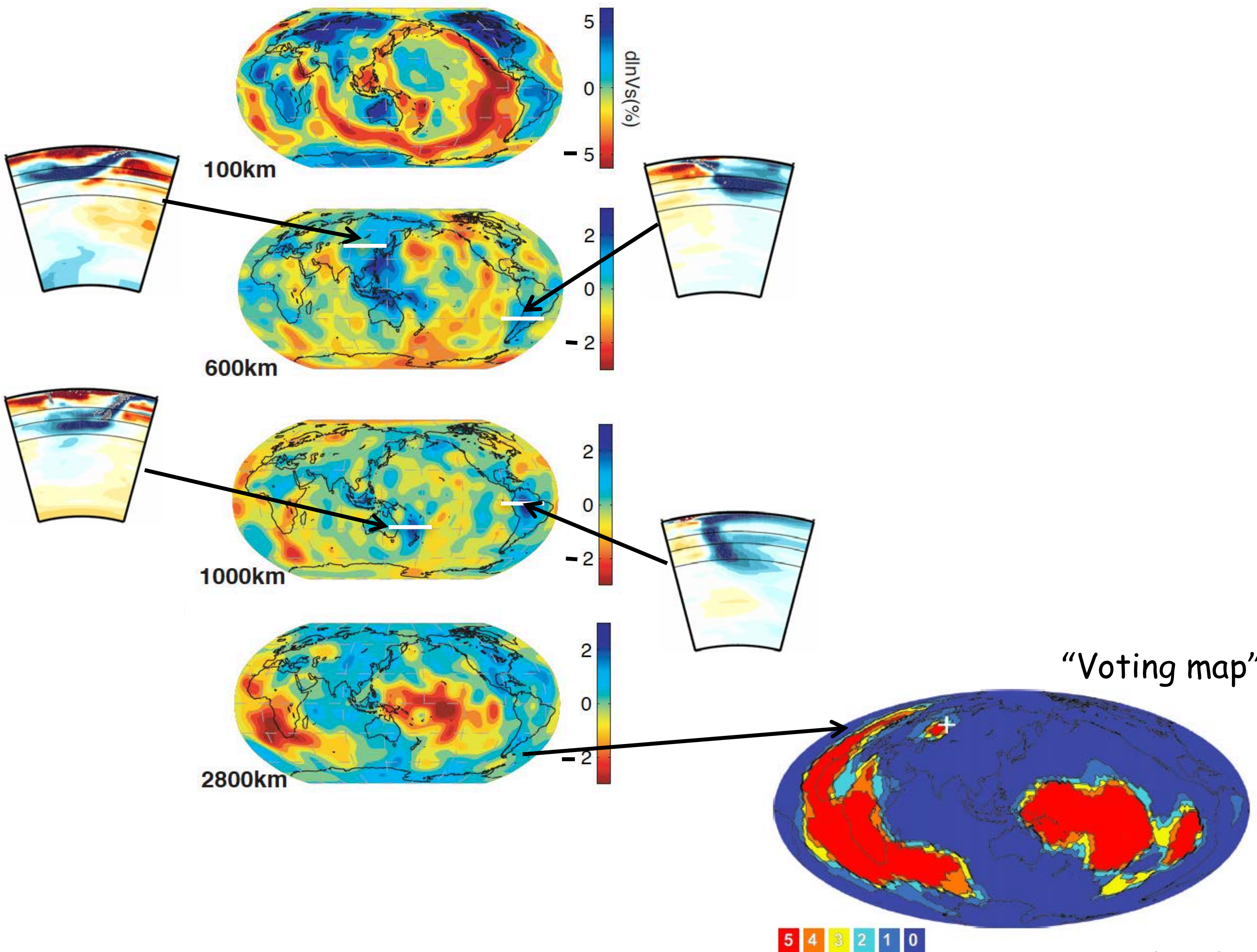






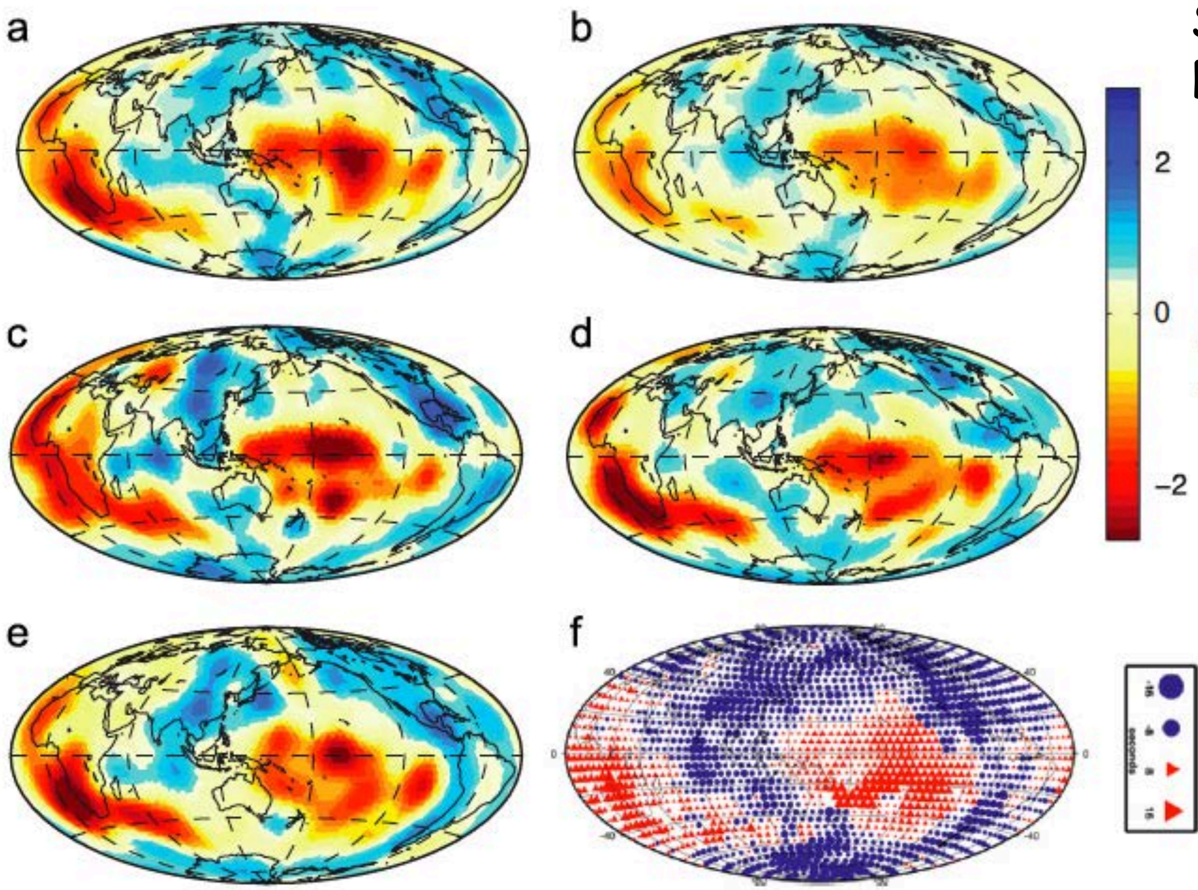
Wolfe, Solomon et al., 2011

Long wavelength global shear velocity models

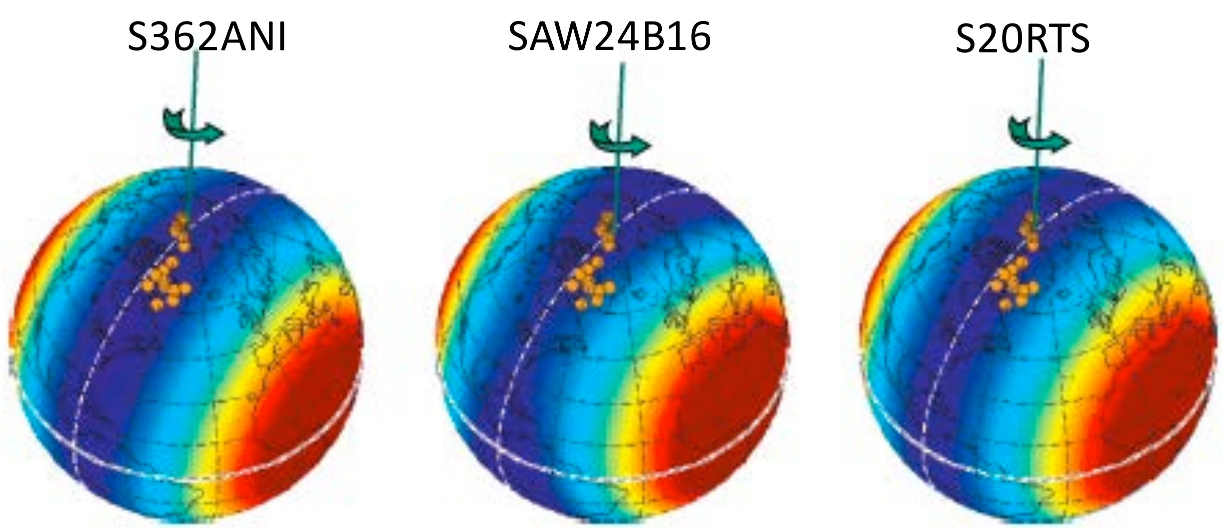


Lekic et al., 2012

Shear velocity
Depth = 2800 km

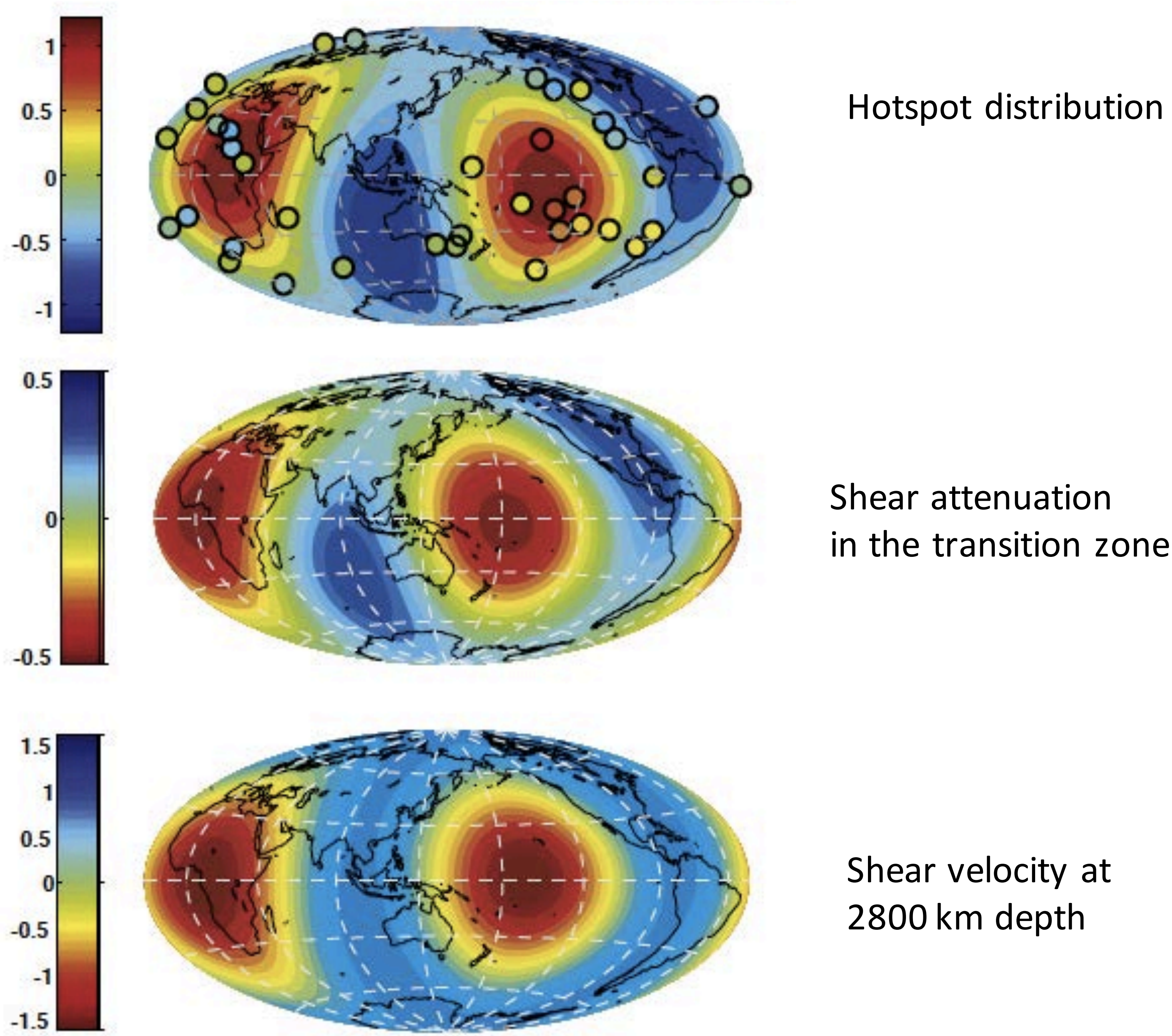


"LLSVP", or…
"Superplumes"



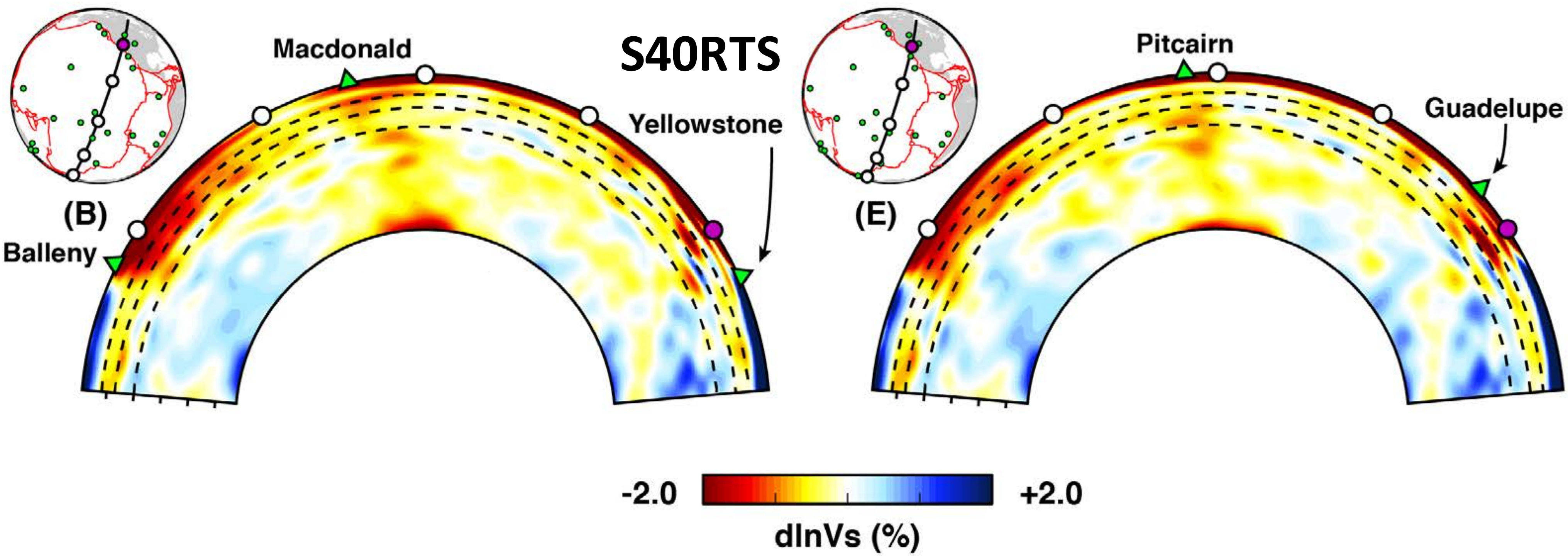
- Paleo-pole locations
  (*Besse and Courtillot, 2002*)

“Degree 2” pattern in the mantle



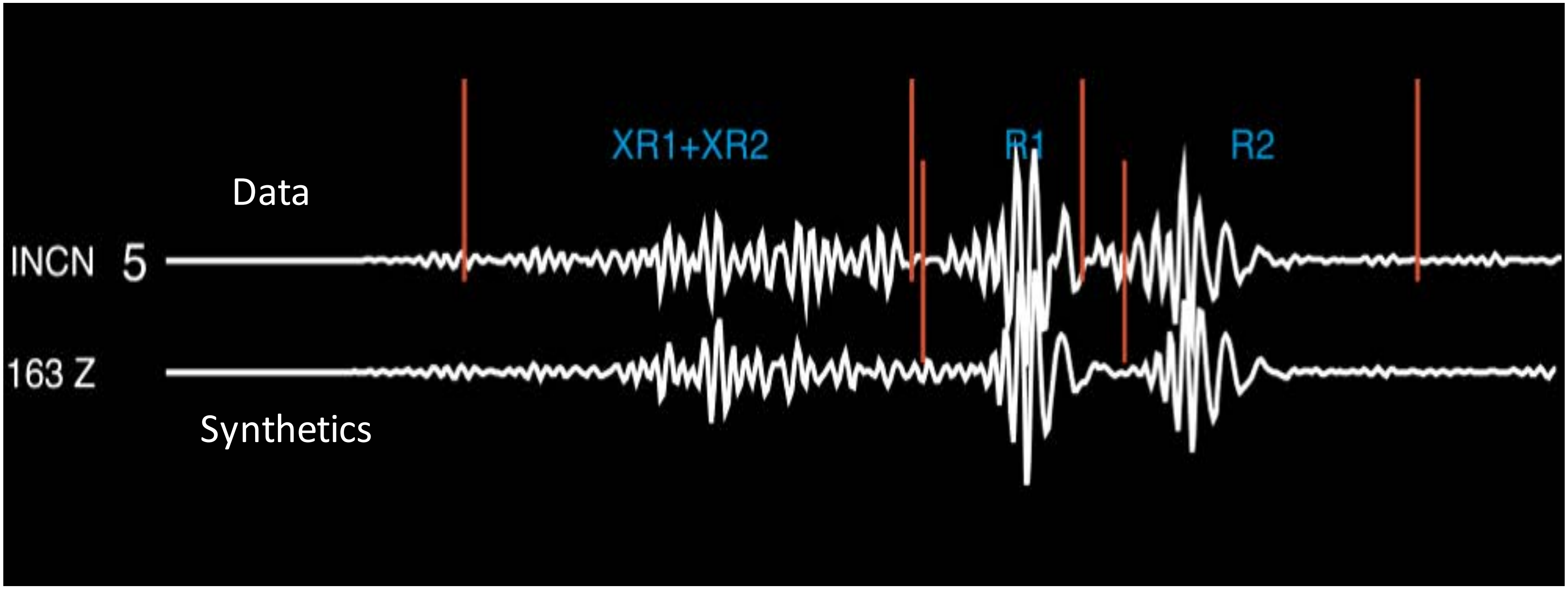
Dziewonski, Lekic and Romanowicz., 2010

S40RTS



S40RTS: Ritsema, Deuss et al, 2011

Full Waveform Tomography

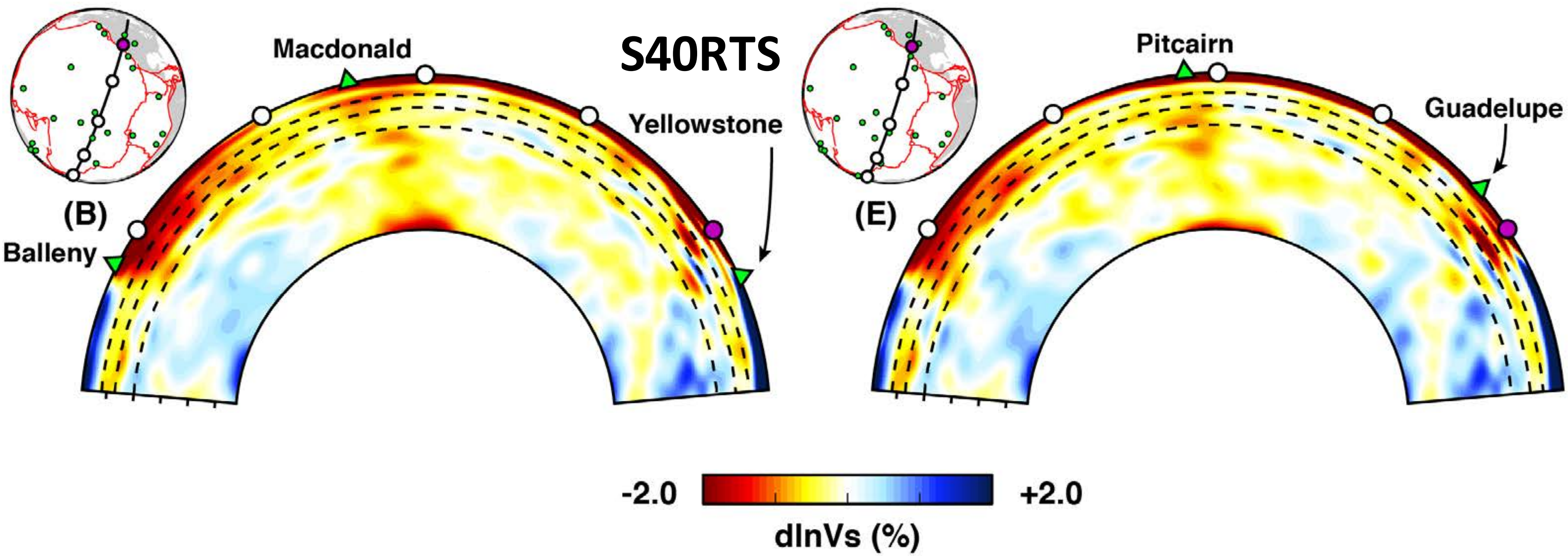


3D Synthetics: seismic wavefield in complex 3D Earth models : now can be computed accurately using the Spectral Element Method (SEM) and directly compared to observed "full" seismograms

- Challenges: computational time increases as ω^3
- Thin slow layers in crust
- Several hundred of events, non-linear (iterations)

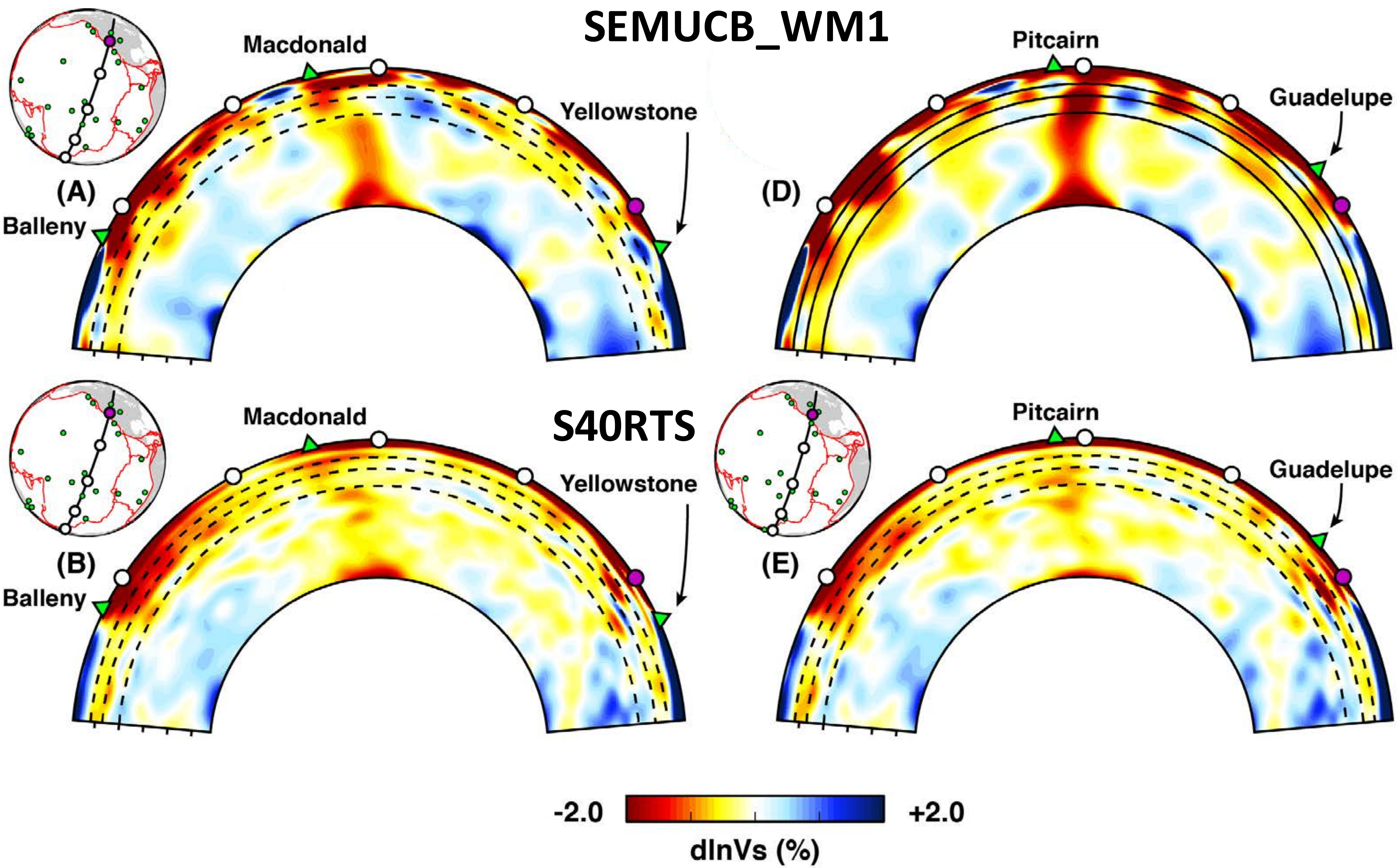
UC Berkeley Global Seismology Group

S40RTS



S40RTS: Ritsema et al, 2011

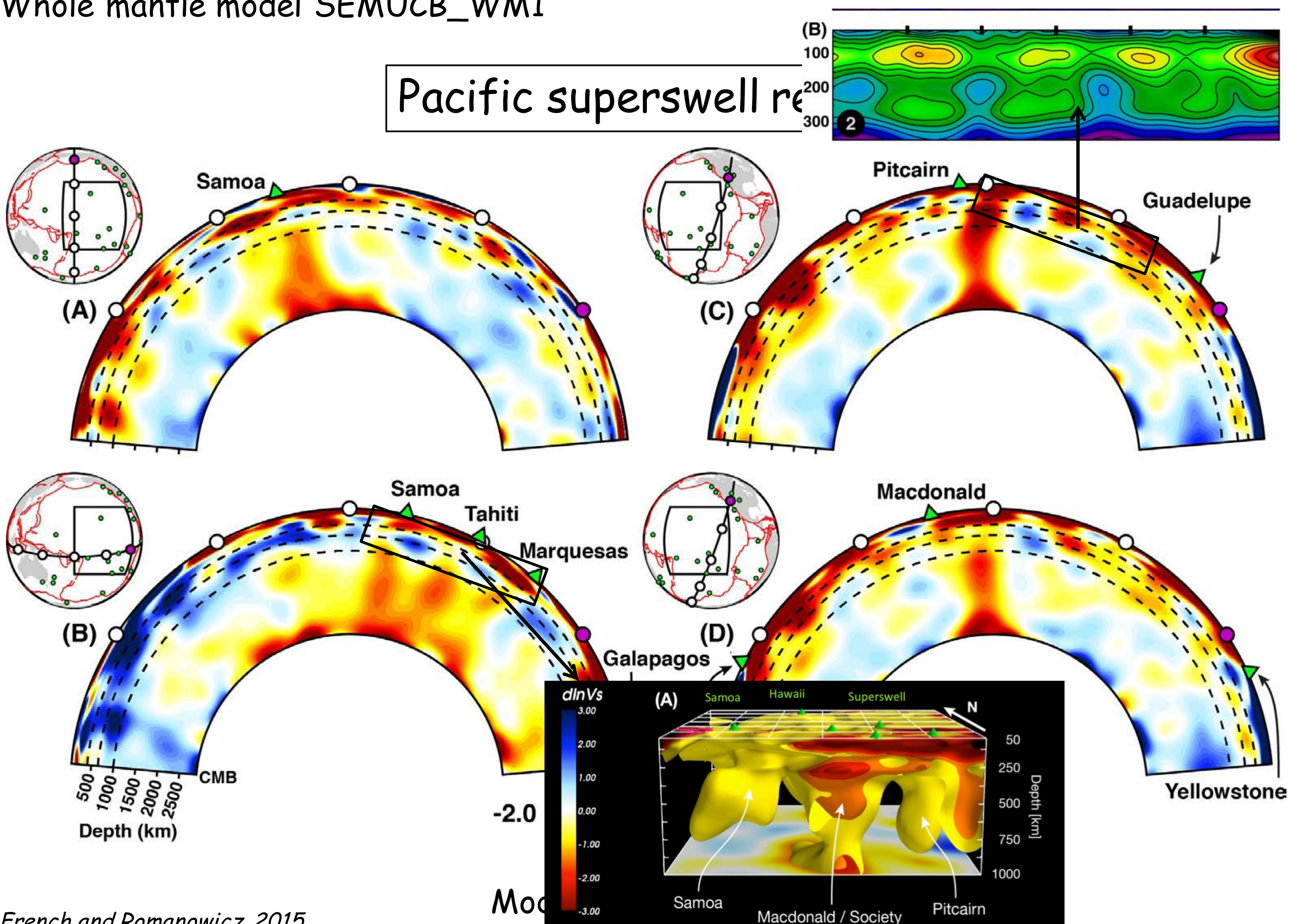
Full waveform tomography



French and Romanowicz, Nature, 2015

Whole mantle model SEMUCB_WM1

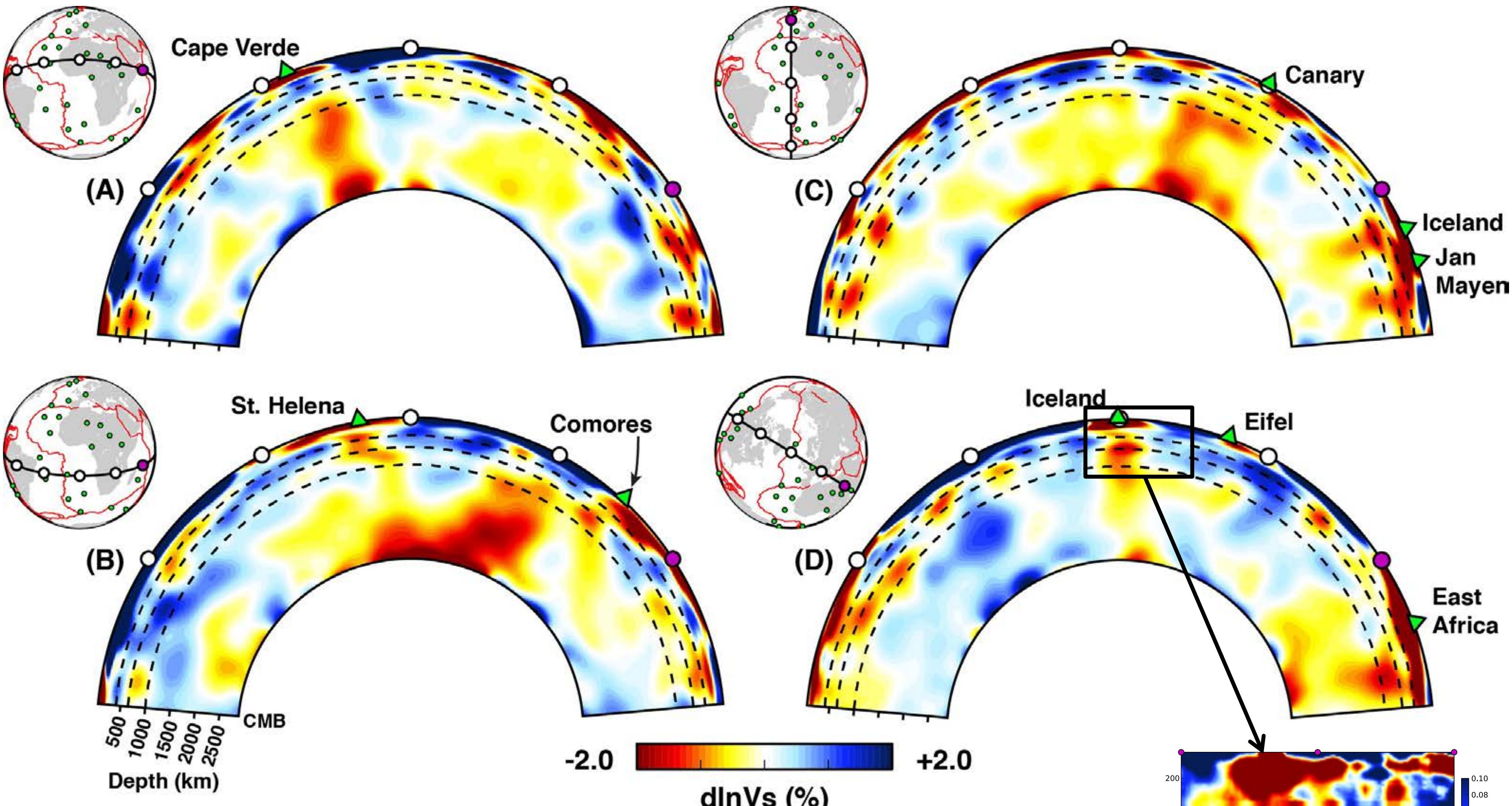
Pacific superswell re

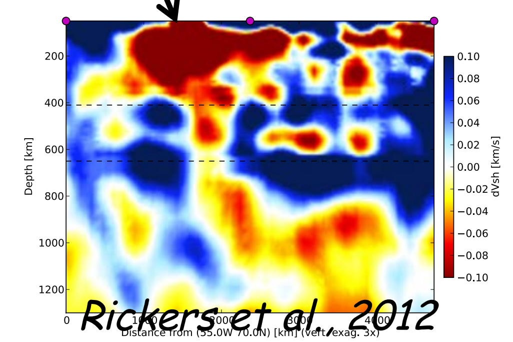


Moc

French and Romanowicz, 2015

Atlantic Plumes

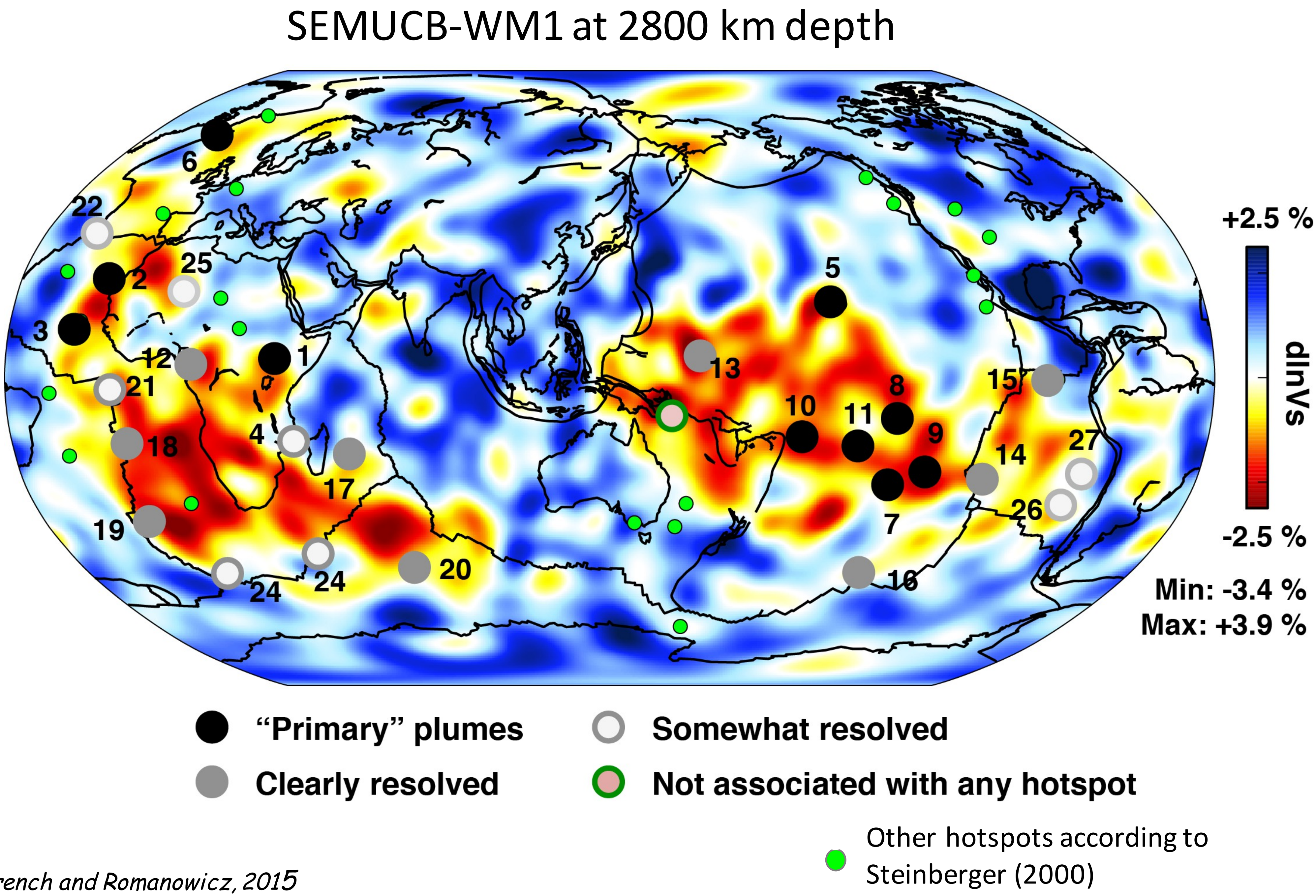




French and Romanowicz, 2015

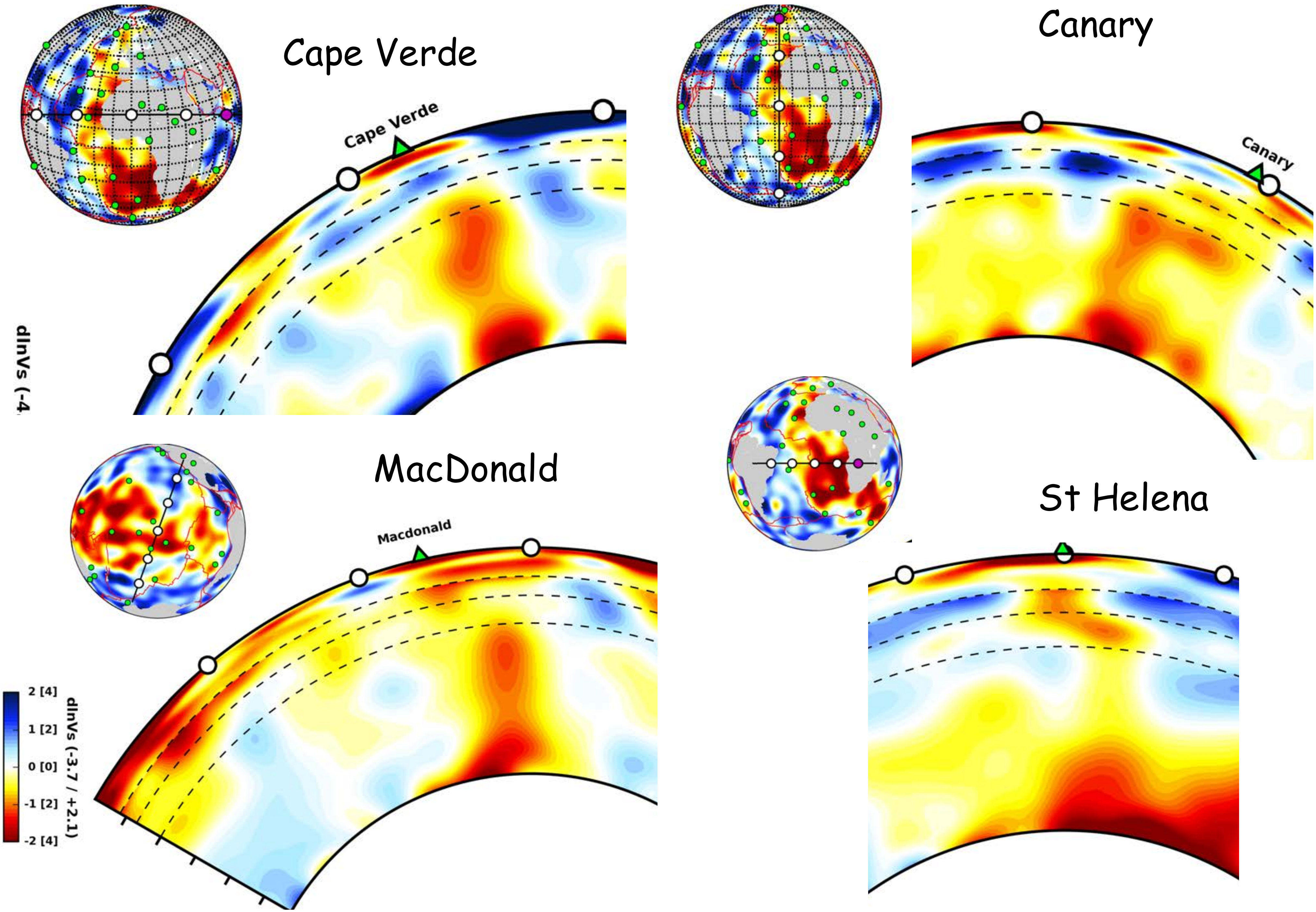
Rickers et al., 2012

These broad plumes are found under major hotspots that lie over the LLSVPs

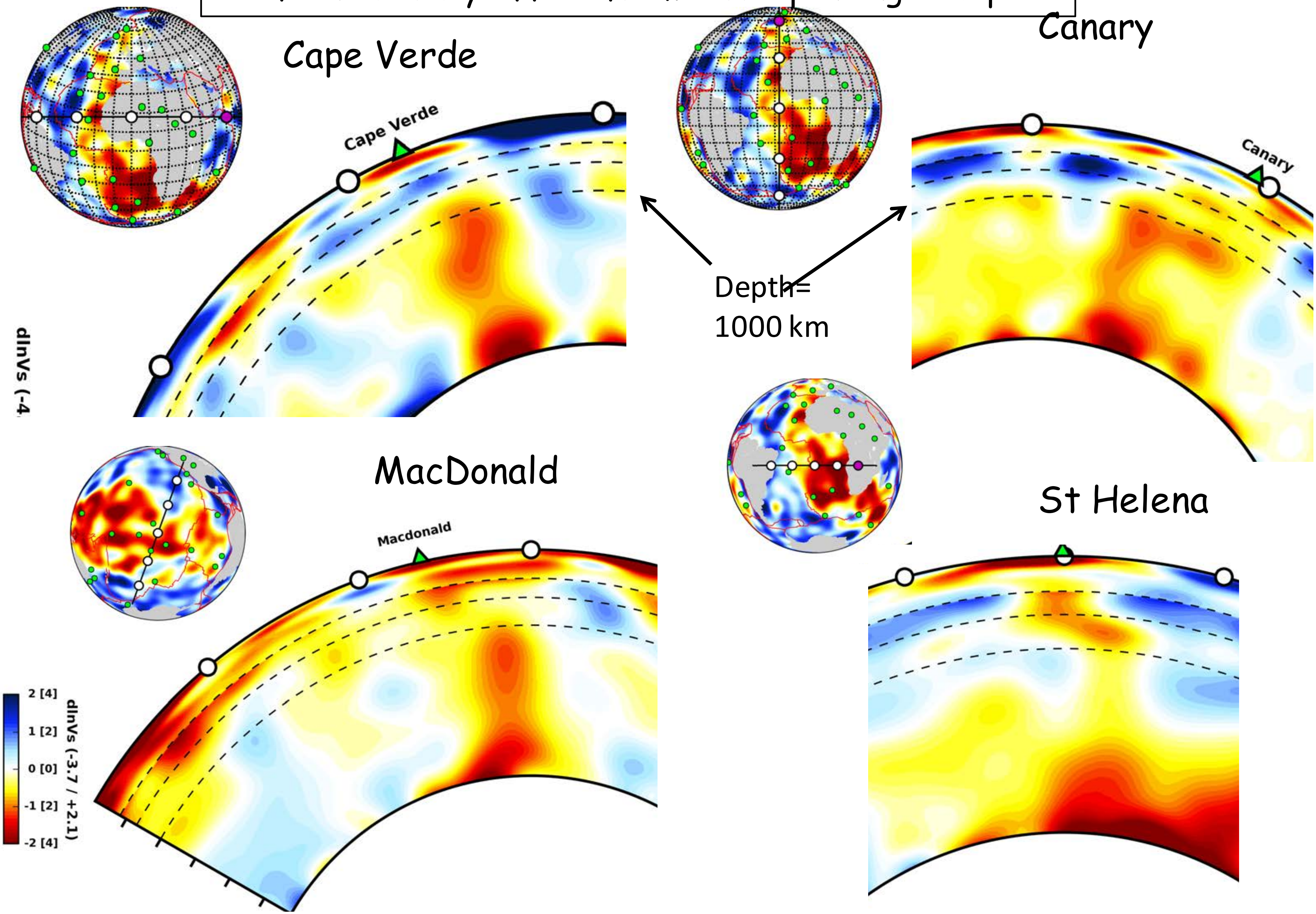


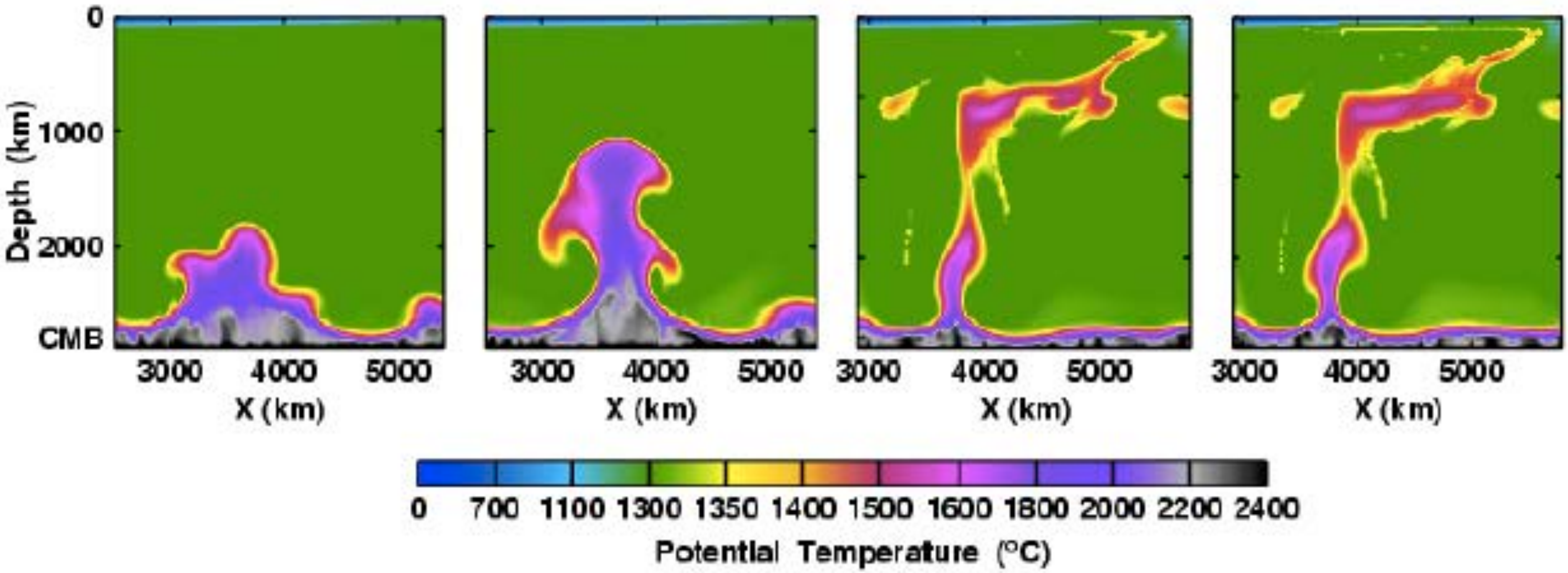
French and Romanowicz, 2015

These "plumes" are broad



-> Quasi-vertical from the CMB to ~ 1000 km depth
-> Often laterally offset from corresponding hotspots

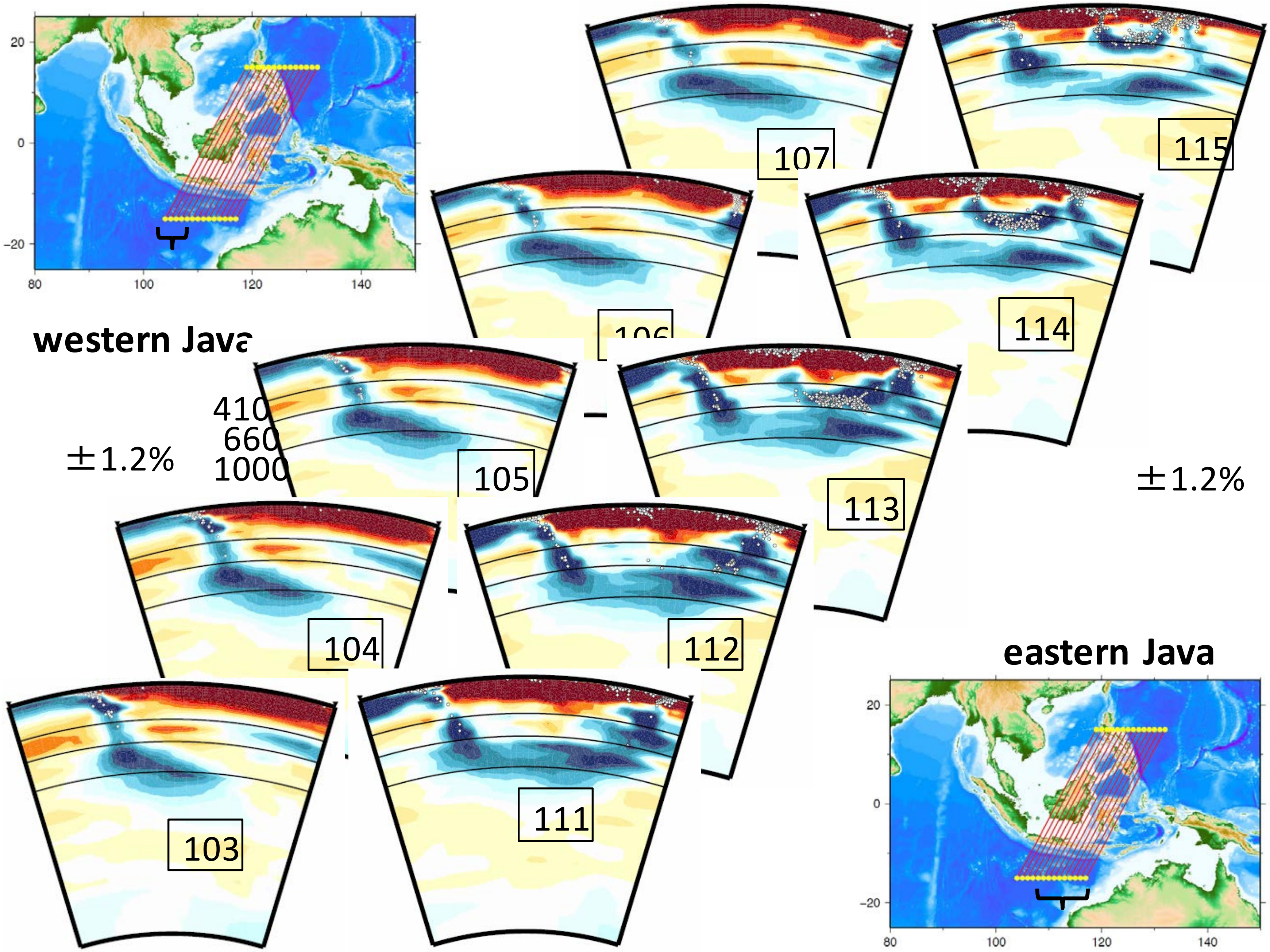




[Farnetani and Samuel, GRL, 2005]

- Denser basal layer
- Viscosity varies with depth and temperature:
  - factor of 10 jump at 660 km
  - hot upwellings 2 orders of magnitude less viscous than background

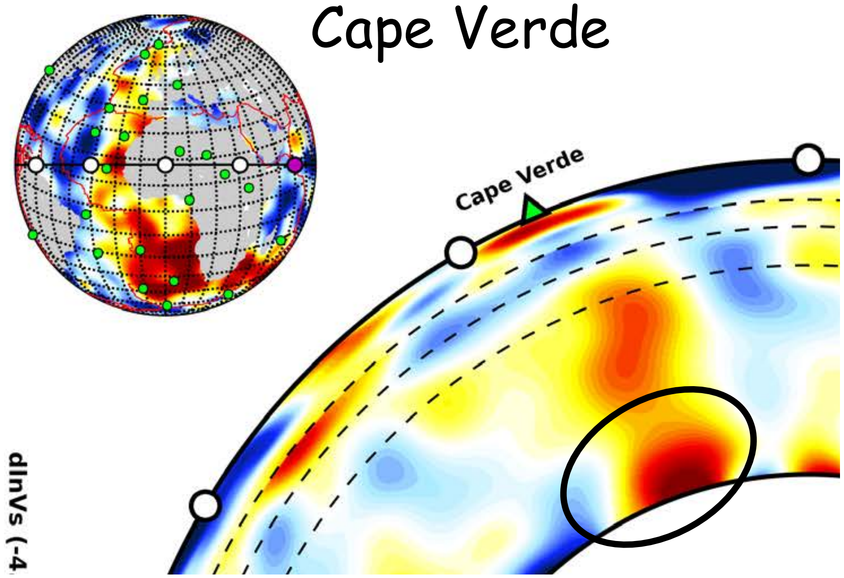
Slabs trapped at 1000 km



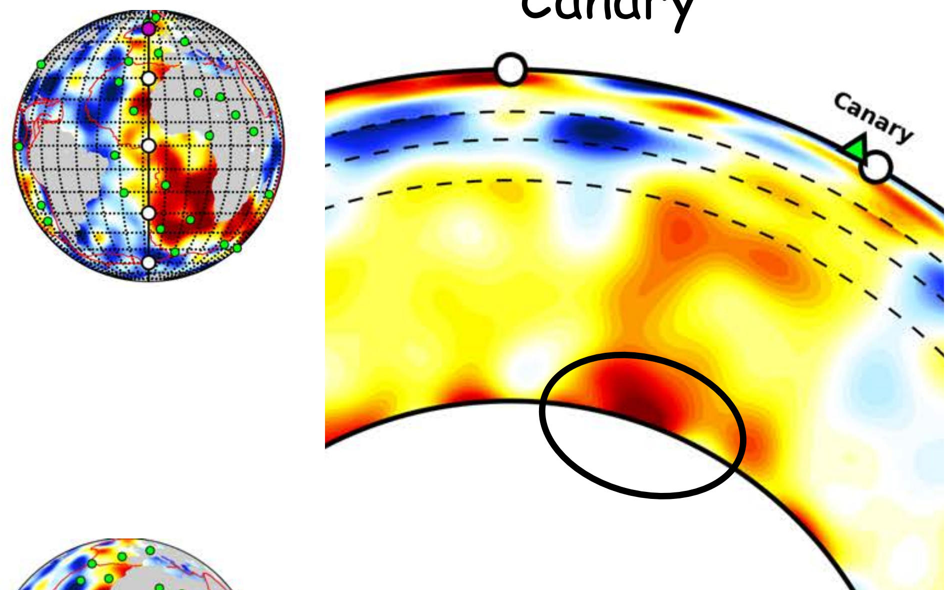
Fukao and Obayashi (2013)

->The plumes are rooted in (mostly) isolated patches of very low shear velocity

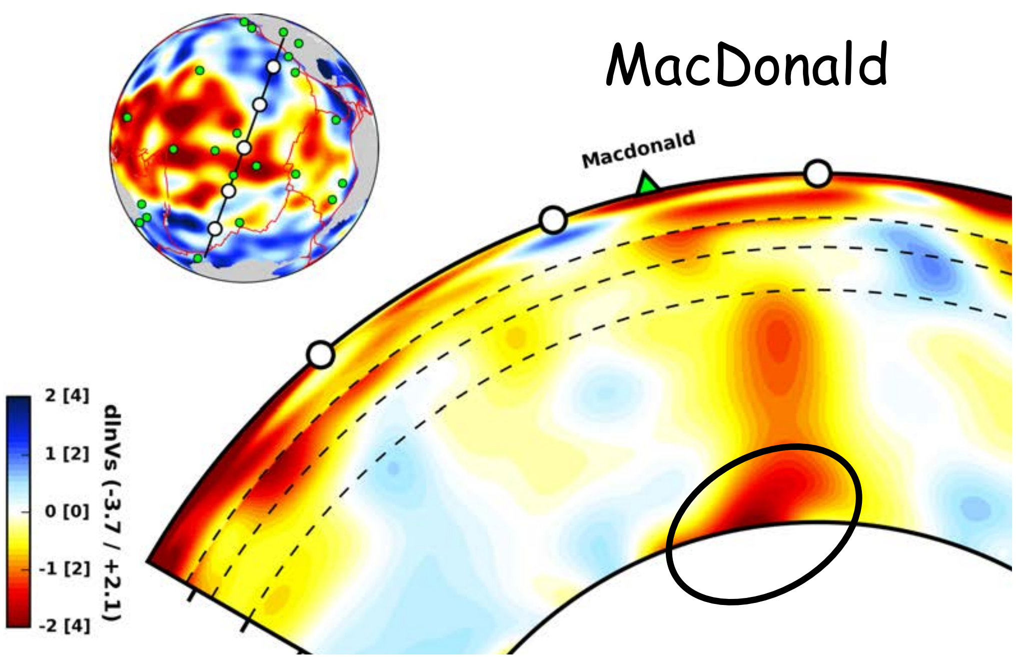
Cape Verde



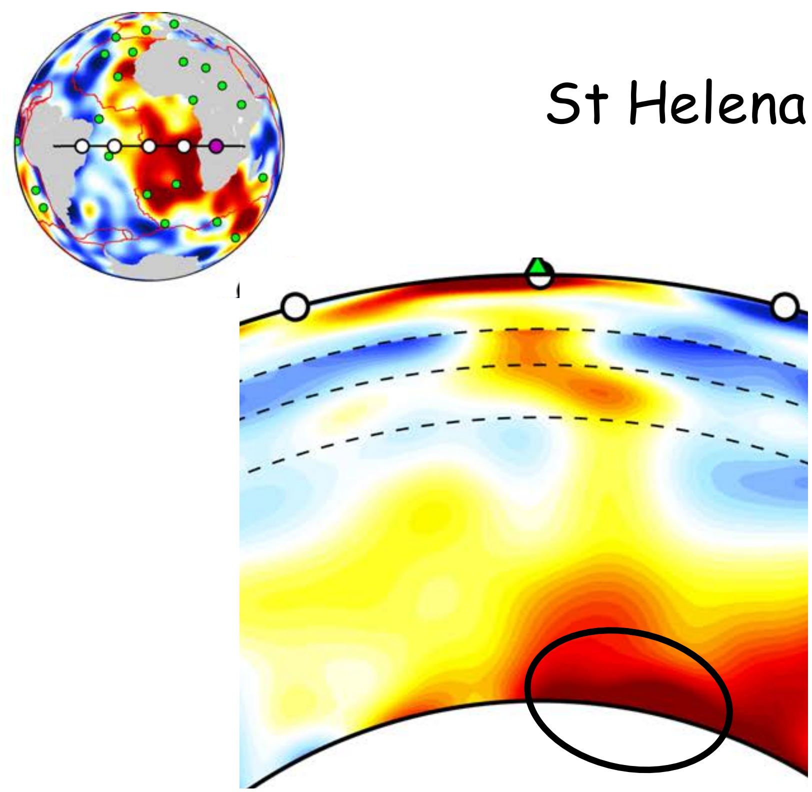
Canary



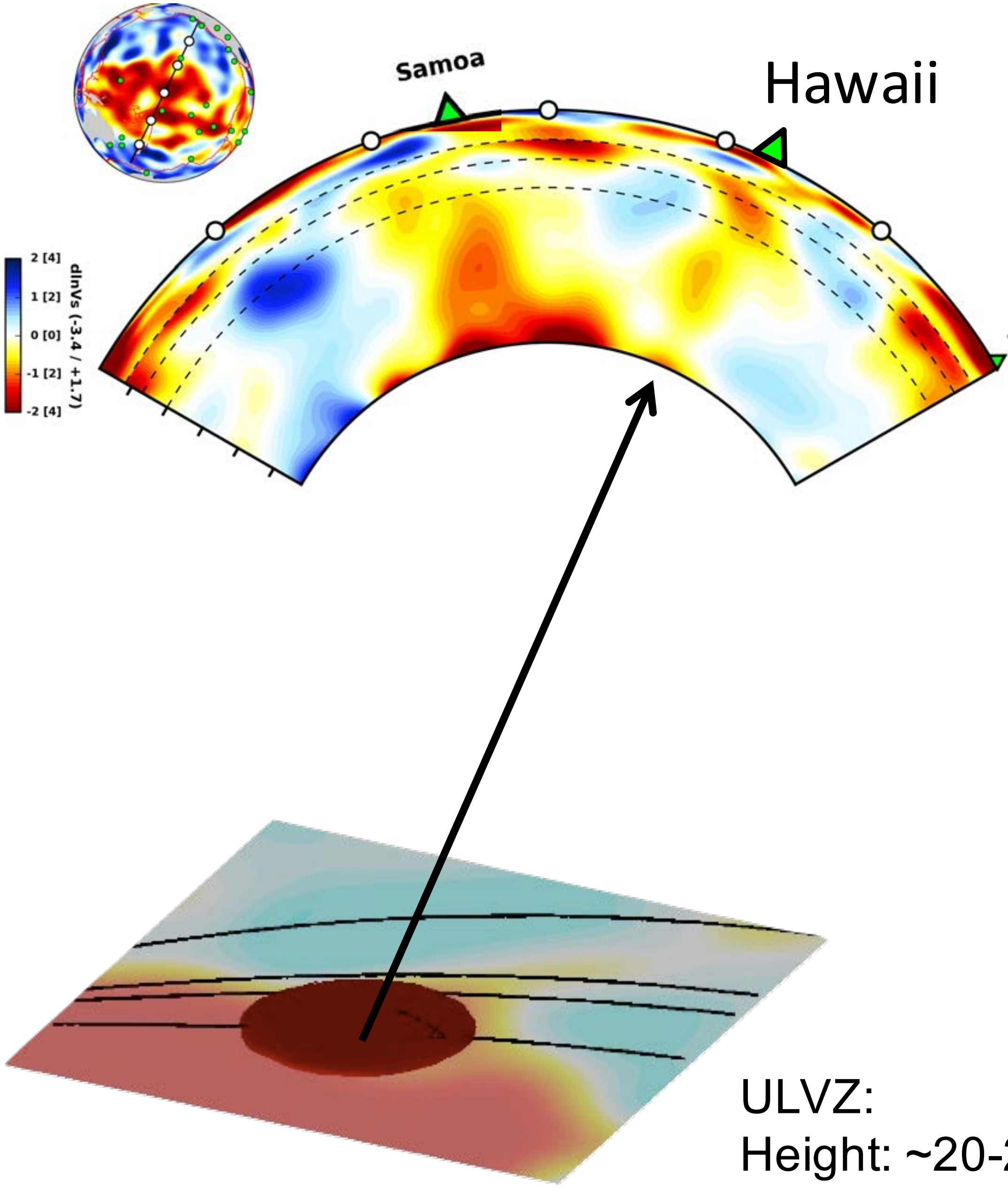
MacDonald



St Helena



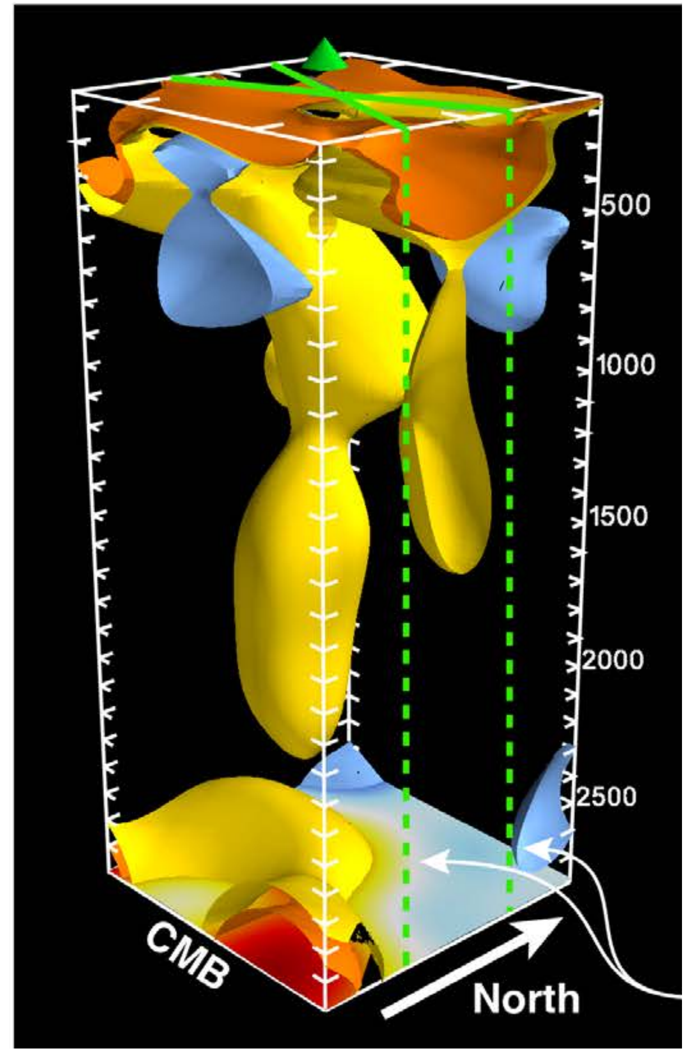
SEMUCB_WM1
Depth = 2800 km



ULVZ:
Height: ~20-25km
Diameter:~910 km
Velocity reduction:~20%

Cottaar and Romanowicz, 2012

Hawaiian plume viewed from South East

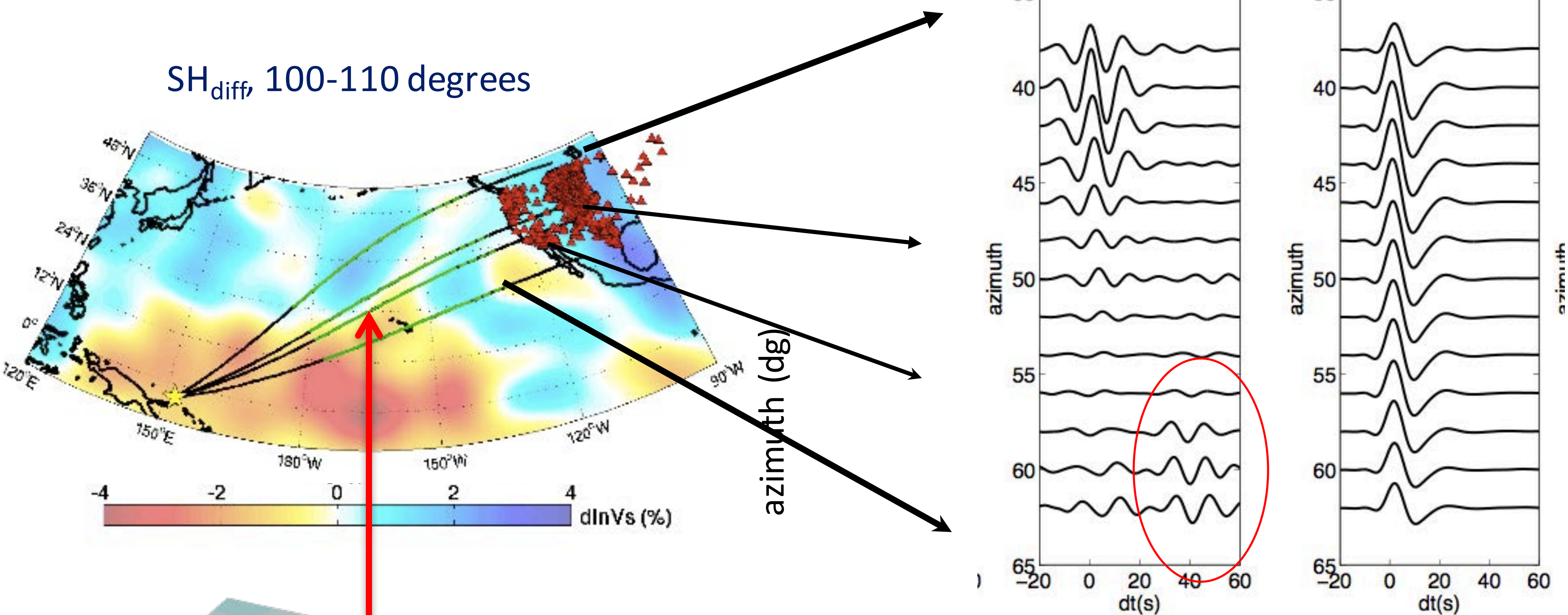


SEMUCB_WM1

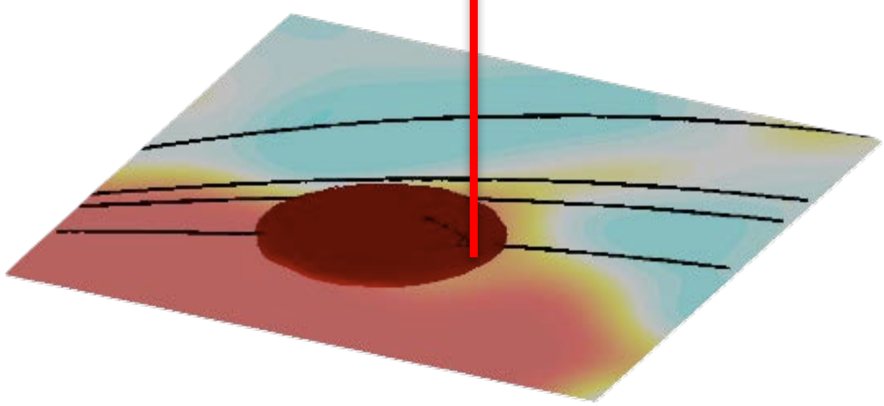
Detection of an "ultra low velocity zone" at the base of the mantle

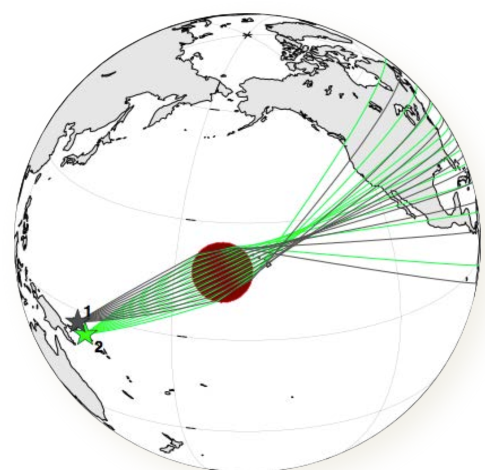
Filter: 10-20 s

Observation *Prediction*



time around S_{diff} (s)

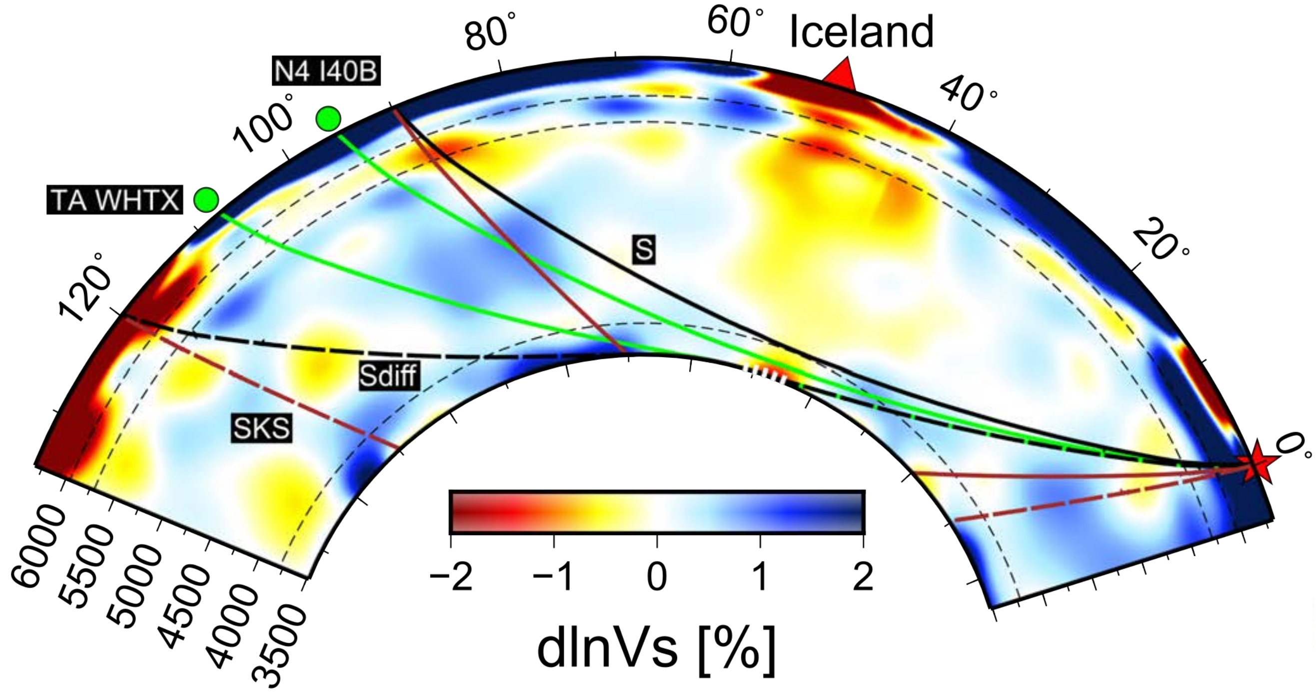


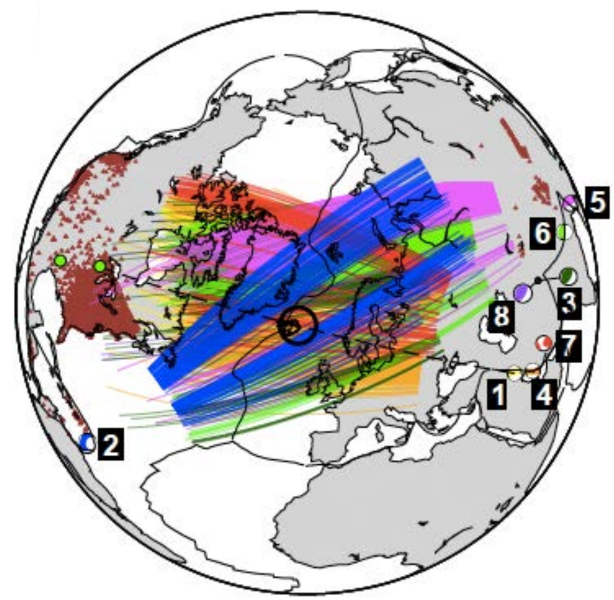


ULVZ:
Height: ~25km
Diameter:~800 km
Velocity reduction:~20%

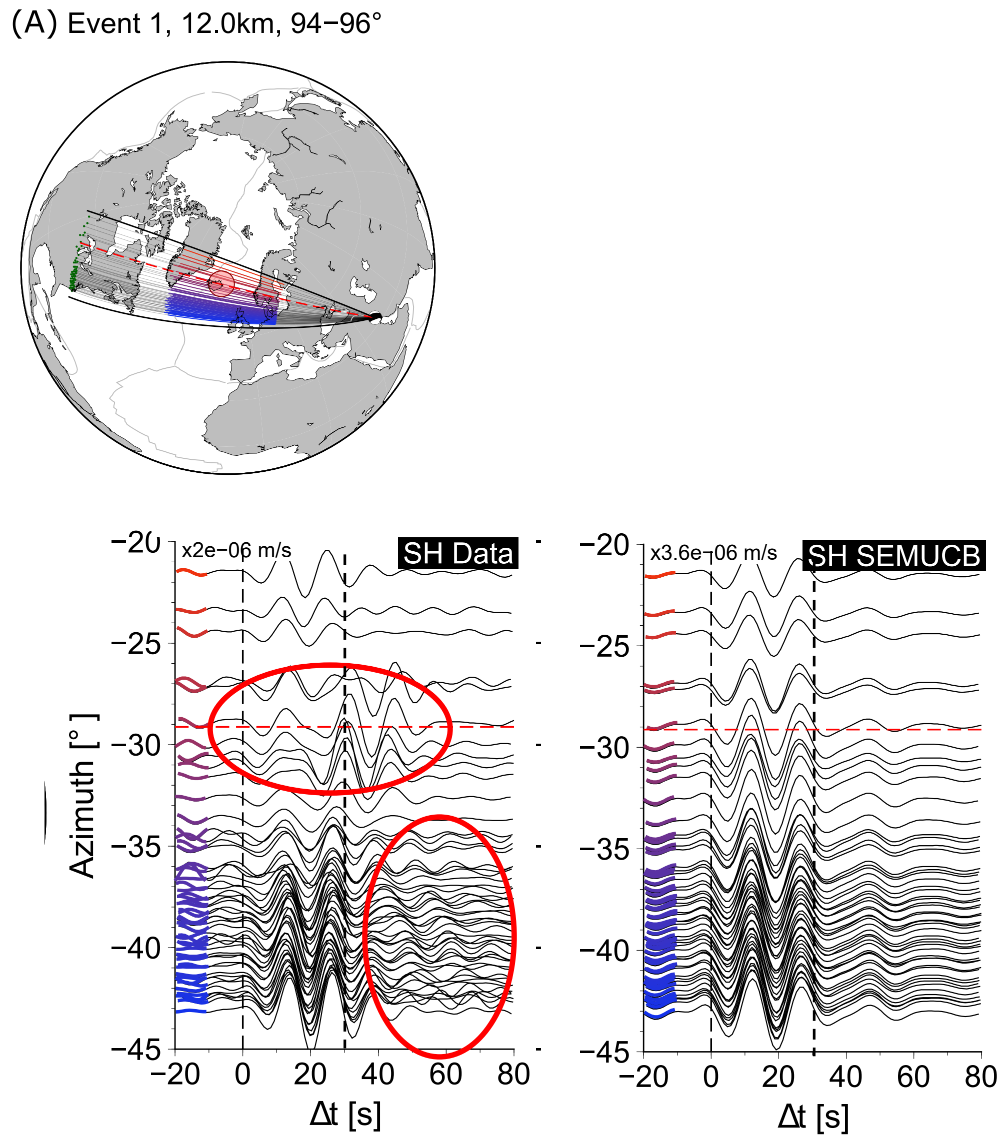
Cottaar and Romanowicz, 2012, EPSL

ULVZ at the base of the Iceland Plume

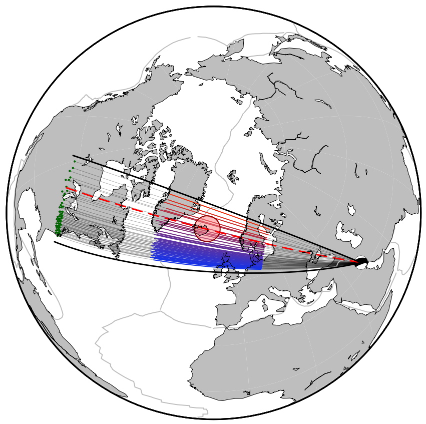


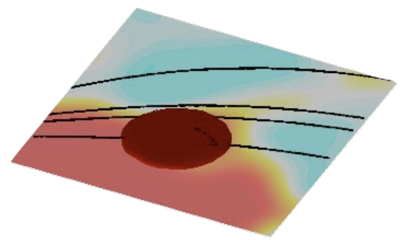


Yuan and Romanowicz, 2017, Science

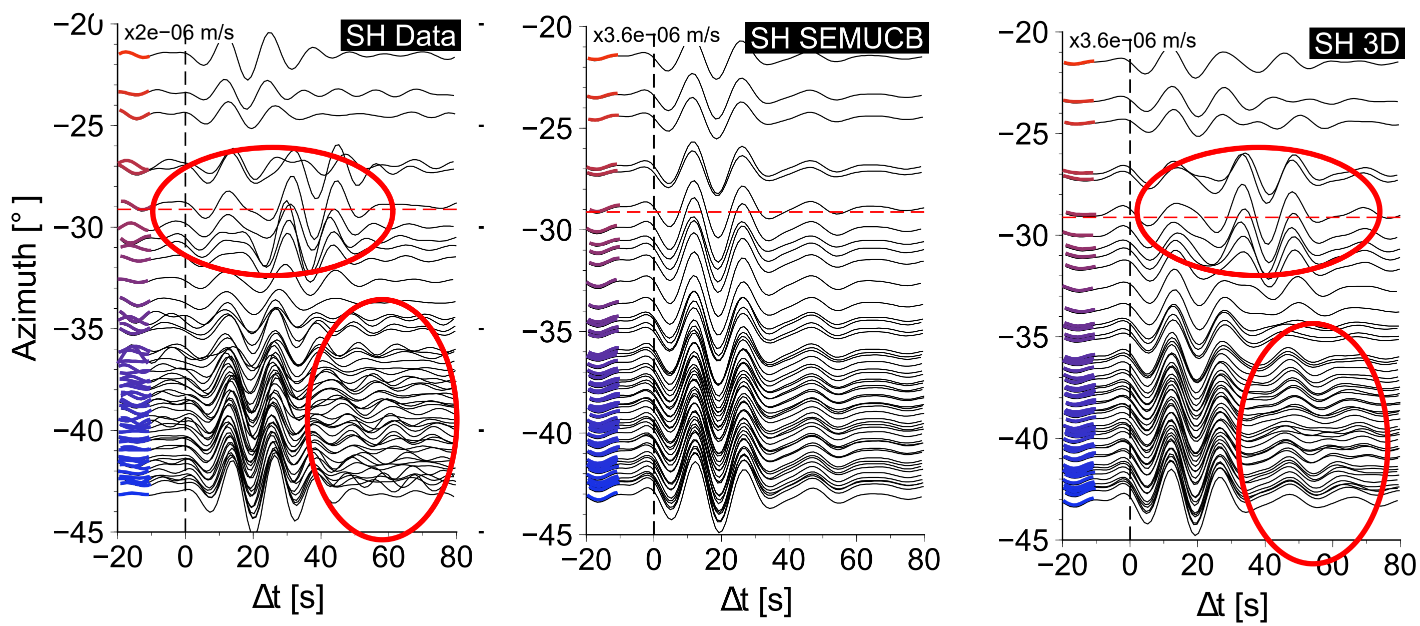


Yuan and Romanowicz, 2017



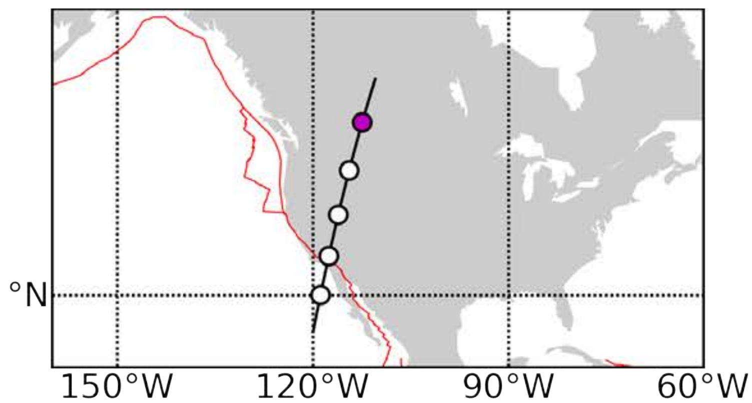


ULVZ:
Circular base
Height: ~15km
Diameter:~800 km
Velocity reduction:~25%

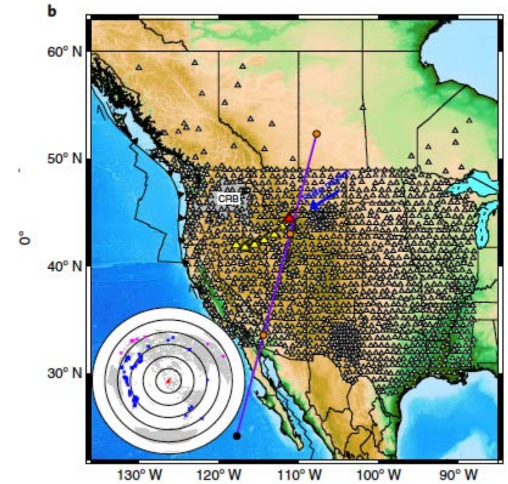


Yuan and Romanowicz, 2017

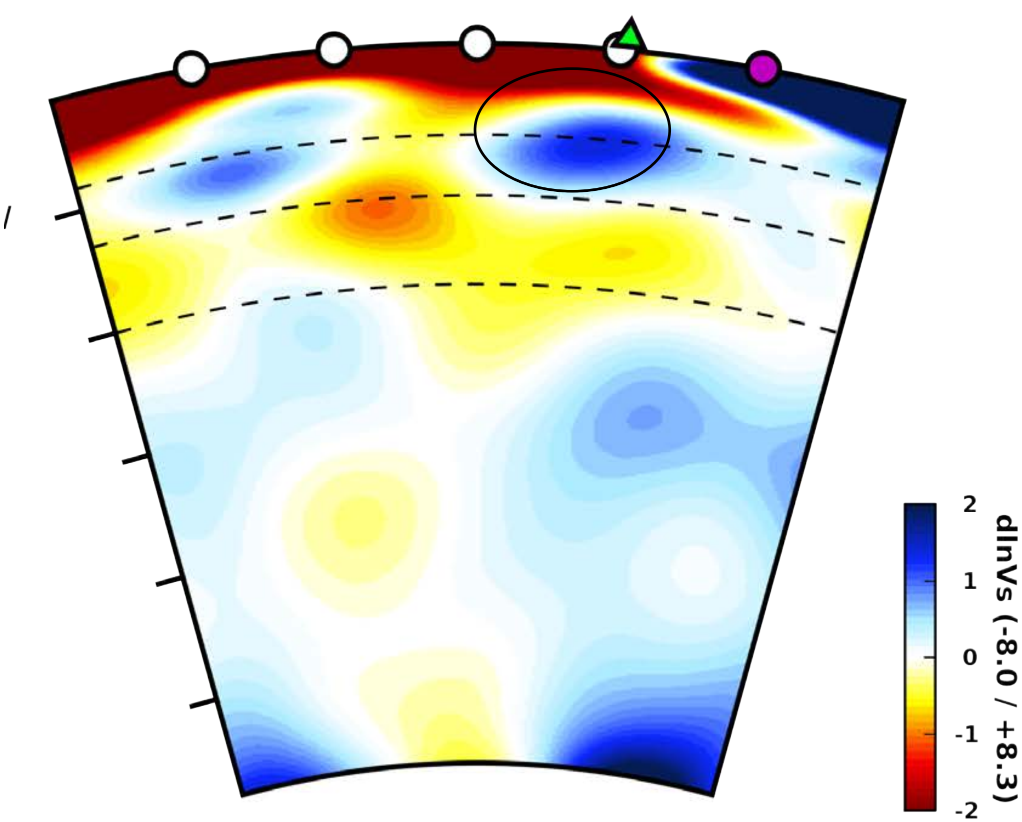
=> Roots of "fat" plumes likely contain partial melt



Yellowstone

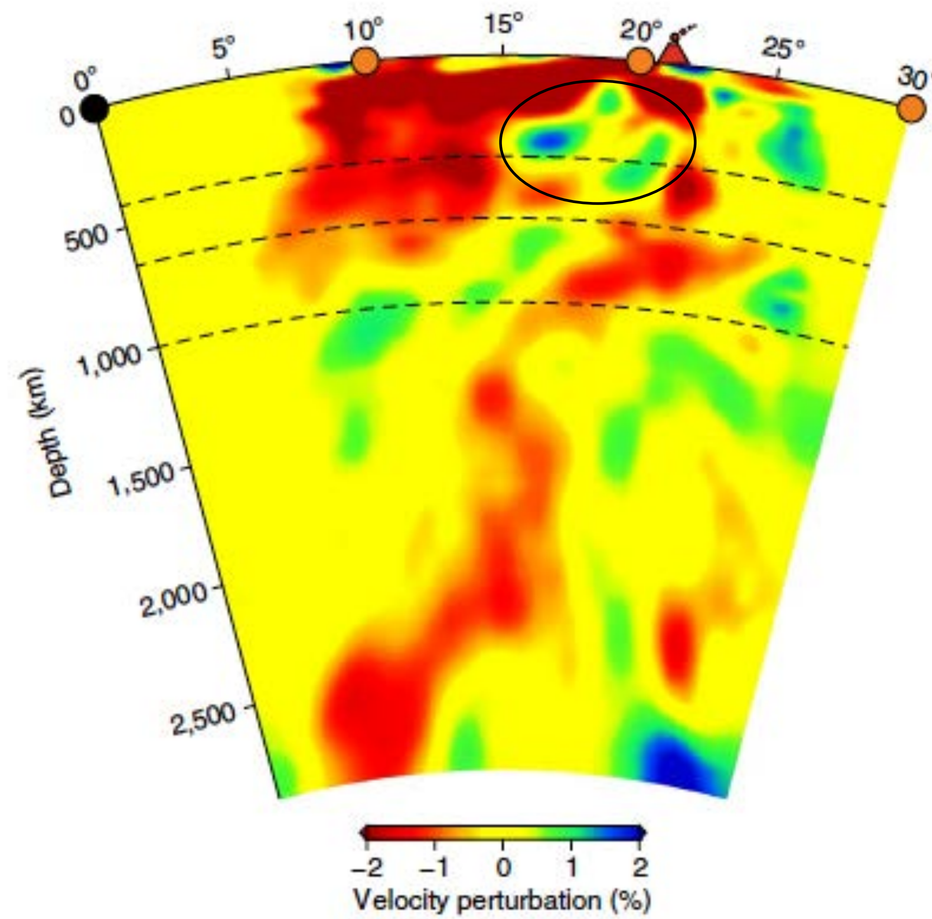


SEMUCB_WM1



French and Romanowicz, 2015

Nelson and Grand,2018



Conclusions

- Mantle plumes do exist !!
- The major upwelling flow is in the form of ~ 25 broad low shear velocity that are located over the large low shear velocity provinces (LLSVPs)
  - They extend quasi-vertically from the CMB to ~1000 km depth -> very sluggish circulation in the lower mantle
  - Horizontally deflected around ~1000 km depth and likely entrained into secondary scale, more vigorous, upper mantle circulation
  - The roots of at least some of these "fat plumes" contain large, axi-symmetric ULVZ's , likely dense and containing partial melt
    - They may be the manifestation of strong topography at the top of an otherwise very thin core-mantle interaction zone of dense partial melt

- LLSVP's may not be piles extending to mid-lower mantle depths, but rather bundles of fat plumes in a halo of hotter than average background.