Diagnosing ambient mantle

Crameri Fabio · Grace Shephard

CEED
The Centre for Earth Evolution and Dynamics

UiO : University of Oslo

Heavy stuff

Not so heavy stuff

Active downwelling

Passive downwelling

What is ambient mantle?

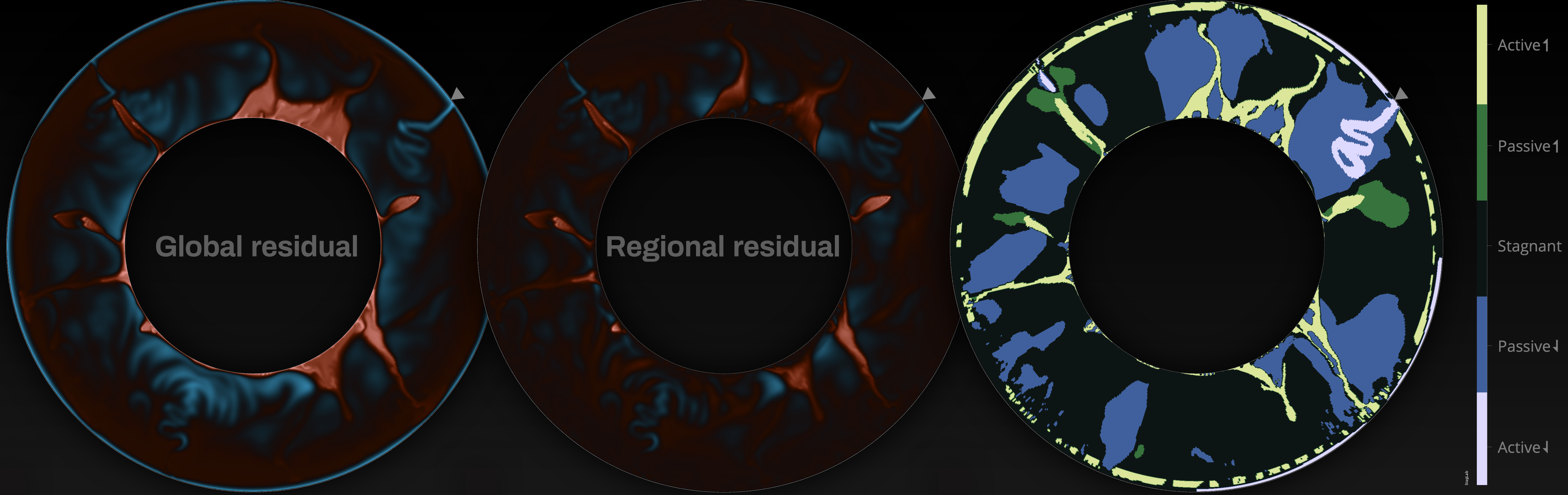
Passive upwelling

Active upwelling

Not so light stuff

Light stuff

Crameri (2019, GMD)



Crameri (2019, GMD)

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^{182}W-^{142}Nd isotope evolution in an open-system model of the Earth: Implication for geodynamic processes on early Earth

Seema Kumari[1,2], Andreas Stracke[1], and Debajyoti Paul[2]

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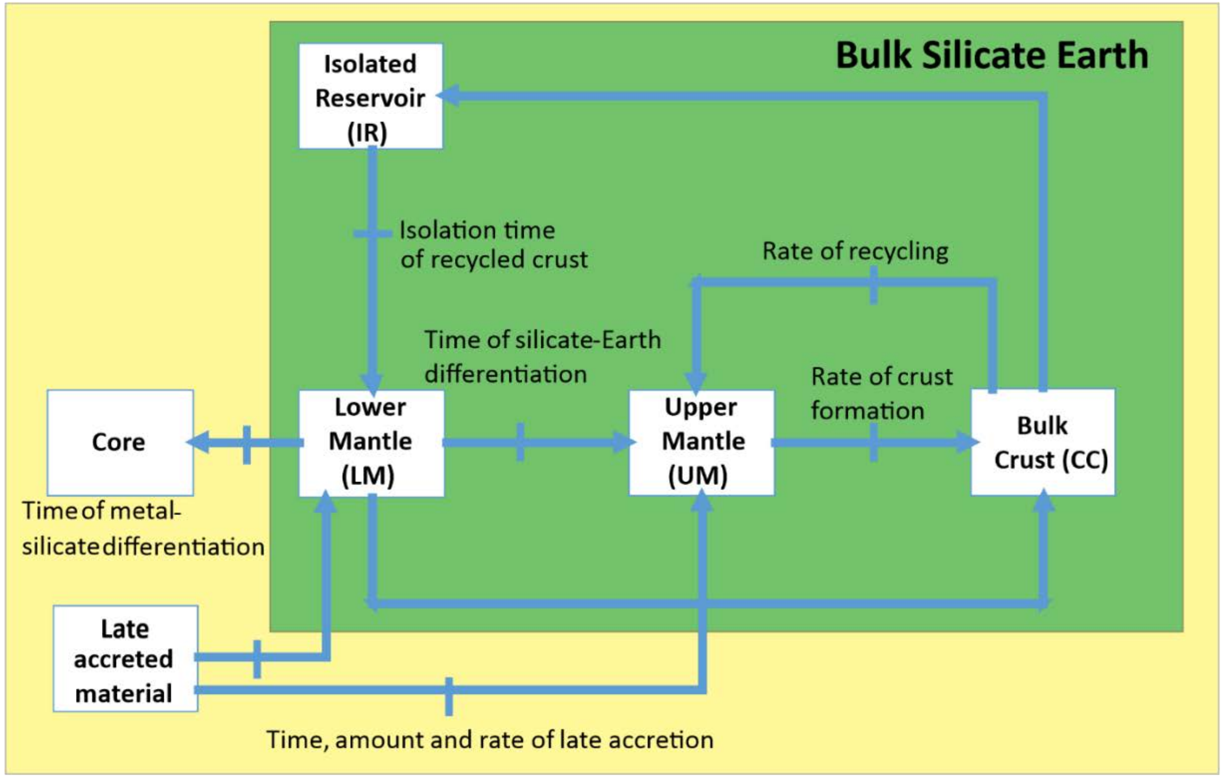
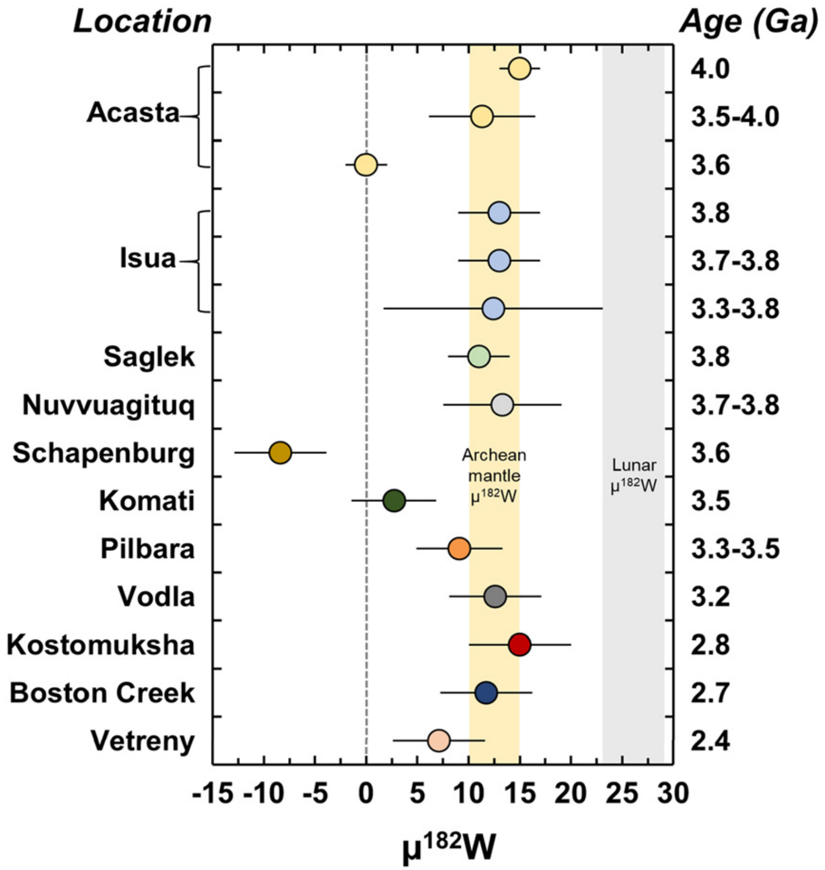
[2]Department of Earth Sciences, Indian Institute of Technology, Kanpur, India.



Presenter: Seema Kumari
Contact: seemak@iitk.ac.in

Clues from measured short-lived isotopic anomalies

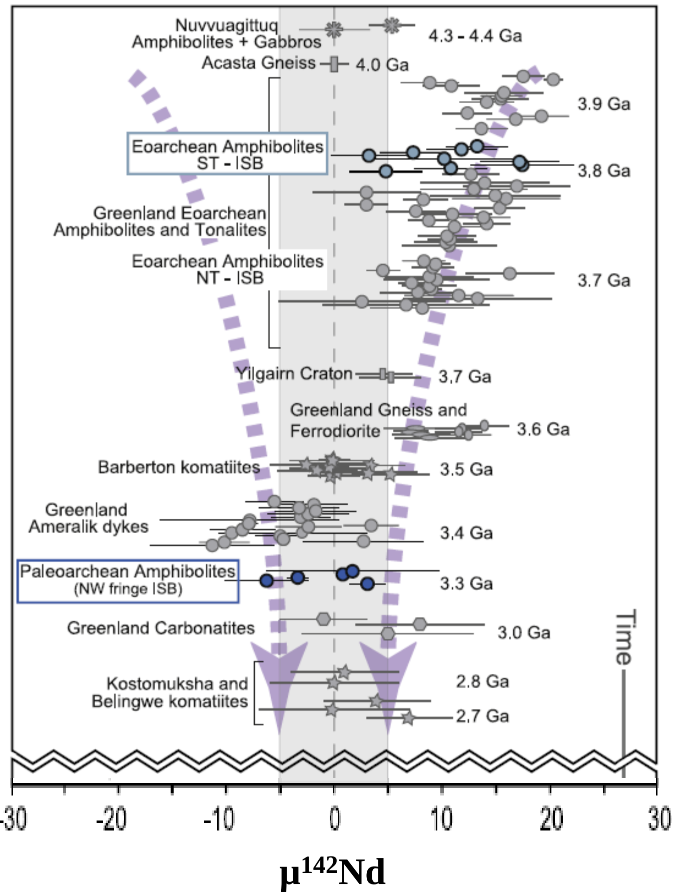


Archer et al. (2019)

- $\mu^{182}W$ ~ +10–15 ppm during 4.0–2.4 Gyr
- Similar excesses in terms of $\mu^{142}Nd$ at 4.0 Ga

$$\mu^{182}W = \left(\frac{\left(\frac{^{182}W}{^{184}W}\right) Sample}{\left(\frac{^{182}W}{^{184}W}\right) Standard} - 1 \right) \times 1{,}000{,}000$$

$$\mu^{142}Nd = \left(\frac{\left(\frac{^{142}Nd}{^{144}Nd}\right) Sample}{\left(\frac{^{142}Nd}{^{144}Nd}\right) Standard} - 1 \right) \times 1{,}000{,}000$$



Rizo et al. (2013)

$^{182}Hf \rightarrow {}^{182}W$ ($t_{1/2}$ = 8.9 Myr)

$^{146}Sm \rightarrow {}^{142}Nd$ ($t_{1/2}$ = 103 Myr)

Deep-rooted plumes sample Hadean refractory domains

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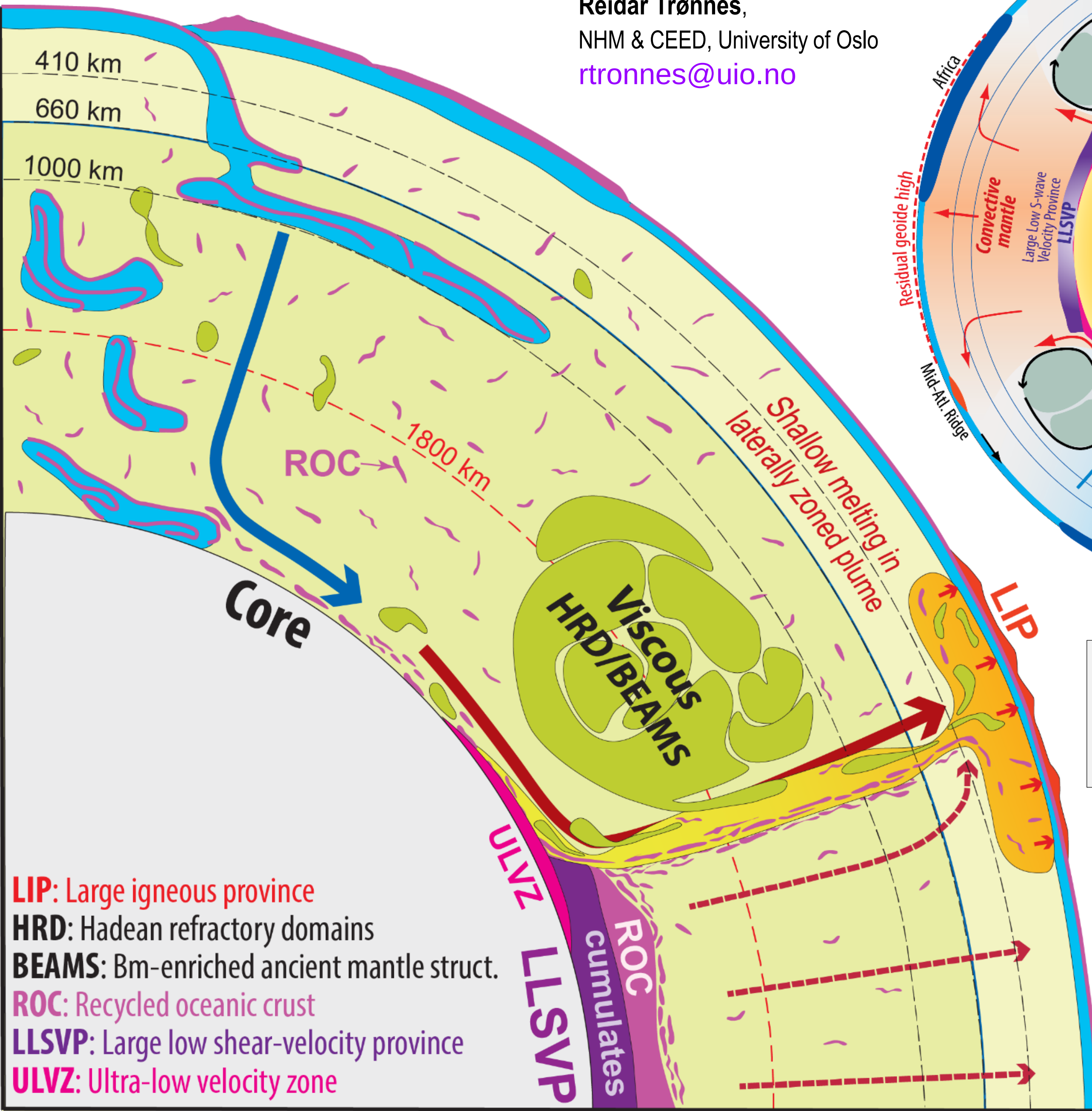
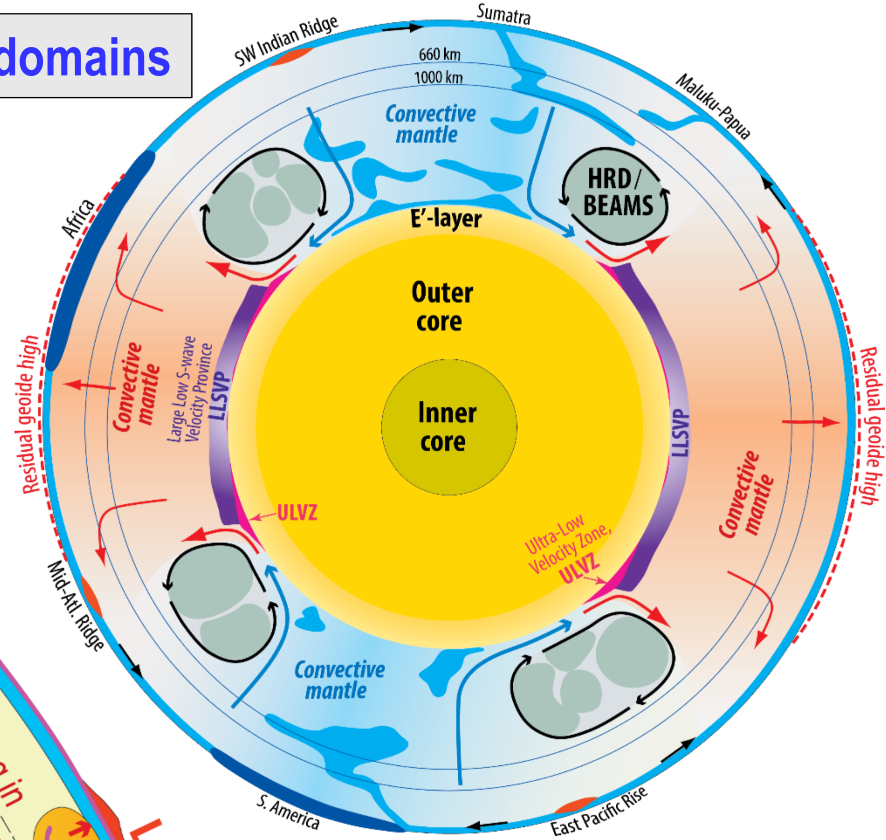




Equatorial sections, illustrating the perceived degree-2 convection pattern, indicated by the **residual geoid**

Modified, based on:
Trønnes 2010, Min. Petrol.
Torsvik et al. 2016, Can. J. Earth Sci.
Ballmer et al. 2017, Nature Geosci.
Trønnes et al. 2019, Tectonophys.

Are "primordial" He-Ne isotope ratios a result of **core contamination**?

Unlikely, because:

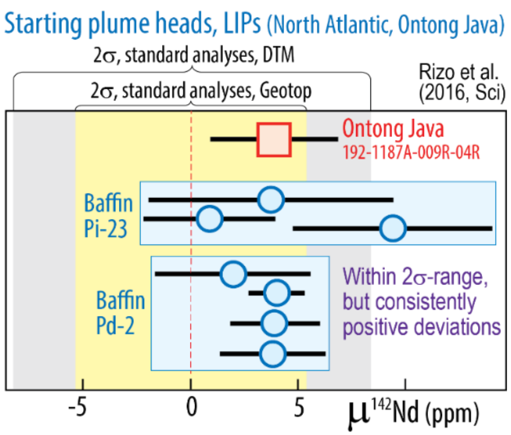
- Small additions of core metal to plume roots are probably insufficient to generate "primordial-like" **He-Ne** isotopes, even if they cause the clear **W-** and weak **Xe**-isotopic signals in OIBs.
- High $^{3}He/^{4}He$ is associated with **refractory mantle** sources (PREMA/FOZO, W-Greenland/Baffin I.).
- Parts of the refractory sources are **Hadean, with $\mu^{142}Nd > 0$** (Ontong J., Baffin I., Reunion, Samoa, Hawaii). "Primordial" He & Ne will easily diffuse into refractory bridgmanite domains during the Hadean.

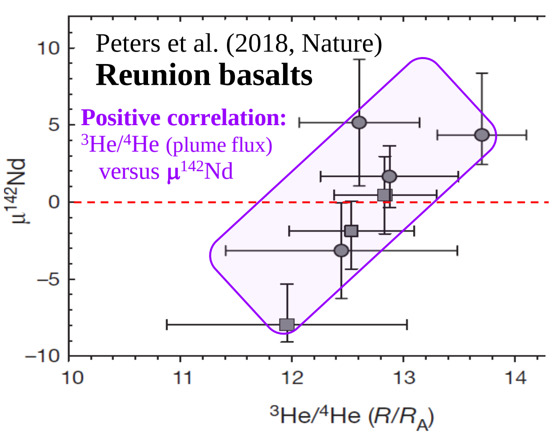
Short-lived Sm-Nd-system

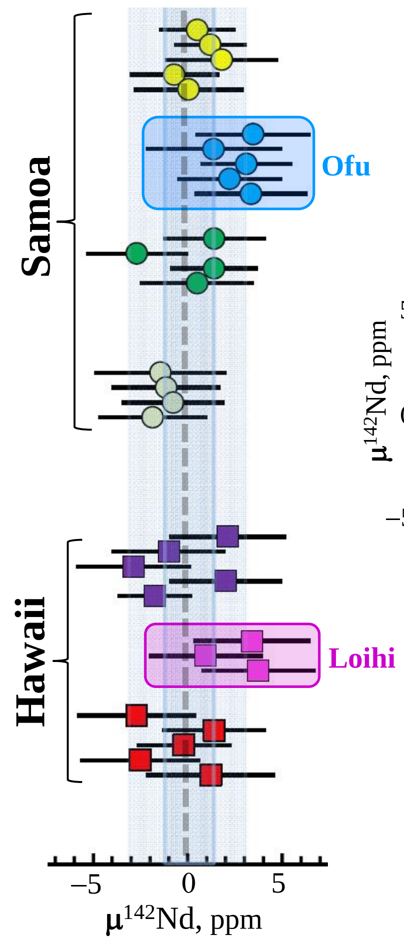
$^{146}Sm \rightarrow {}^{142}Nd$ t_h: 103 My

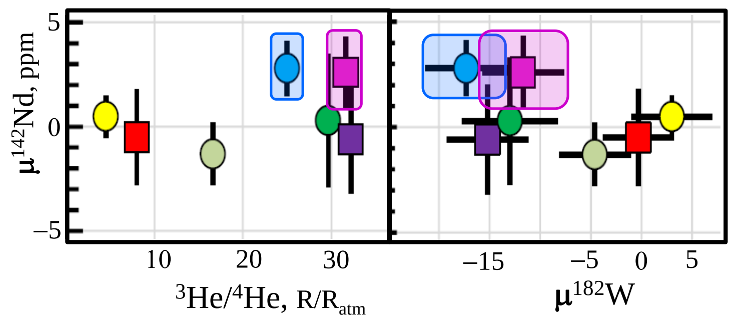
$\mu^{142}Nd = ({}^{142/144}Nd_{sample} / {}^{142/144}Nd_{standard} - 1) \cdot 10^{6}$

- Nd-daughter partitions to melt, relative to Sm
- **Hadean bm-residues: $\mu^{142}Nd>0$** (high Sm/Nd)
- The **$\mu^{142}Nd$ signal** is inherently **weak**









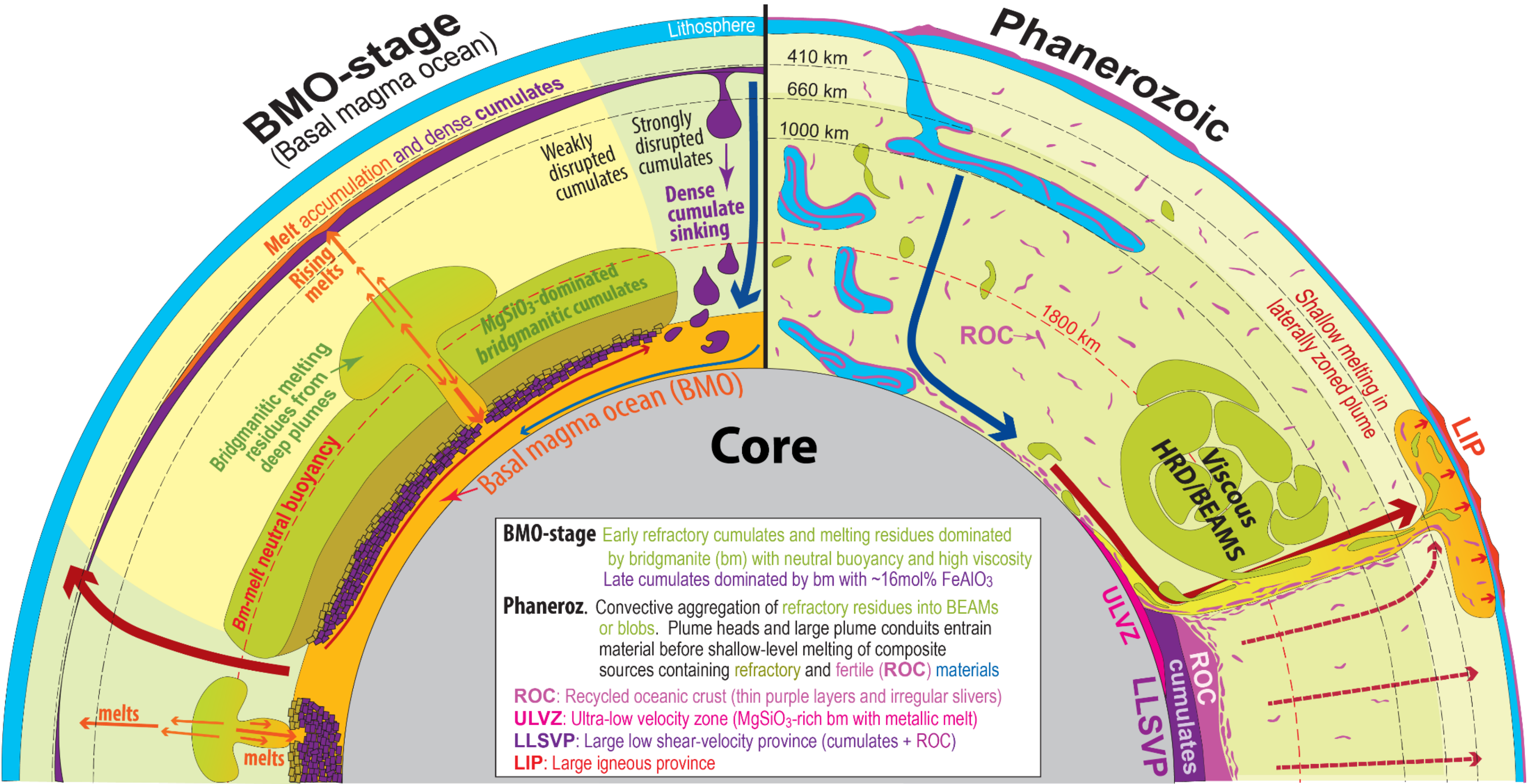
Horan et al. (2018, EPSL)

Hadean refractory domains, **HRD /** bridgmanite-enriched ancient mantle structures, **BEAMS**

Likely origin of the HRD / BEAMS:

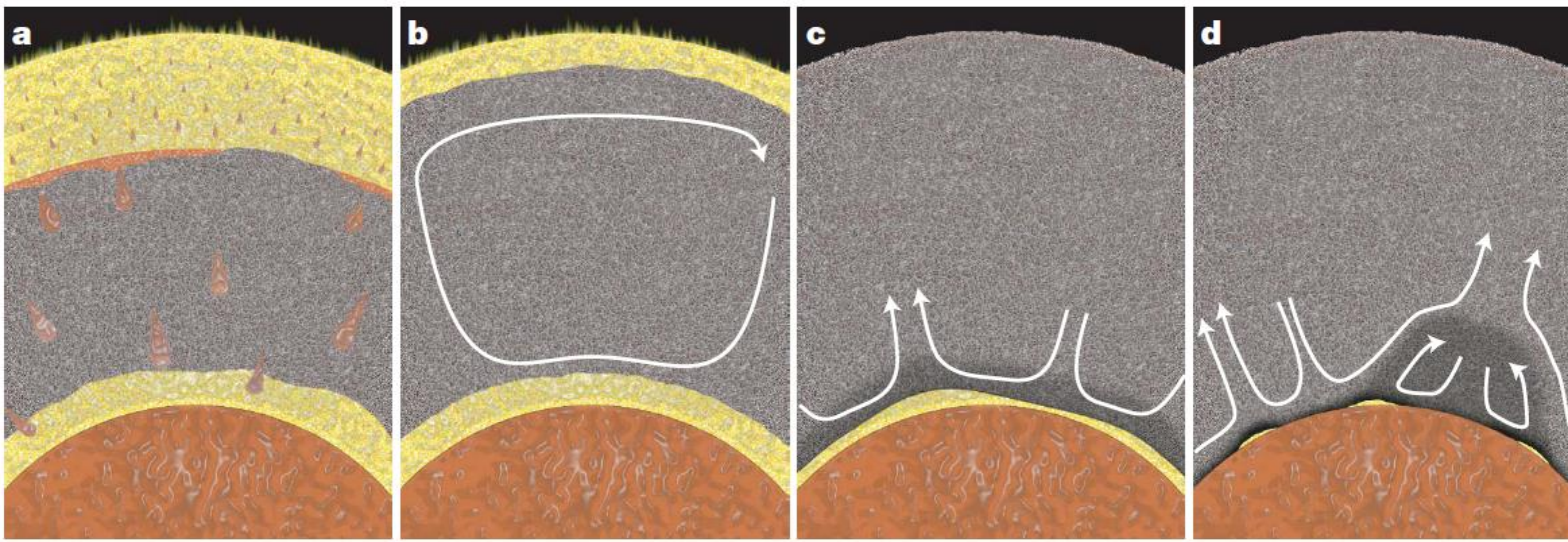
- **early magma ocean cumulates**, deposited above and below the neutral buoyancy level (~1800 km depth)
- residues from partial (re-)melting above the basal magma ocean

Trønnes et al. (2019, Tectonophysics)



Maxim D. Ballmer, Rob Spaargaren, Ananya Mallik, Kenny Vilella, Daniela Bolrão, Miki Nakajima, Adrien Morison

>Reactive< Crystallization of the Basal Magma Ocean



(Labrosse et al., 2007)

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ENS DE LYON

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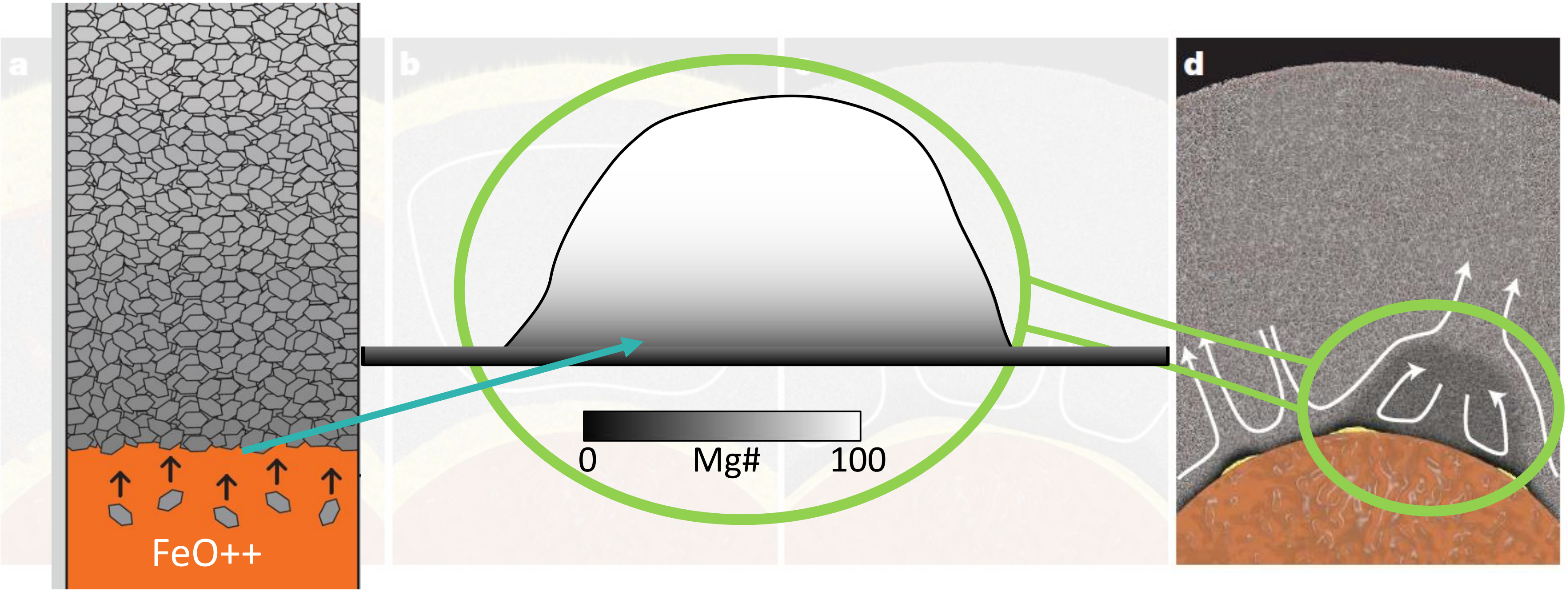
>Reactive< Crystallization of the Basal Magma Ocean



(Labrosse et al., 2007)

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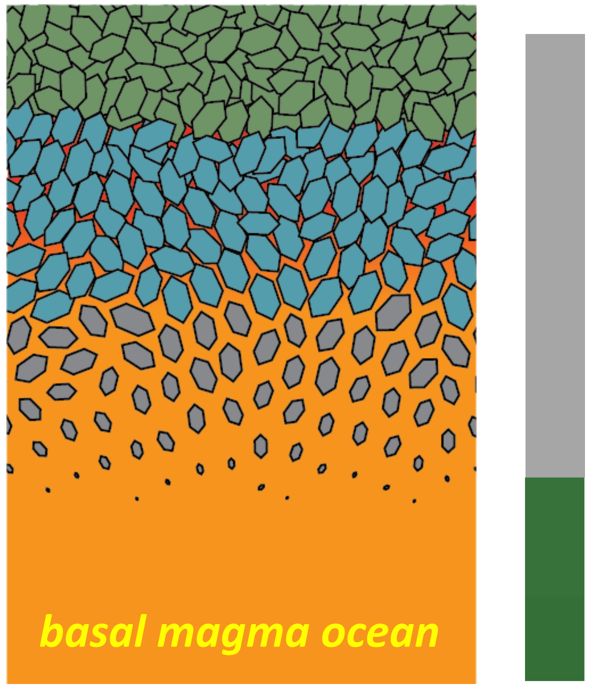
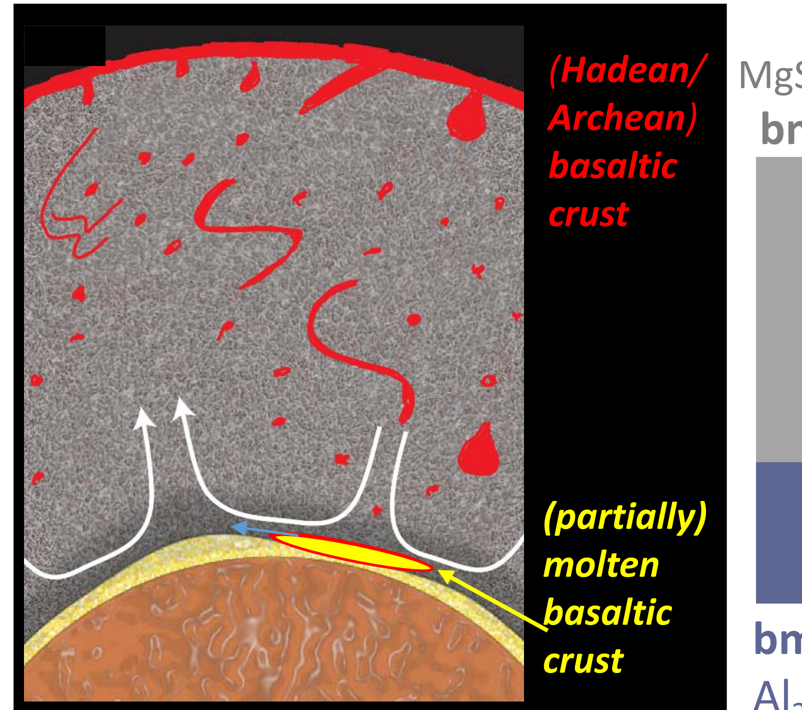
Ballmer *et al:* **Reactive Crystallization of the Basal Magma Ocean** (BMO)

BMO fractional crystallization sequence:

1) Crystallization due to reaction with the overlying solid mantle



2) Delivery of (molten) early crust to BMO



Take home messages:

problem: Fractional crystallization of the BMO should result in a long-lived layer at the base of the mantle, but such a layer does not exist, at least not on planet Earth

solution: The mantle is in (or evolves to) chemical disequilibrium with the BMO, which should hence freeze by reaction and not by fractional crystallization due to cooling

alternatively: delivery of early crustal material to the lowermost mantle, and efficient reaction of the BMO with (partially) molten crust

Contact: m.ballmer@ucl.ac.uk for discussion

The lithospheric-to-lower mantle carbon cycle recorded in diamonds

Regier, M.E., Pearson, D.G., Stachel, T. et al. **Nature** 585, 234-238 (2020)

Margo Regier

University of Alberta

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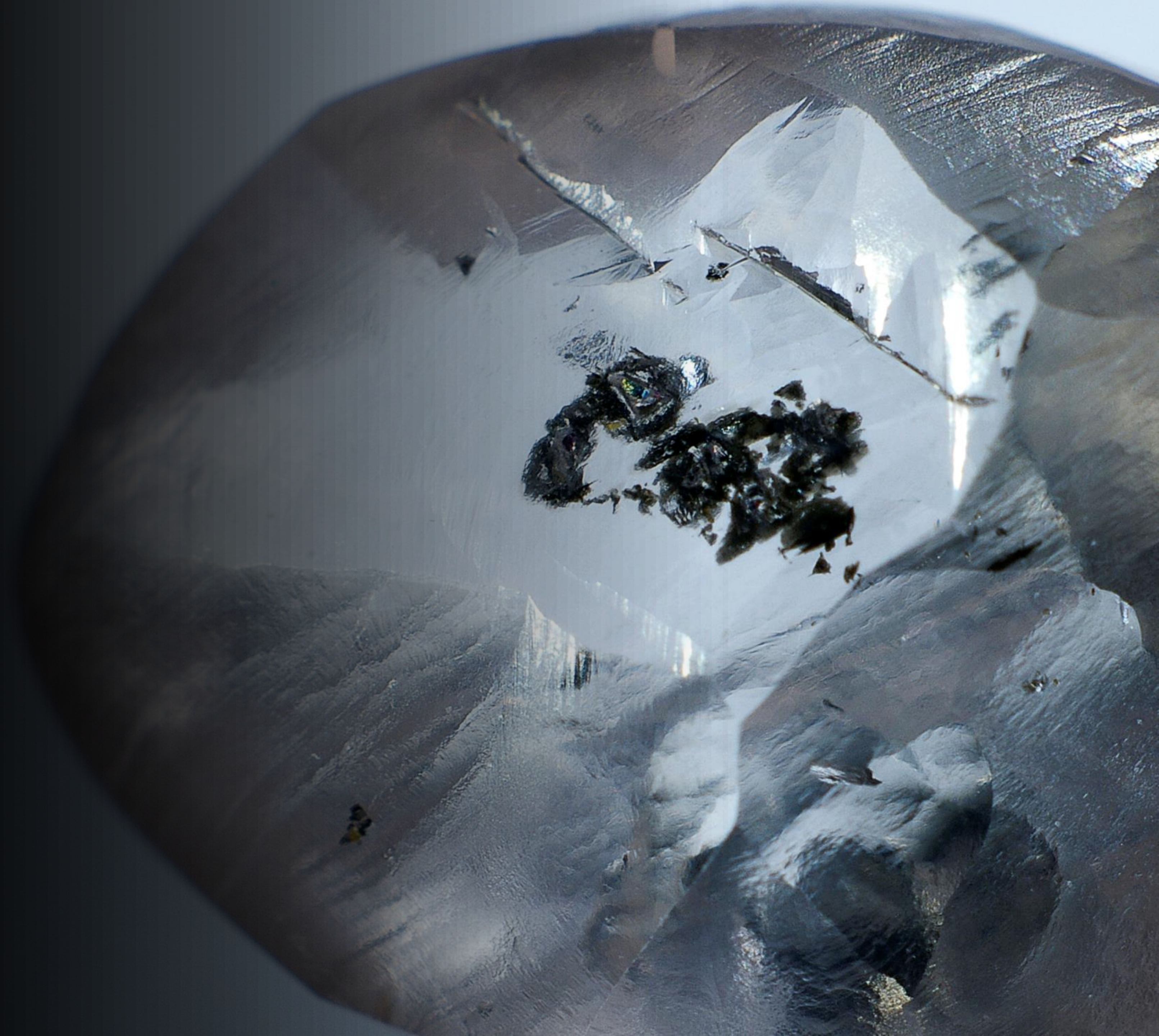
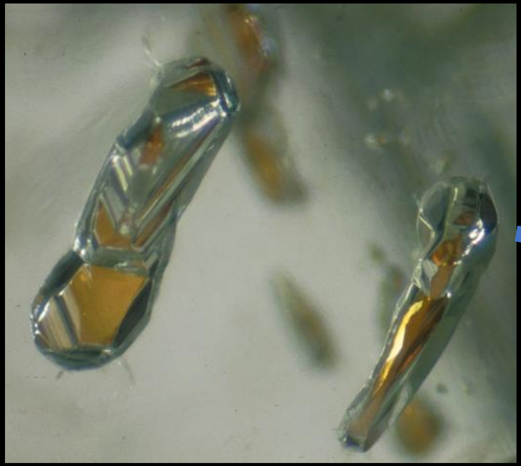
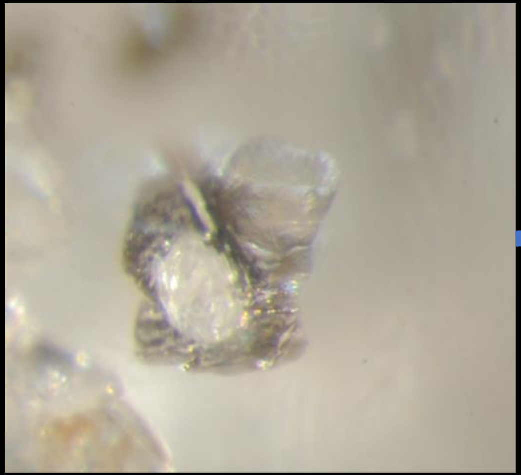


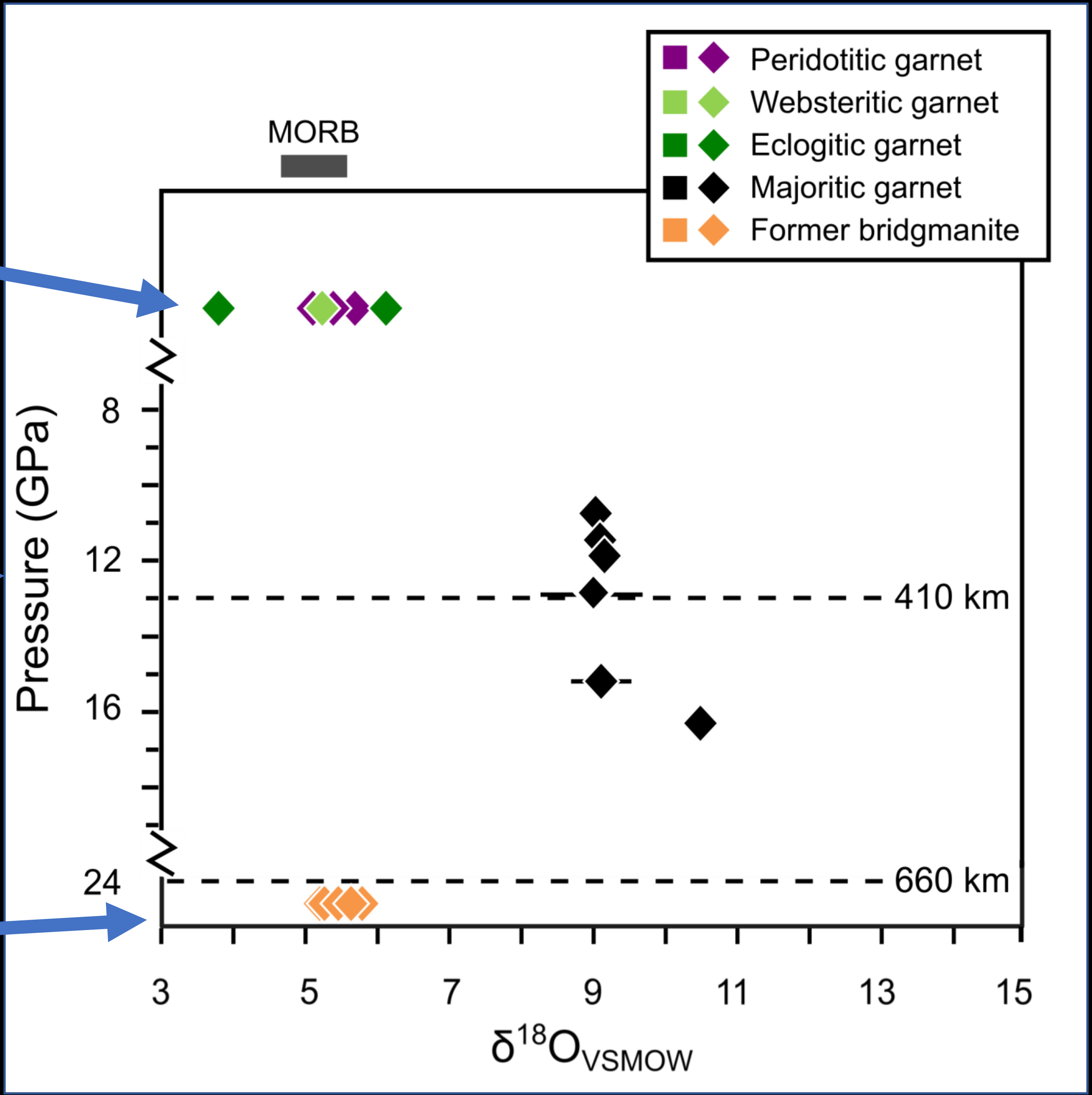


Lithospheric garnets

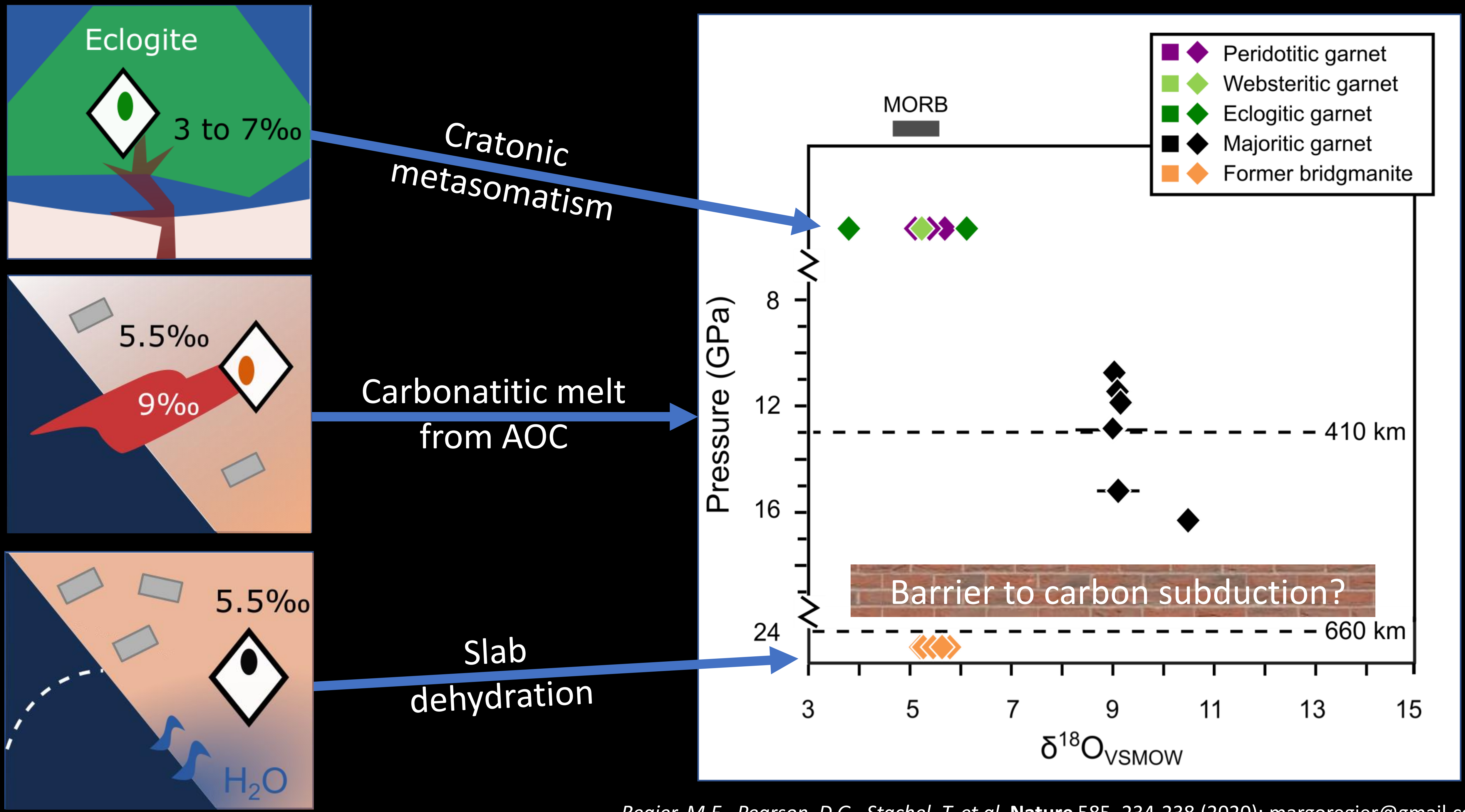
Transition zone majoritic garnets



Lower mantle 'bridgmanite'

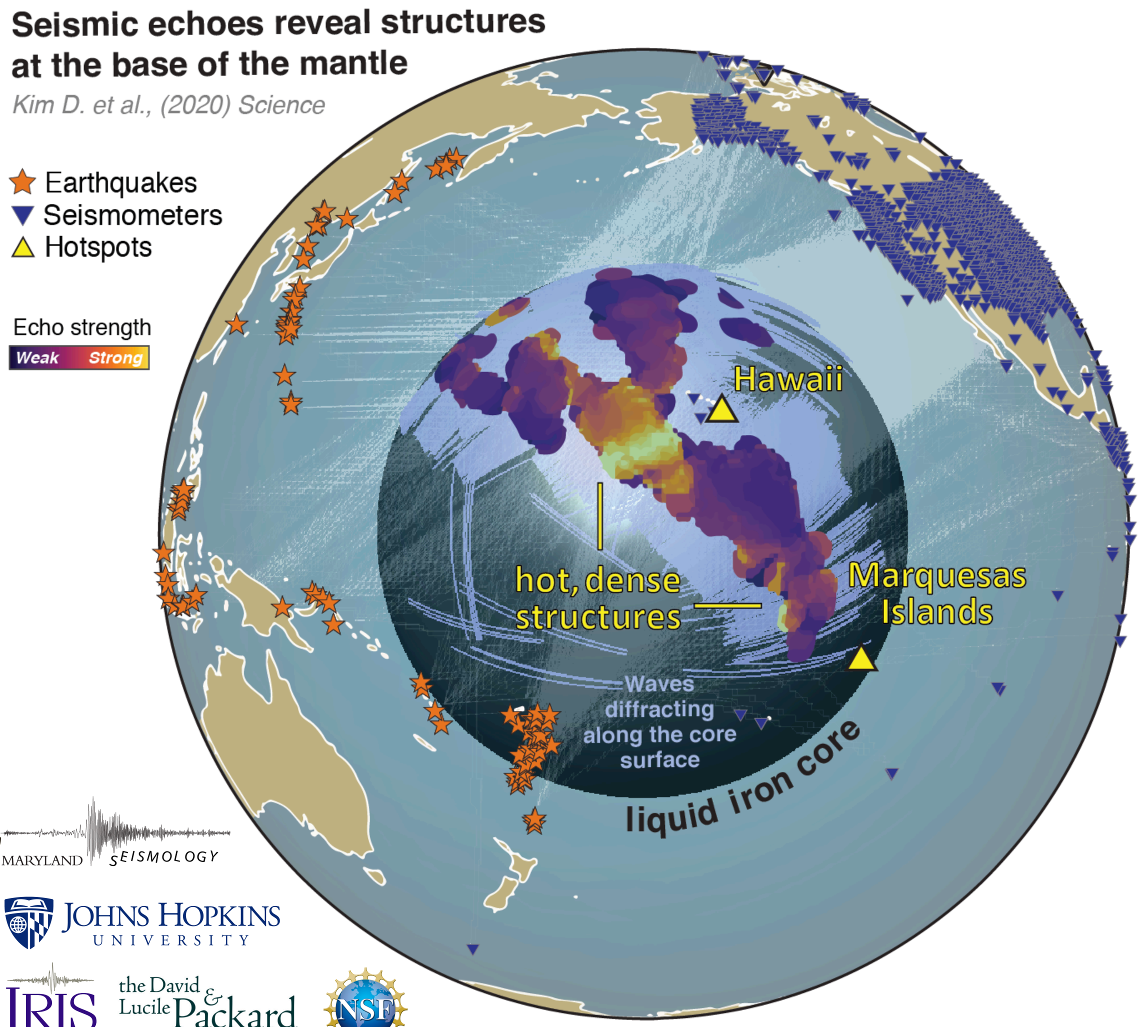


Regier, M.E., Pearson, D.G., Stachel, T. et al. **Nature** 585, 234-238 (2020); margoregier@gmail.com



Regier, M.E., Pearson, D.G., Stachel, T. et al. **Nature** 585, 234-238 (2020); margoregier@gmail.com

Sequencing Seismograms: A Panoptic View of Scattering in Core-Mantle Boundary Region



Kim, Doyeon[1*]., V. Lekic[1],
B. Menard[2], D. Baron[3], M. Taghizadeh-Popp[2]

[1]University of Maryland, College Park;
[2]Johns Hopkins University;
[3]Tel-Aviv University

Takeaway: Sequencing seismograms reveals an **ultralow-velocity zone beneath Marquesas Islands**, and **pervasive scattering** near the core-mantle boundary **strongest from a plume root under Hawaii**

For more details:
http://doyeonkim.us/sequencing_seismograms
http://sequencer.org/

email: dk696@cornell.edu

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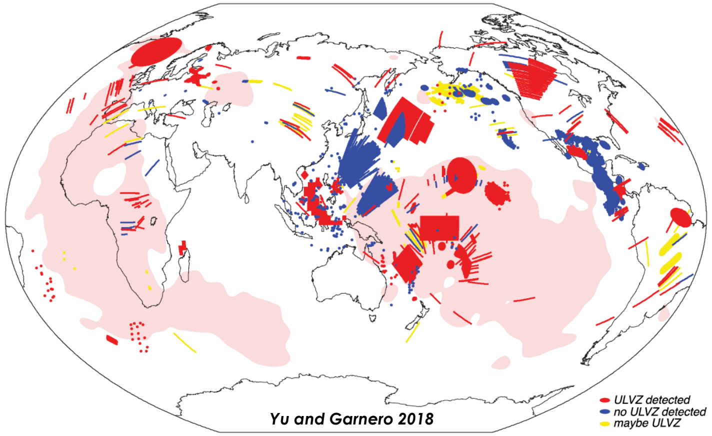
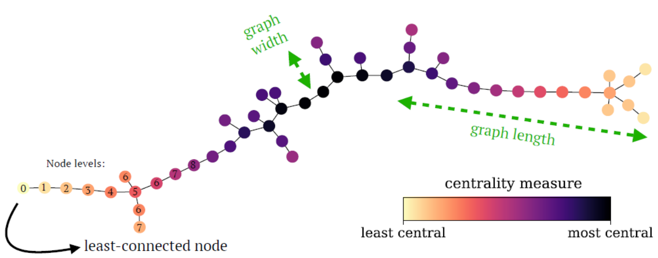
Global distribution of ULVZs

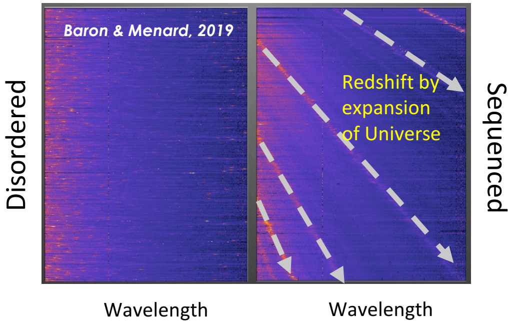


- Traditionally approaches are done in a piecemeal way **focused on specific target areas**
- This makes us difficult to understand the lowermost mantle structures in a global context

The Sequencer

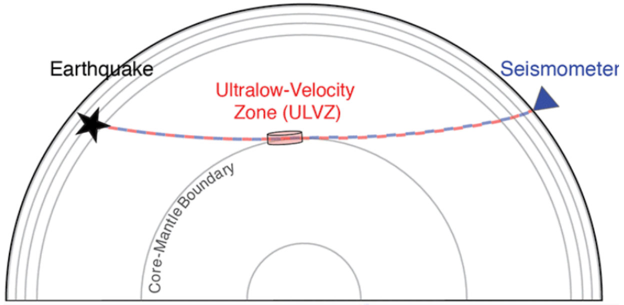


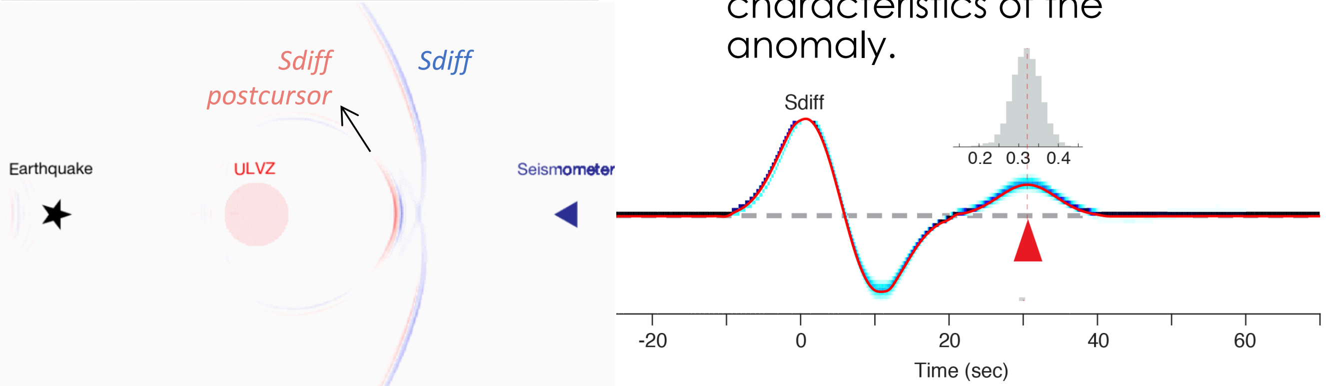
Minimum spanning tree



Quasar spectra example

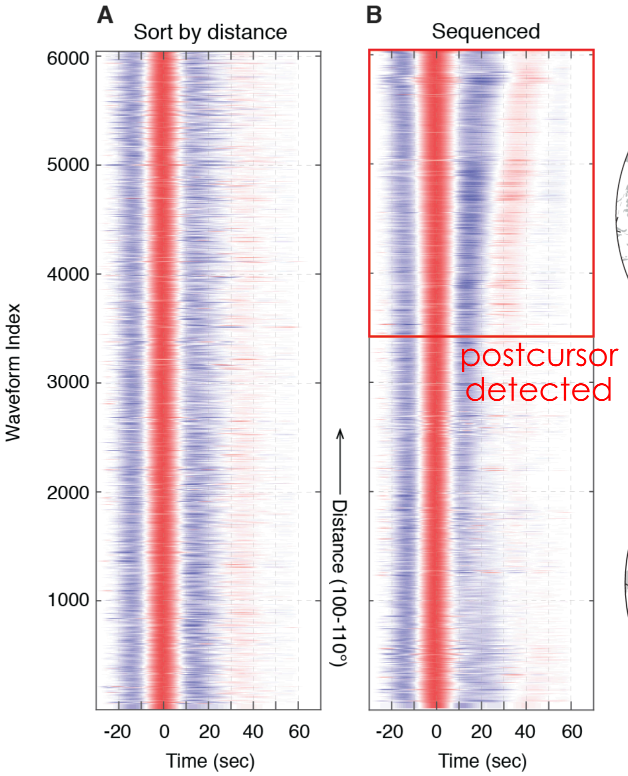
Sdiff/Sdiff postcursors and ULVZs

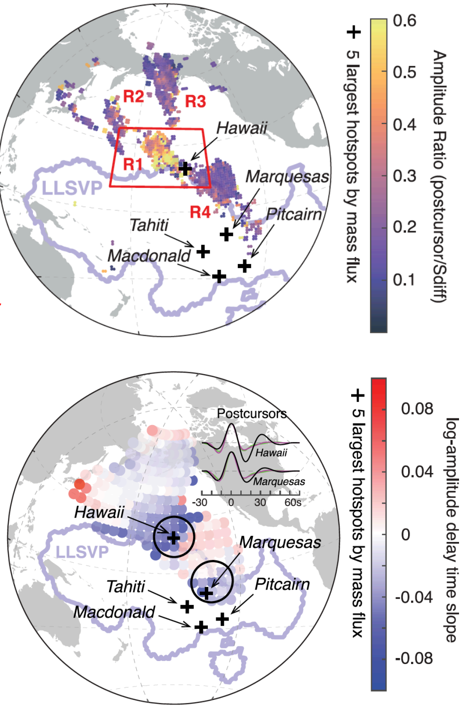




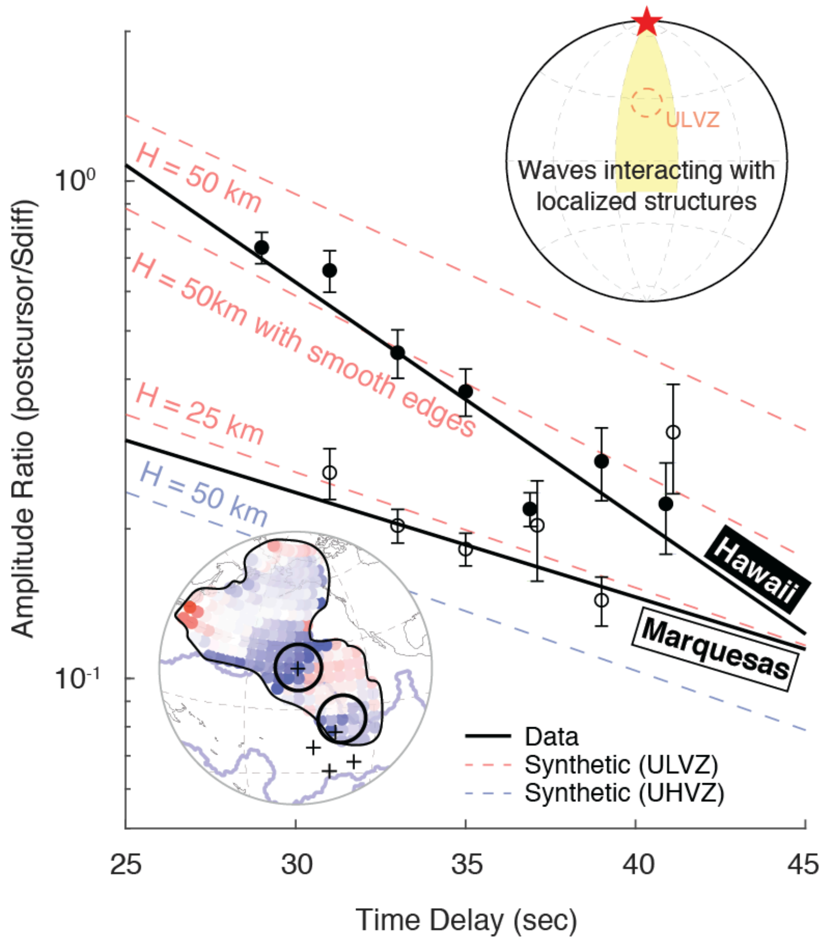
- Seismic waves either **transmit through** or **scatter off from** the anomaly.
- **Amplitude** and **delay time** of the postcursors vs. the main Sdiff arrivals can be measured and they tell characteristics of the anomaly.

Sequencing Sdiff seismograms

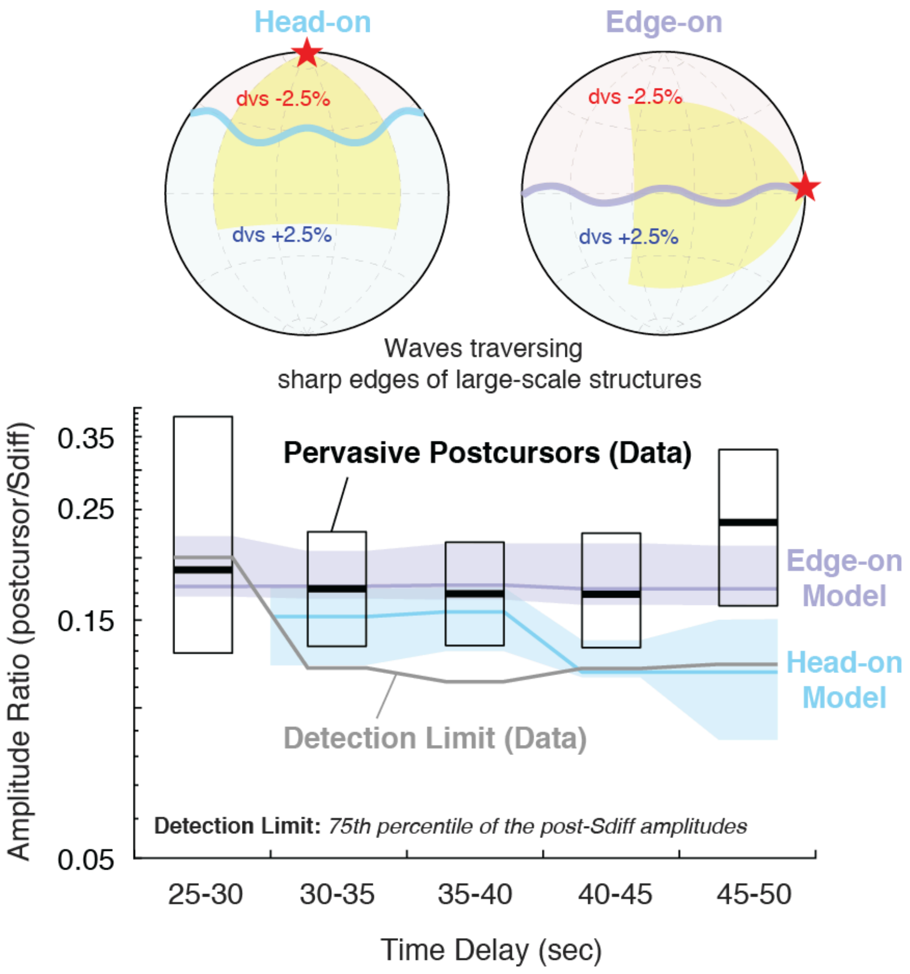




Local vs. distributed anomalies beneath the Pacific



Localized structures beneath **Hawaii** and **Marquesas** Islands



Large-scale structures perhaps be **more widespread** than previously thought

Analysing Lower Mantle Structure using Slowness Vector Measurements

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Lateral Velocity Gradients in the African Lower Mantle Inferred From Slowness Space Observations of Multipathing

Jamie Ward[1], Andy Nowacki[1], and Sebastian Rost[1]

[1]School of Earth and Environment, University of Leeds, Leeds, United Kingdom

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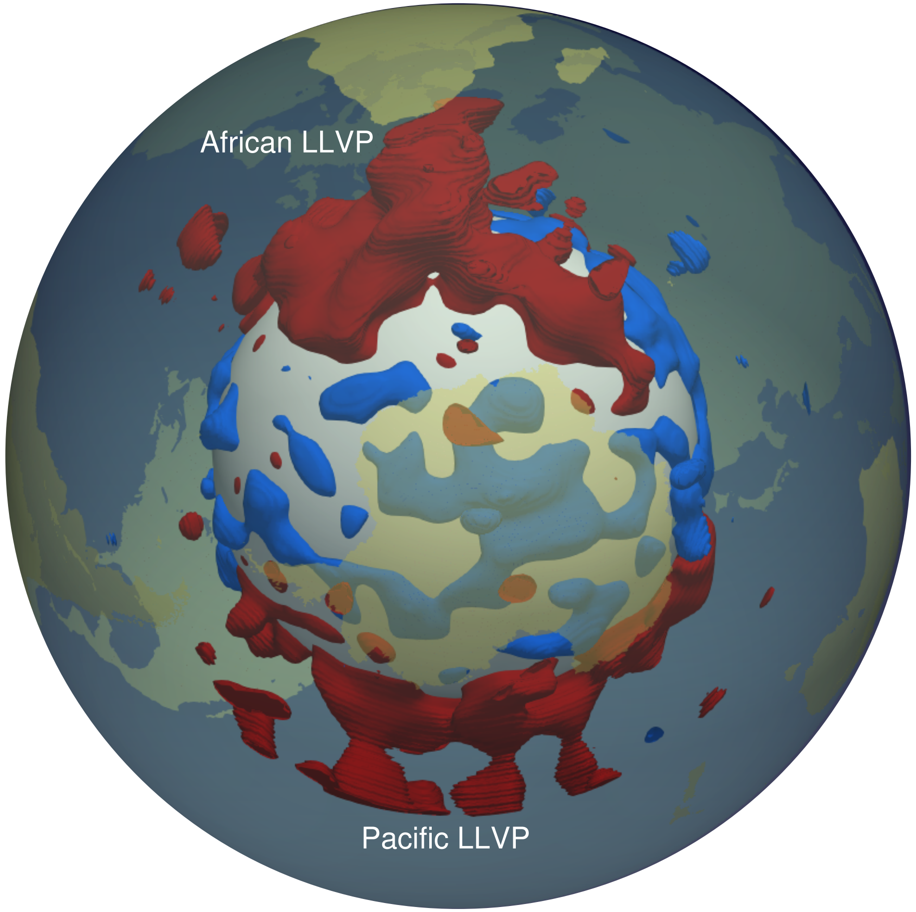
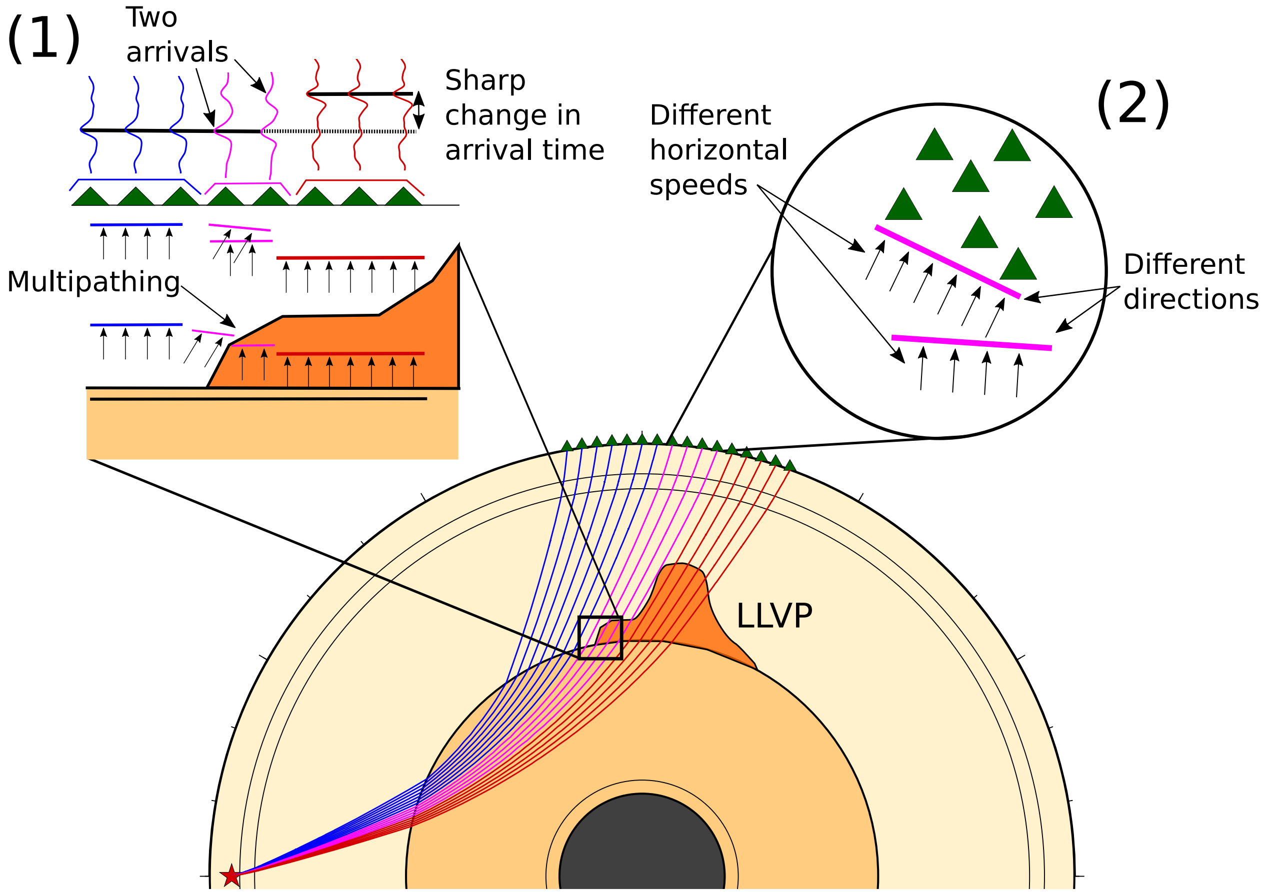
NERC SCIENCE OF THE ENVIRONMENT

Introduction - Multipathing

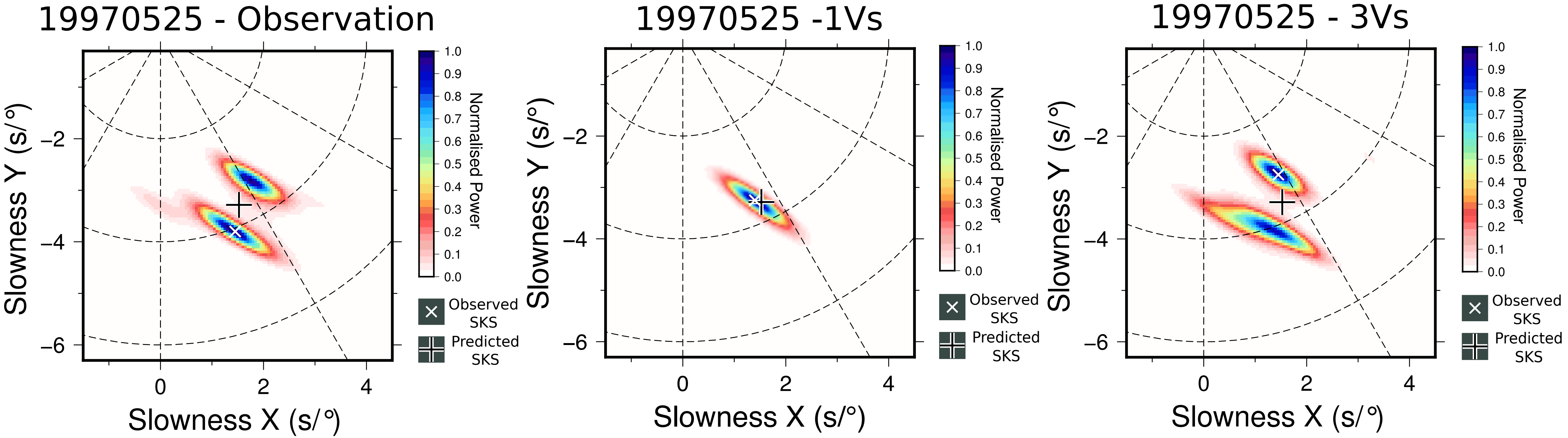


+1 and -1 % δV_s contours of SEMUCB-WM1 (French & Romanowicz, 2014) edited from Figure 1 in Ward et al. (2020).



Explanatory figure of multipathing at LLVP boundaries. Edited from Ward et al. (2020).

Forward Modelling



- Velocity gradients in seismic tomography (centre) are not enough to produce observable multipathing using this method.
- Trebling velocity perturbations in the lower mantle is enough to reproduce our observations for this example (right).
- The maximum velocity gradient sampled along this path is approximately 0.7% δV_s per 100 km, an order of magnitude lower than the strongest velocity gradient estimates.

Burying Earth's primitive mantle in the slab graveyard

Workshop on Feedbacks Between Mantle Composition, Structure, and Evolution

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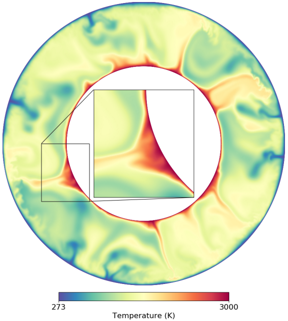
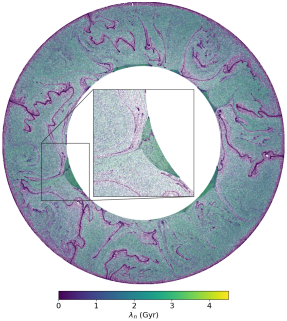
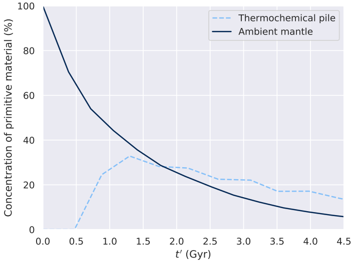
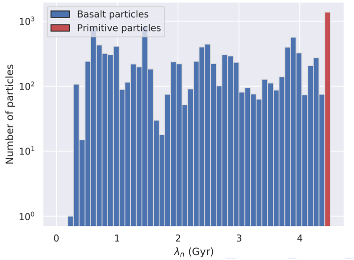
t6jones@ucsd.edu | DOI = 10.1002/essoar.10504078.1

Thermochemical piles from recycled slabs

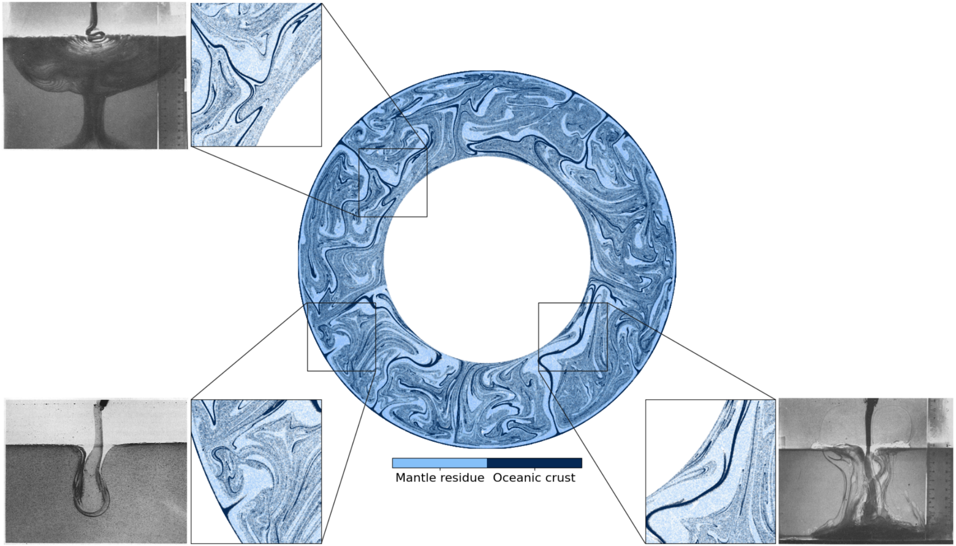








Three modes of viscous entrainment

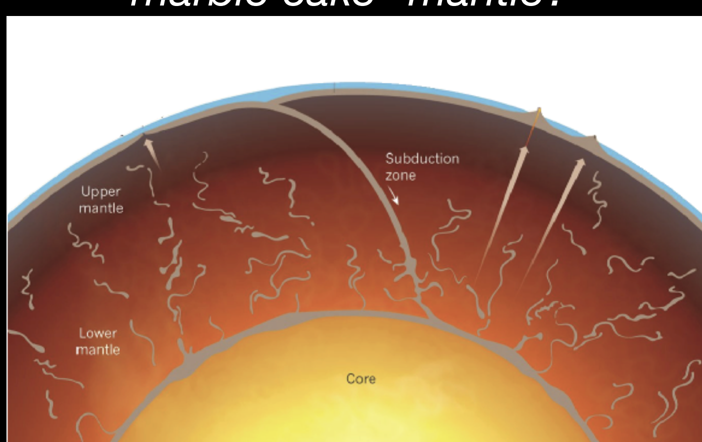


The coexistence of recycled and primordial heterogeneity in Earth's lower mantle

a geodynamical perspective

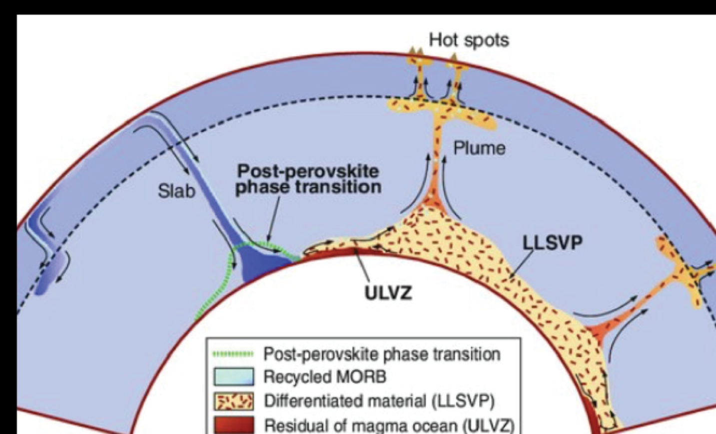
- *What is the **nature** of present-day chemical heterogeneity in Earth's mantle?*
- *How are they **formed** and **preserved** in the presence of whole mantle convection?*

"marble cake" mantle?



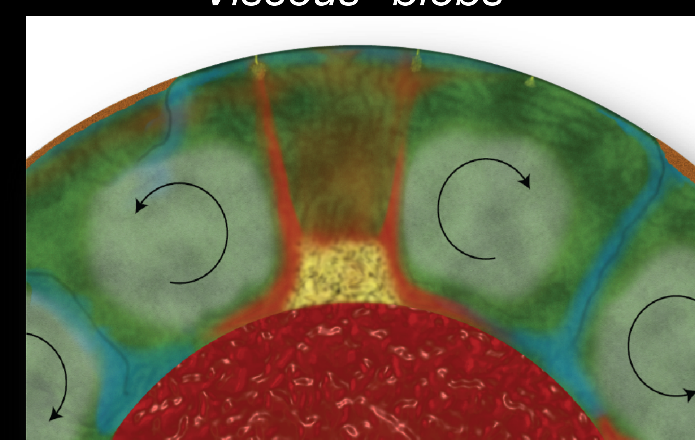
Woodhead (2015)

Piles?



Deschamps (2015)

Viscous "blobs"

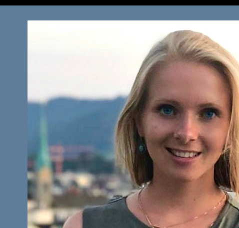


Ballmer et al. (2017)

Anna J. P. Gülcher[1], Maxim D. Ballmer[2,1] and Paul J. Tackley[1]

[1] Institute of Geophysics, Department of Earth Sciences, ETH Zürich, Zürich, Switzerland

[2] Department of Earth Sciences, University College London, London, UK



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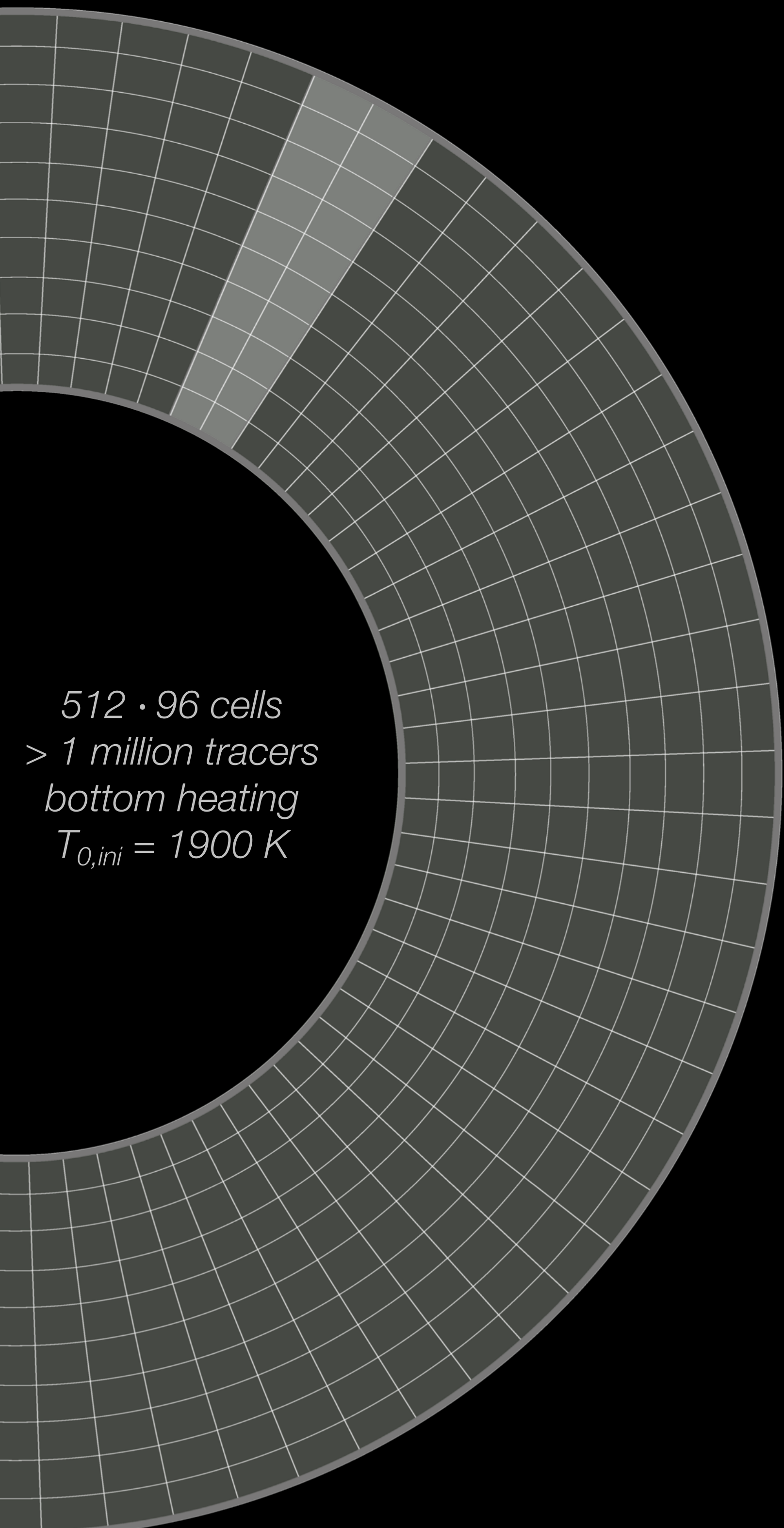
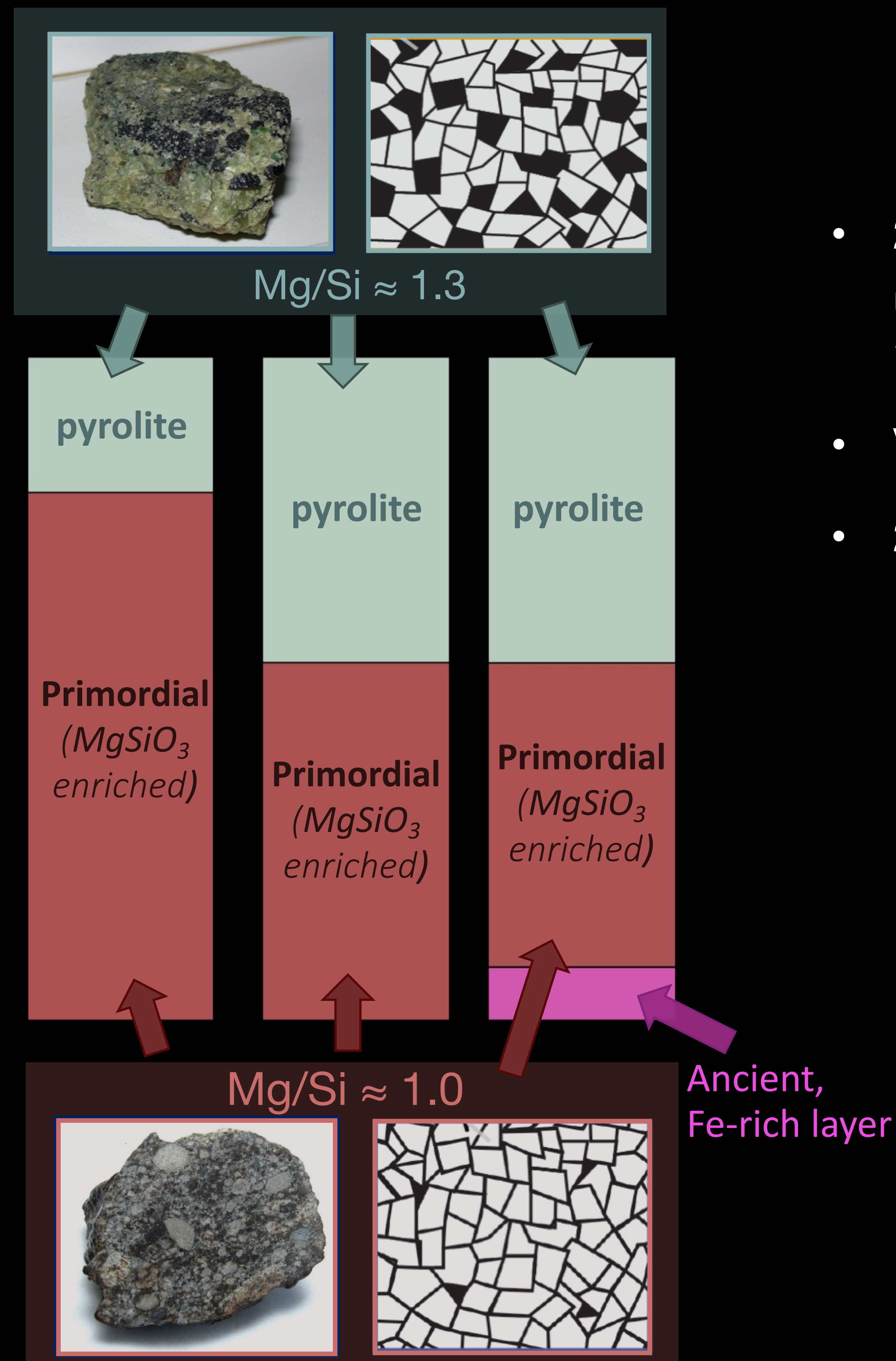
Contact: anna.guelcher@erdw.ethz.ch

@AnnaGeosc

Primordial and recycled heterogeneity





- 2D mantle convection models using *StagYY* *(Hernlund and Tackley, 2008)*
- Visco-plastic rheology
- 2 types of heterogeneity:
  - **Recycled oceanic crust** (**ROC**) heterogeneity ($\Delta\rho$)
  - **Primordial** heterogeneity ($\Delta\eta$ and/or $\Delta\rho$)

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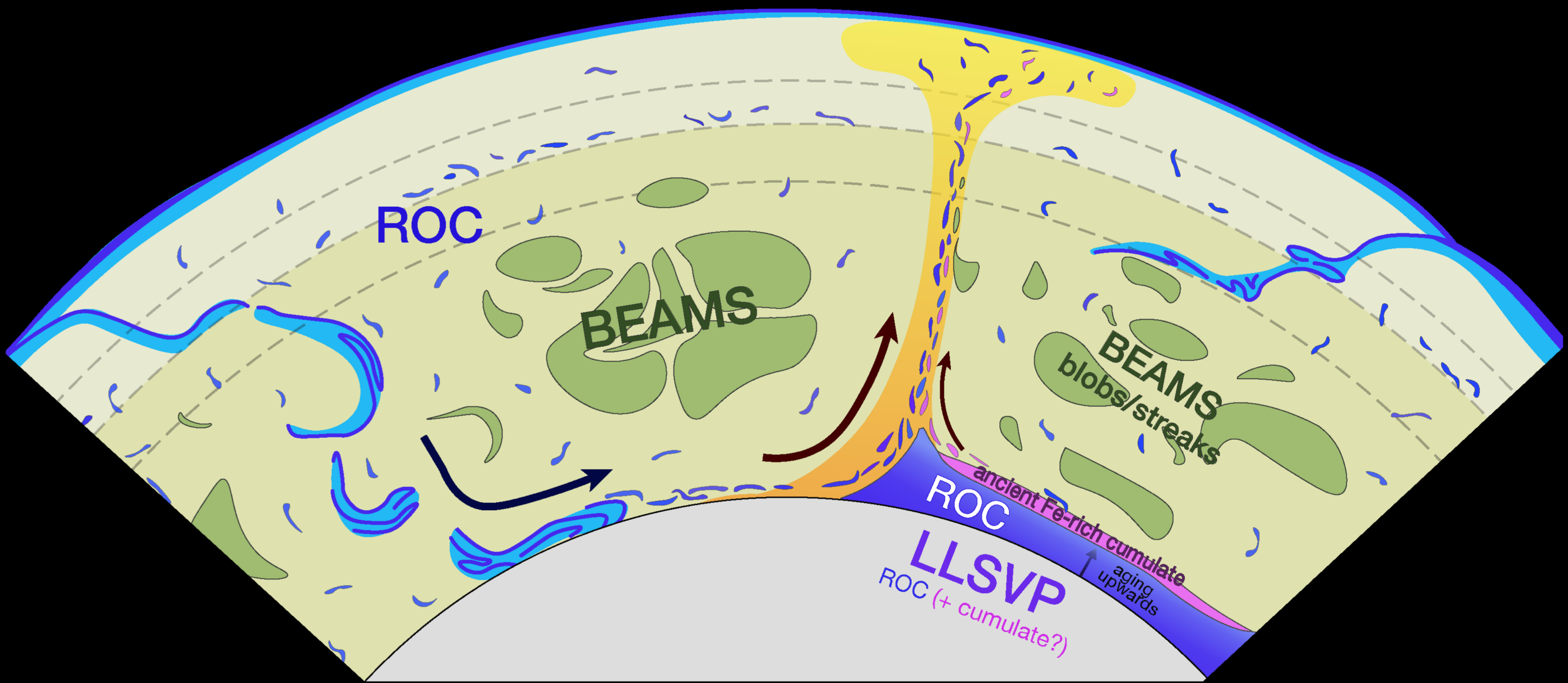
“marble cake” + “plum pudding” mantle?

Coexistence of viscous, primordial blobs in the mid-mantle with dense piles in the lowermost mantle is robustly predicted!

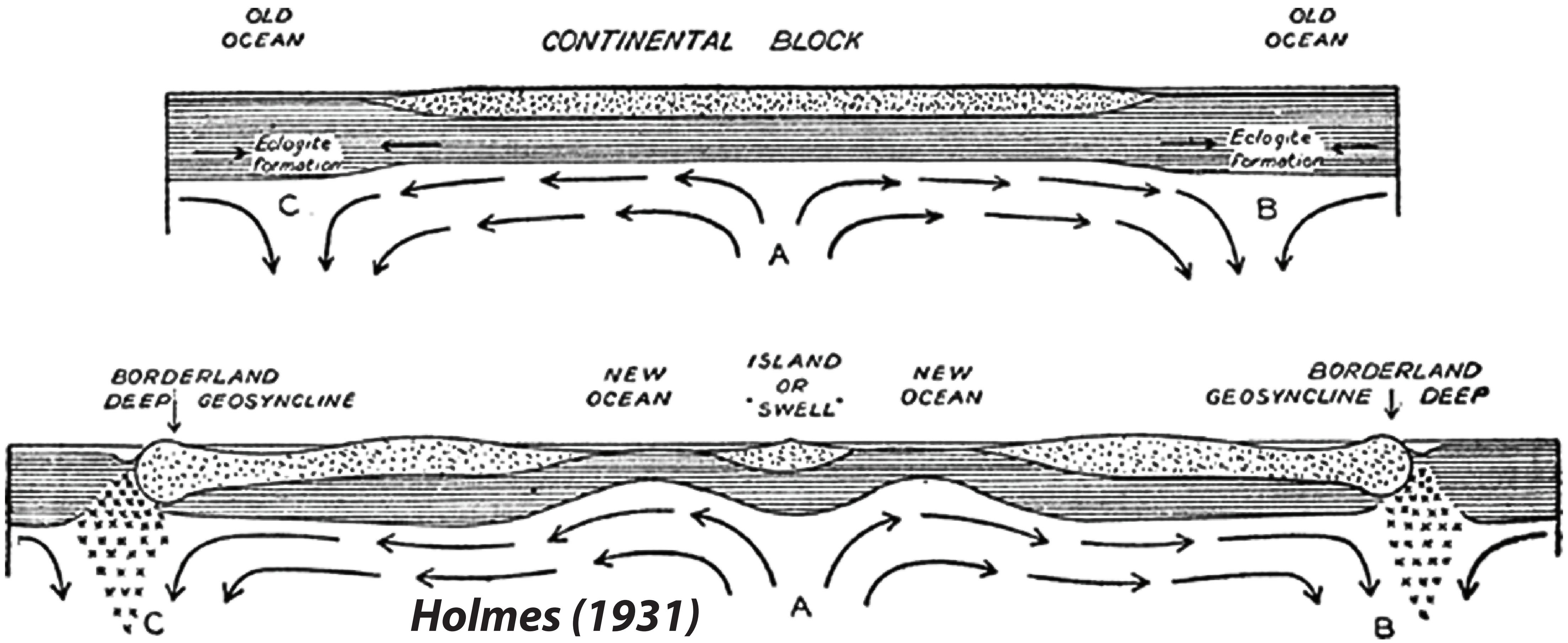


Gülcher et al. (in prep.)

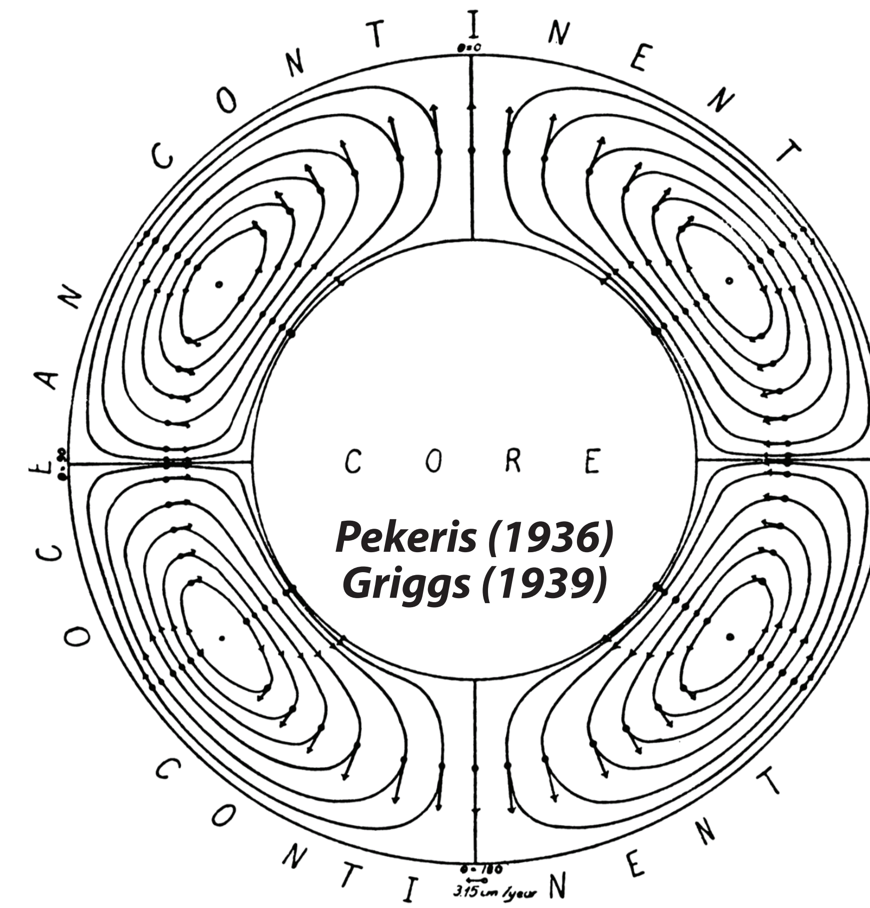
Contact: anna.guelcher@erdw.ethz.ch @AnnaGeosc

Does Mantle Convection Mix the Mantle?

The "fluid-like mantle": A historically useful (but crude) abstraction



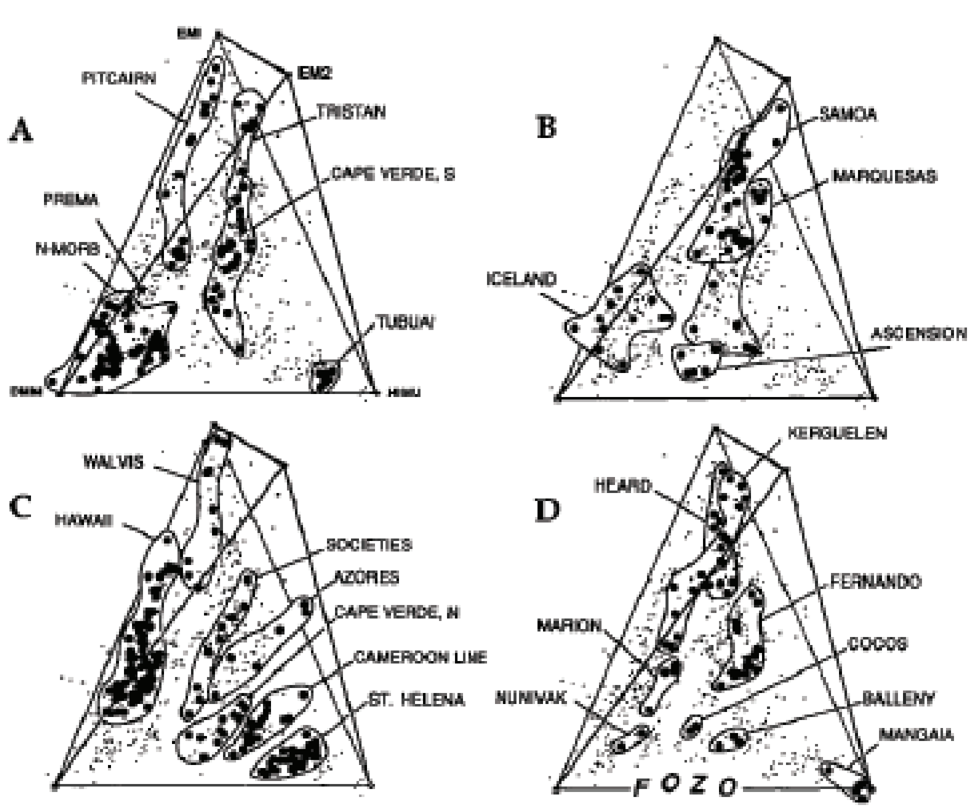
Holmes (1931)



Pekeris (1936)
Griggs (1939)

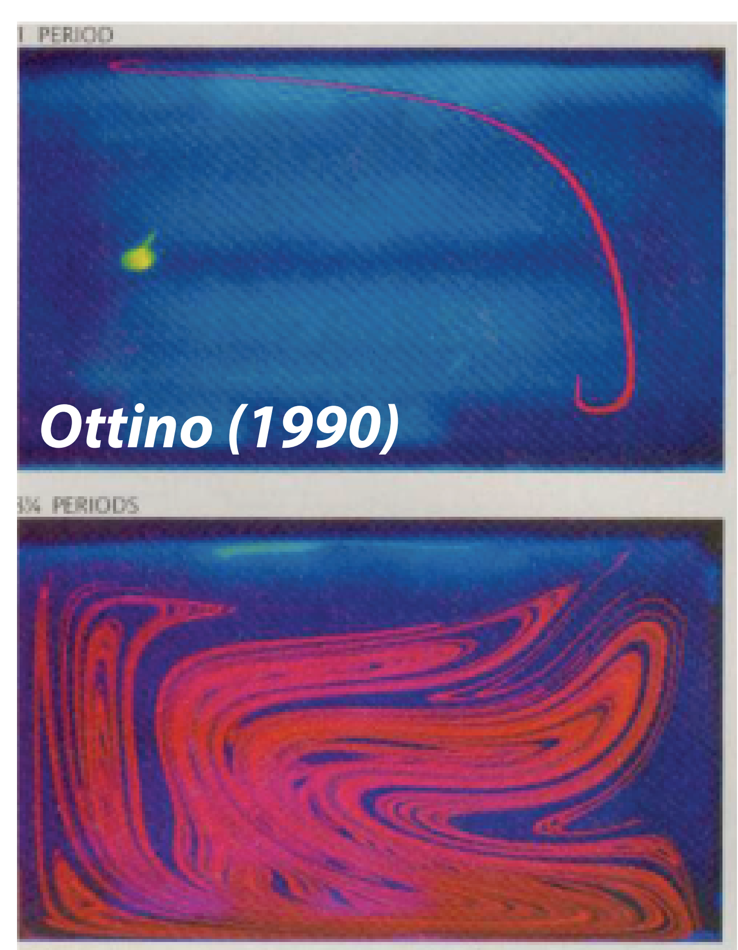
The fluid-like mantle concept applied to mantle mixing

Heterogeneous Mantle



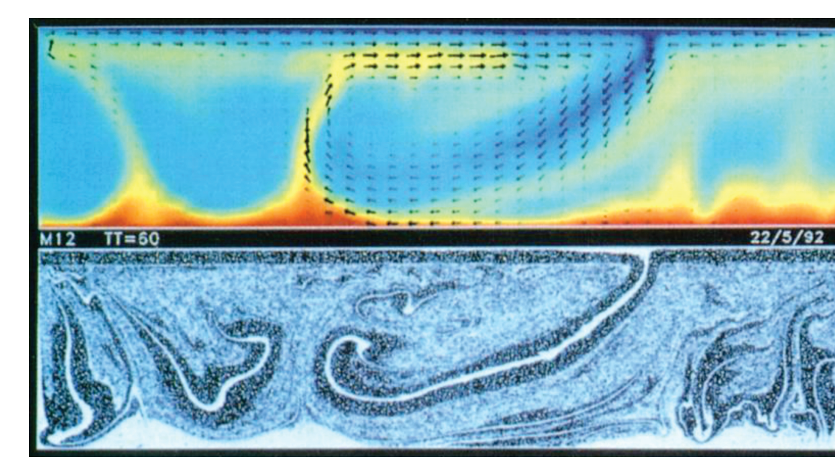
Hart et al. (1992)

Basic Fluid Convection



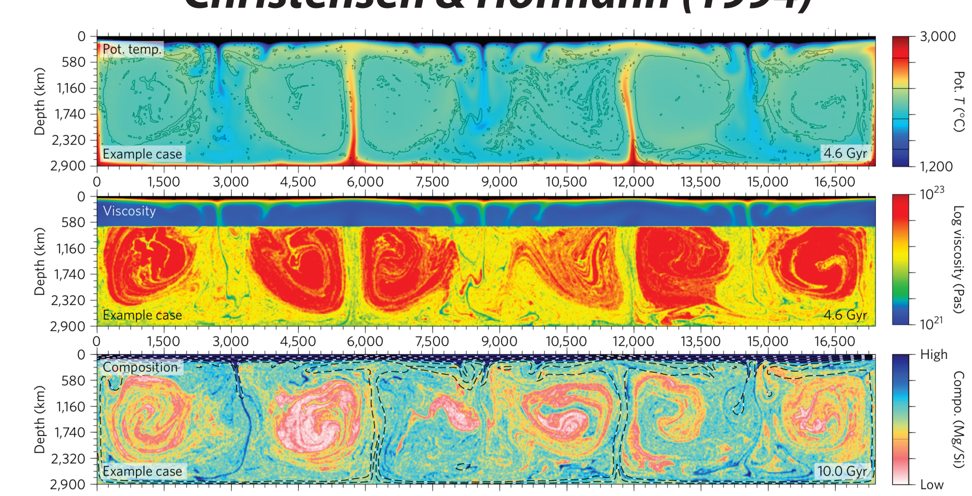
Ottino (1990)

Crust Formation and Density-Driven Accumulation →



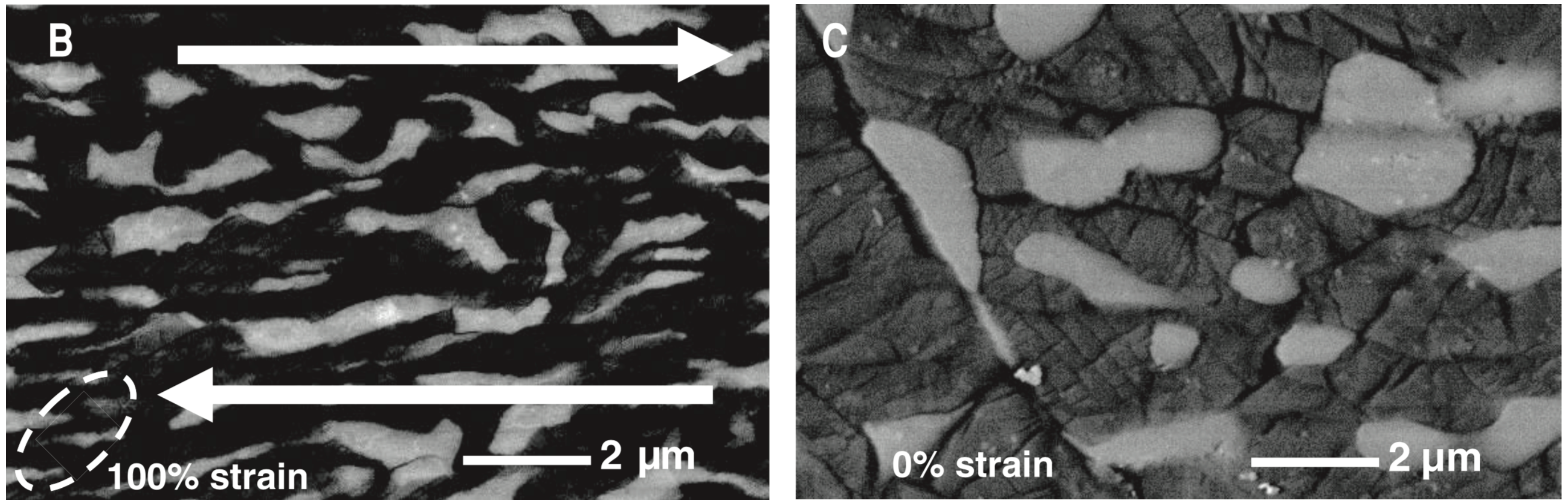
Christensen & Hofmann (1994)

Composition-Dependent Density/Viscosity →

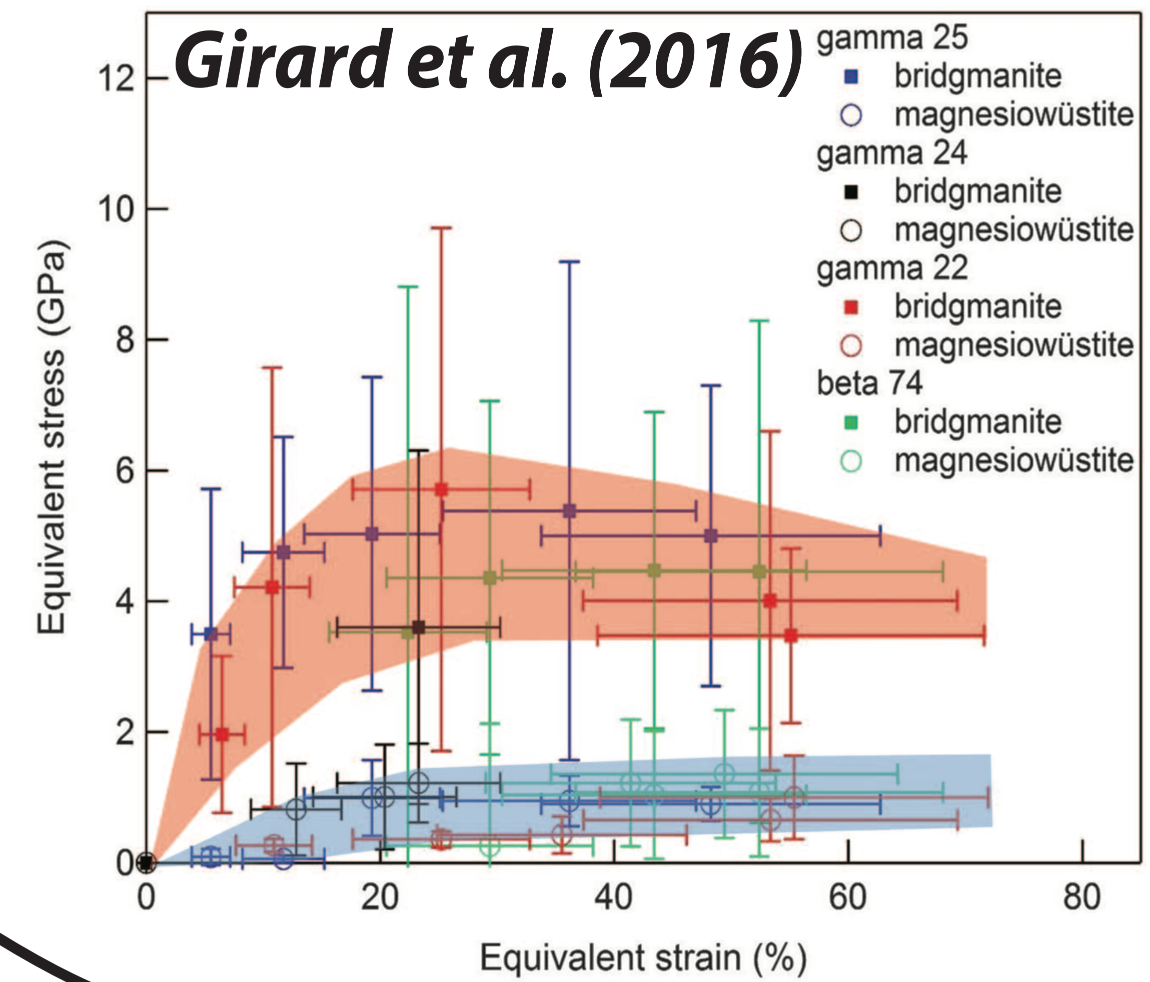


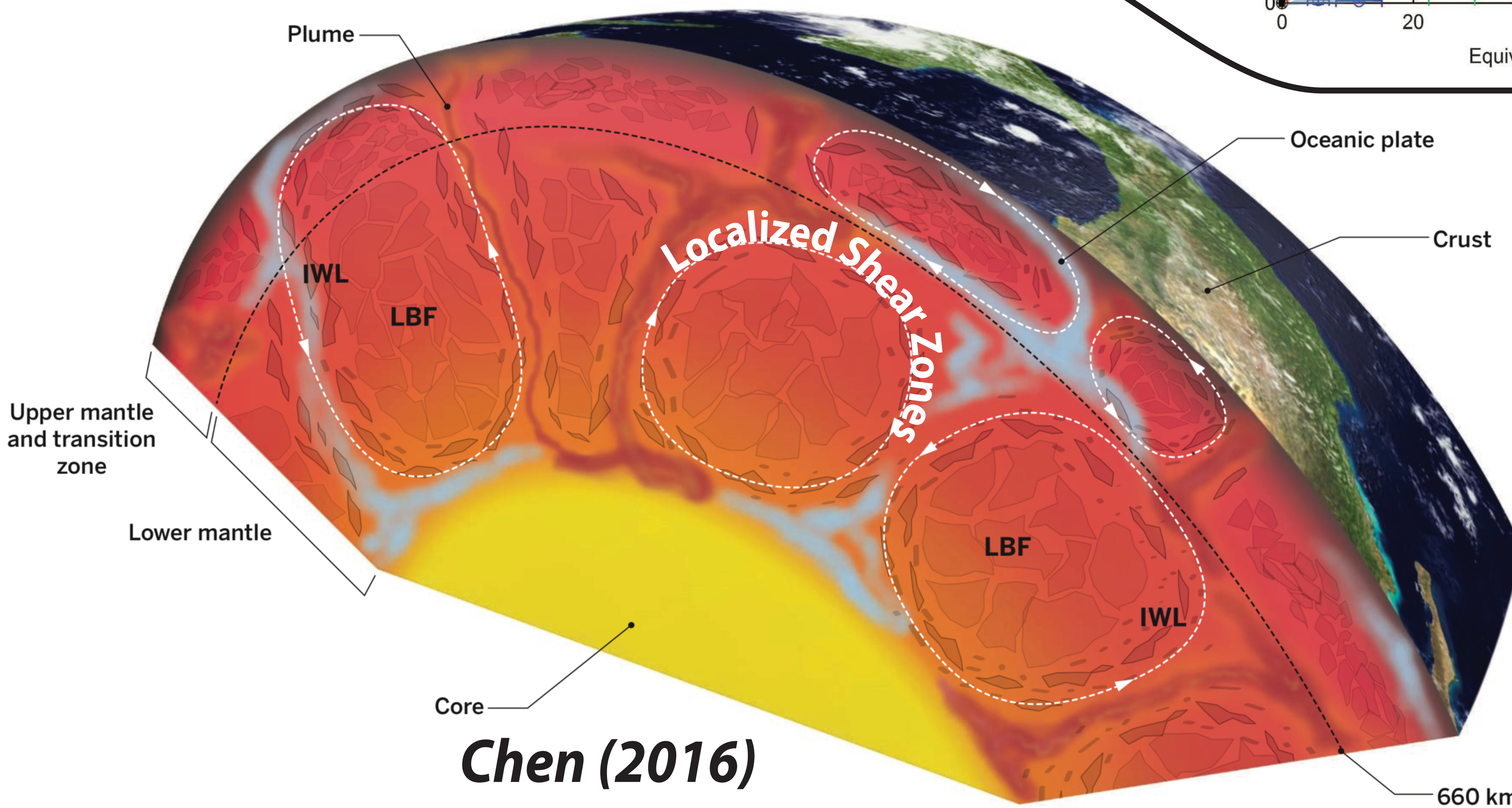
Ballmer et al. (2017)

Does Mantle Convection Mix the Mantle?



Girard et al. (2016)





Chen (2016)