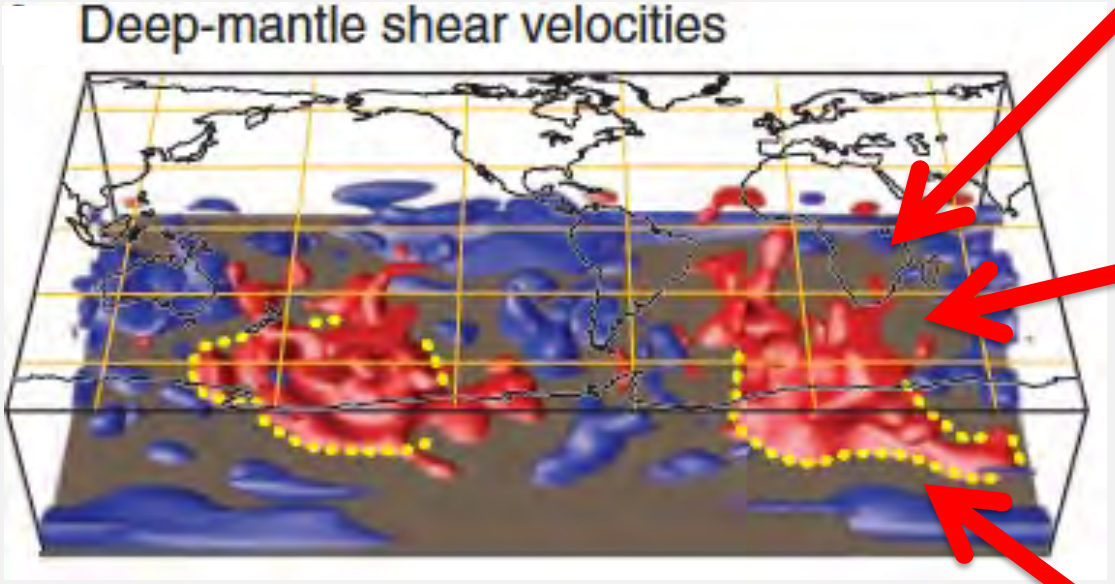
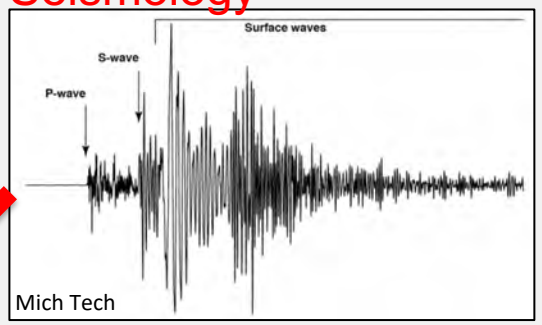
A geoneutrino "telescope" to view the inaccessibly deep interior of the Earth: Ushering in a new era of multi-messenger geophysics

Inspired by multi-messenger astrophysics: expensive detectors for photons, cosmic rays, neutrinos, and gravity waves.

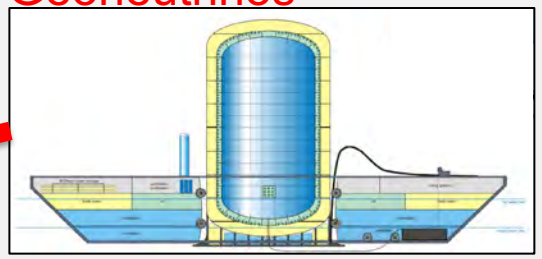


Ed Garnero

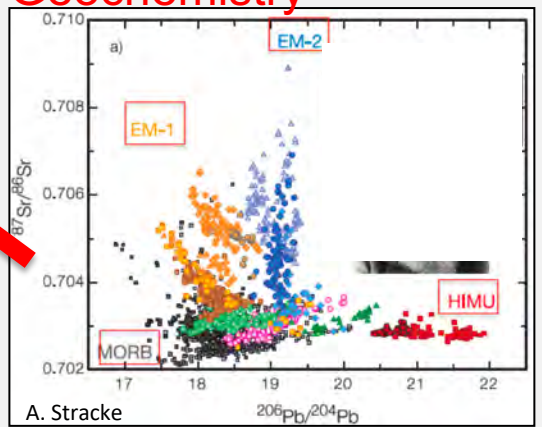
Seismology



Geoneutrinos



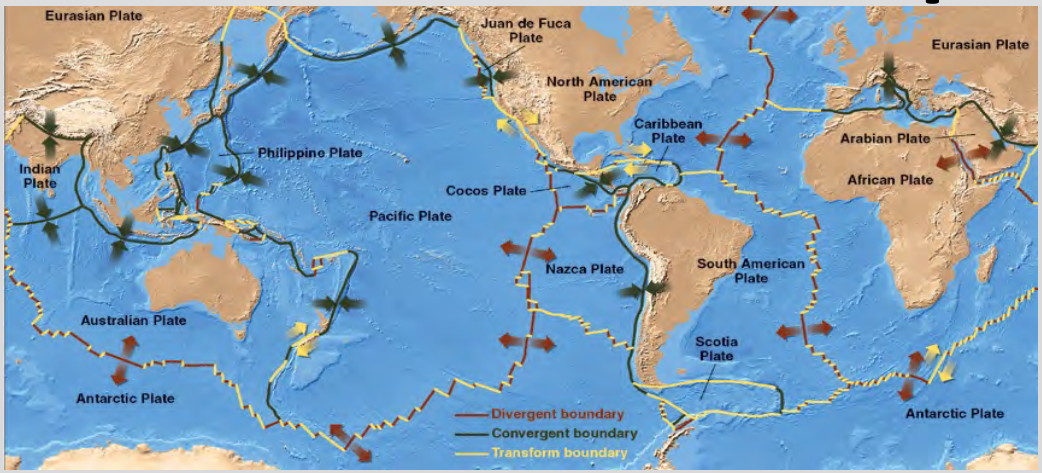
Geochemistry

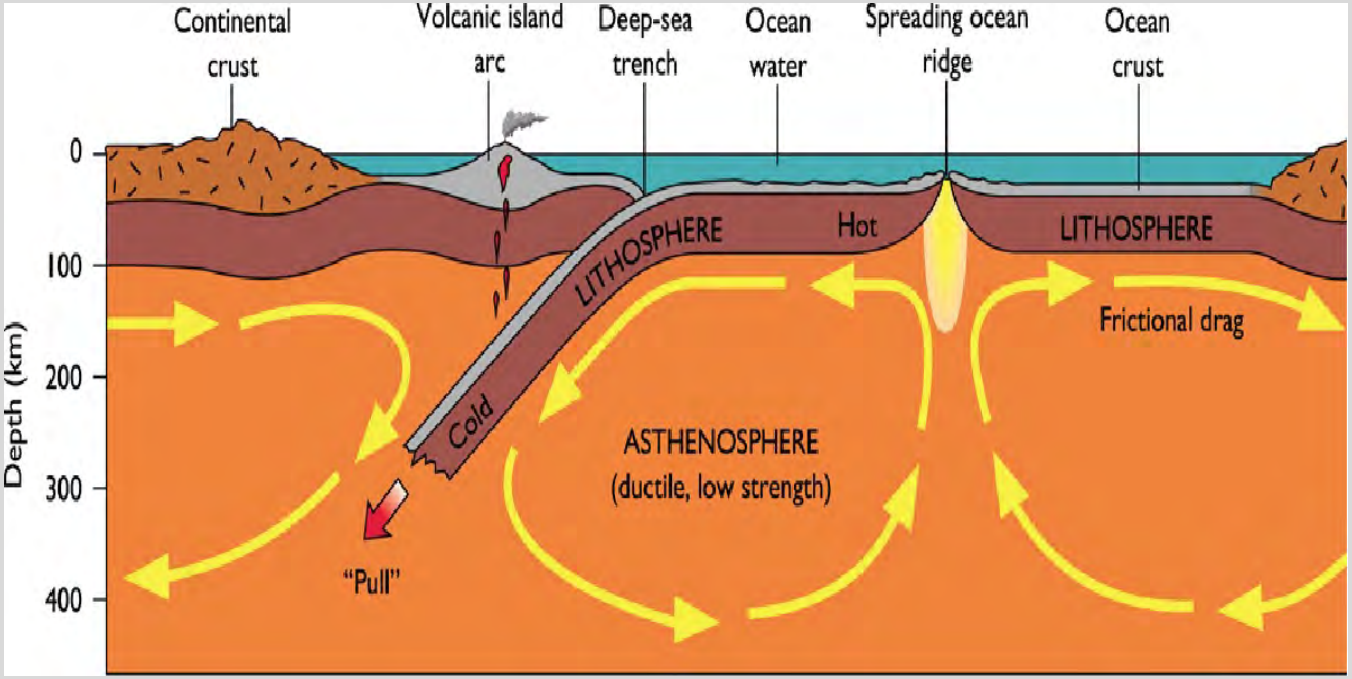


Matt Jackson

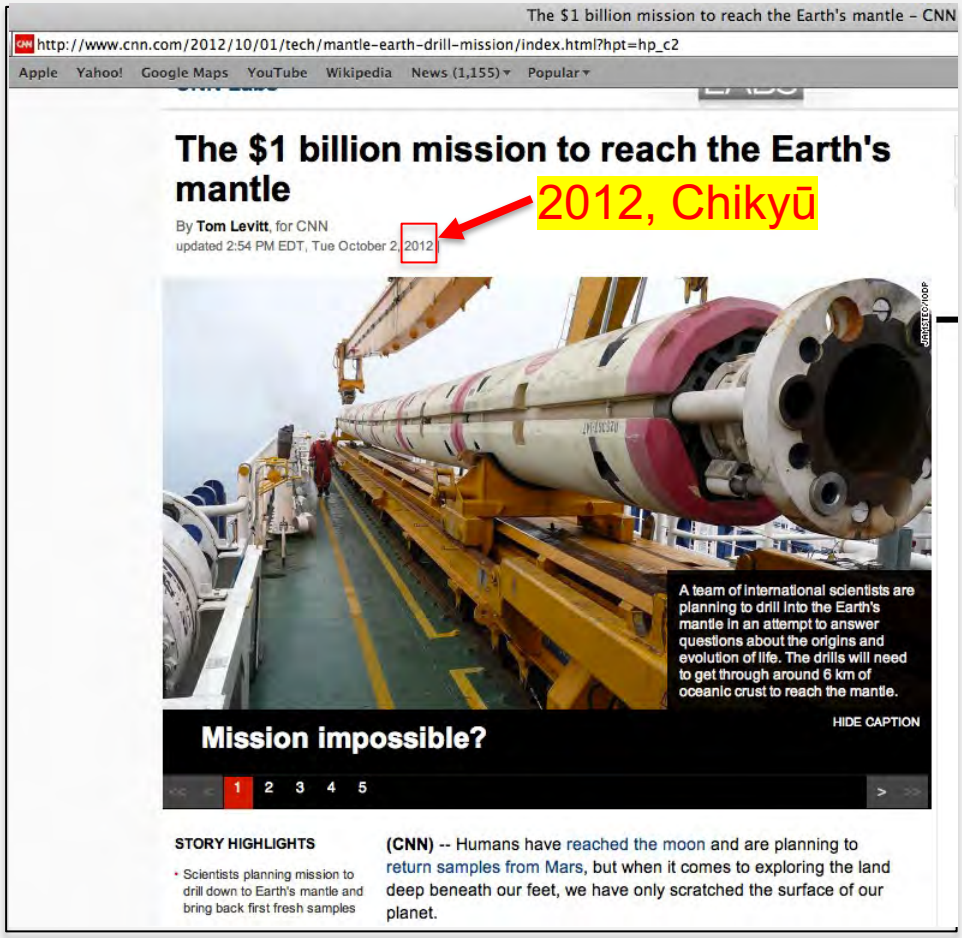
UC Santa Barbara

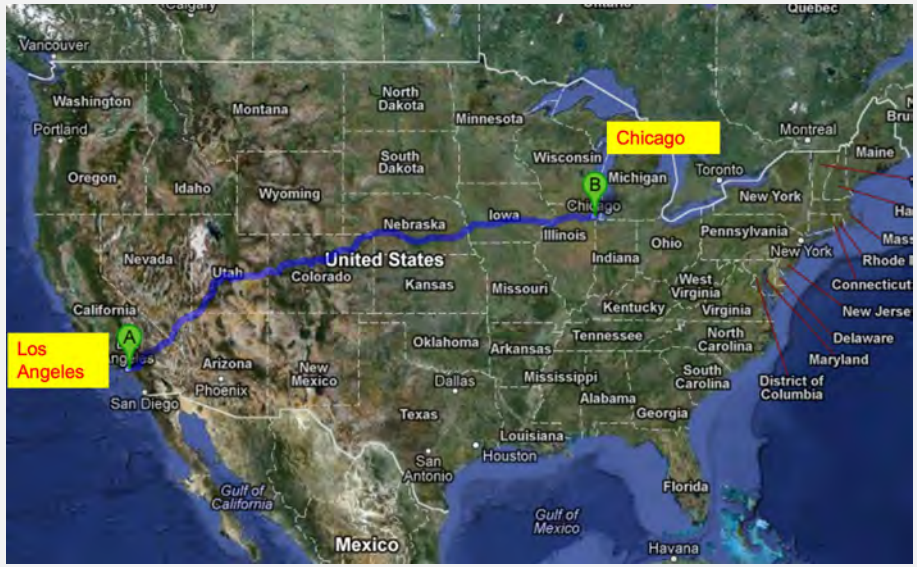
A Dynamic Earth with a virtually inaccessible interior: **A deep frontier!**



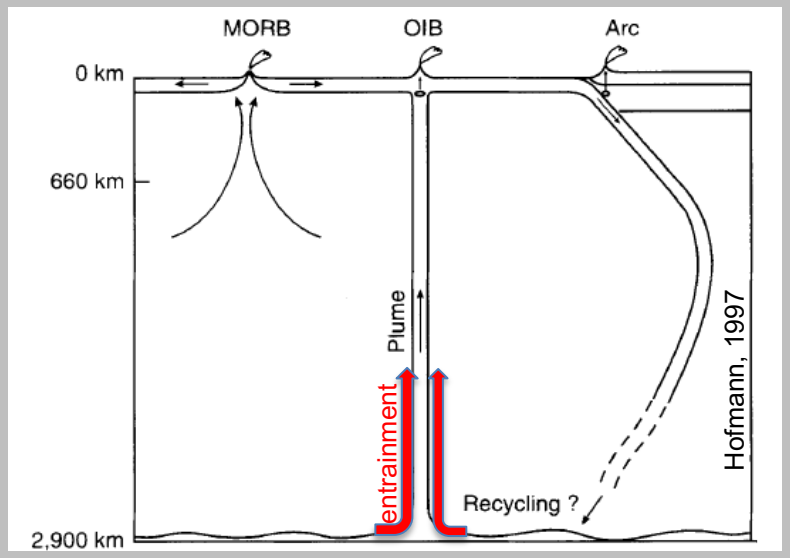


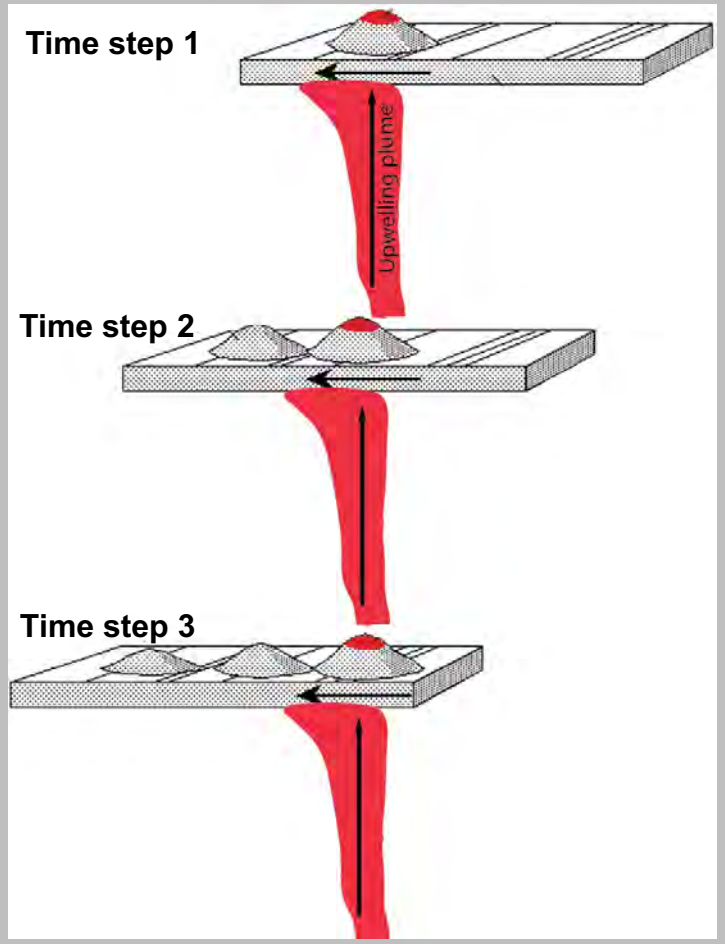
Accessing the Earth's deep interior?

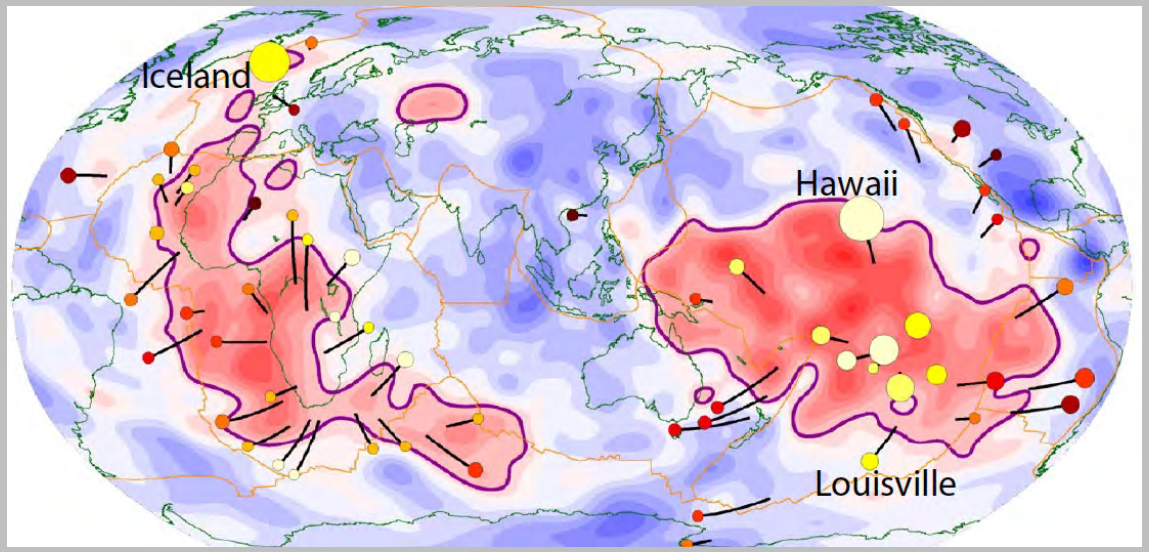




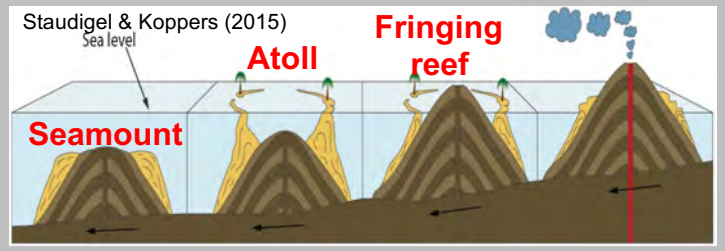
The Earth's mantle is a virtually inaccessible domain: Sampled by intraplate "hotspot" volcanoes



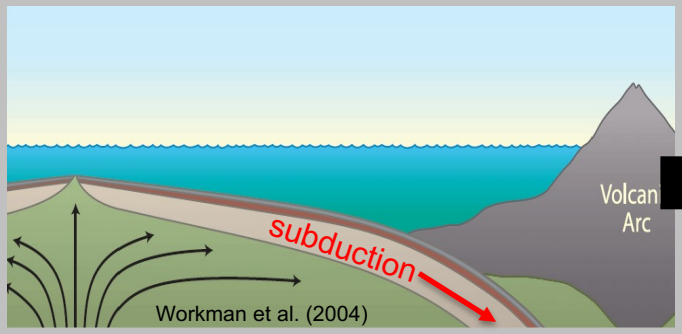


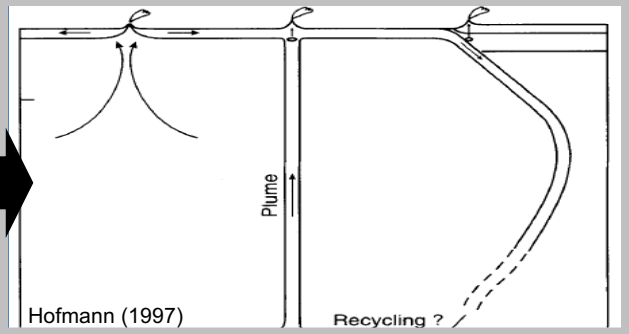


Large Low Shear Wave Velocity Provinces (LLSVPs) are largest seismically-constrained features visible in the deep mantle



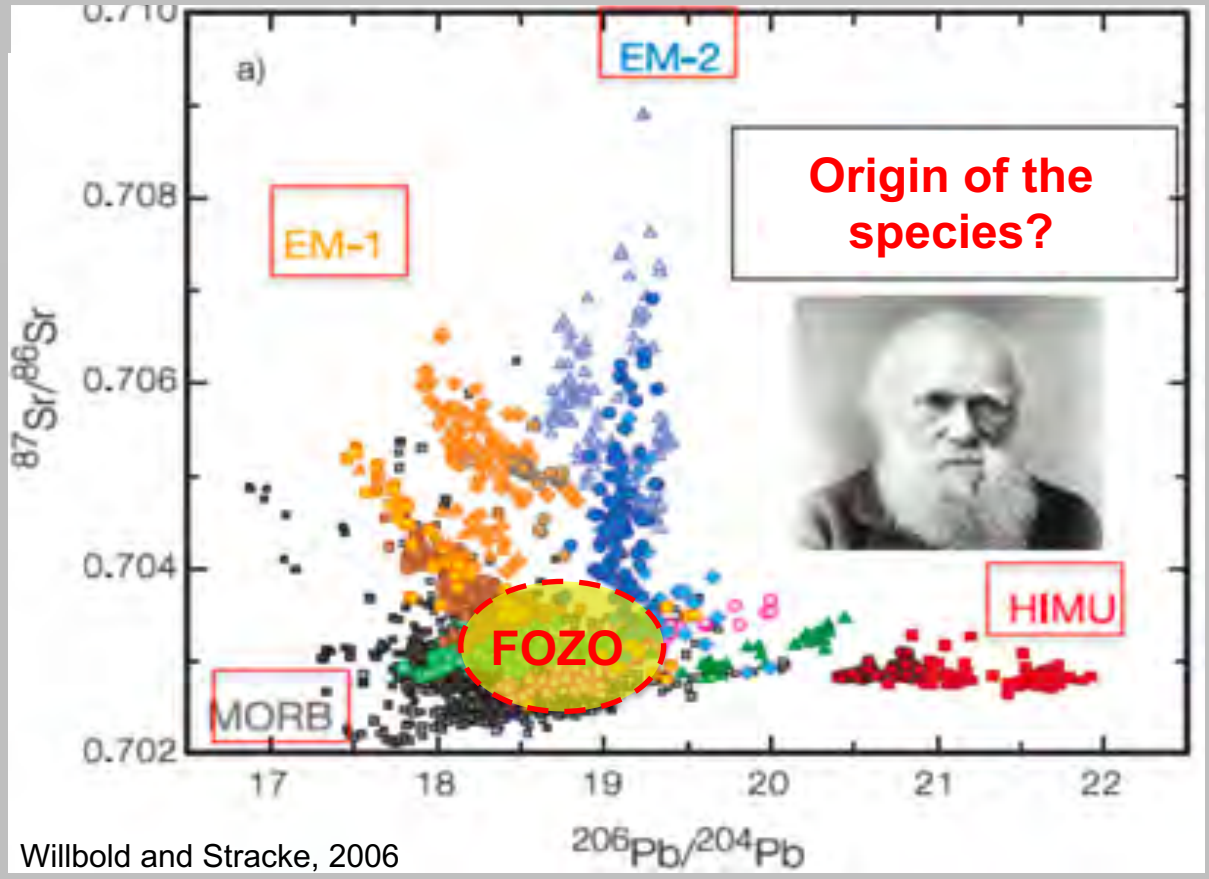
The "mantle zoo": origin of the species?





~20 km^3/year oceanic crust & ~1 km^3/year continent subducted

Hofmann & White (EPSL, 1982): HIMU from ancient subducted oceanic crust



Willbold and Stracke, 2006

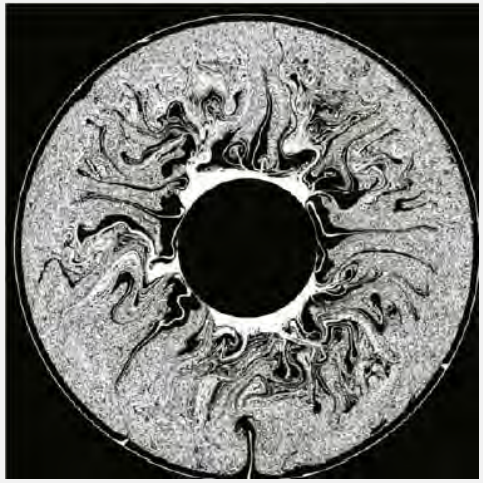
White & Hofmann (Nature, 1982): EM-1 & EM-2 from ancient subducted continental crust

Lavas as probes of the Earth's deep interior

The observation that the mantle is heterogeneous leads to some key questions in the study of the deep Earth:

1. **How** did the mantle become heterogeneous? Subduction?

2. **What** are the bulk compositions of geochemical reservoirs in the mantle?

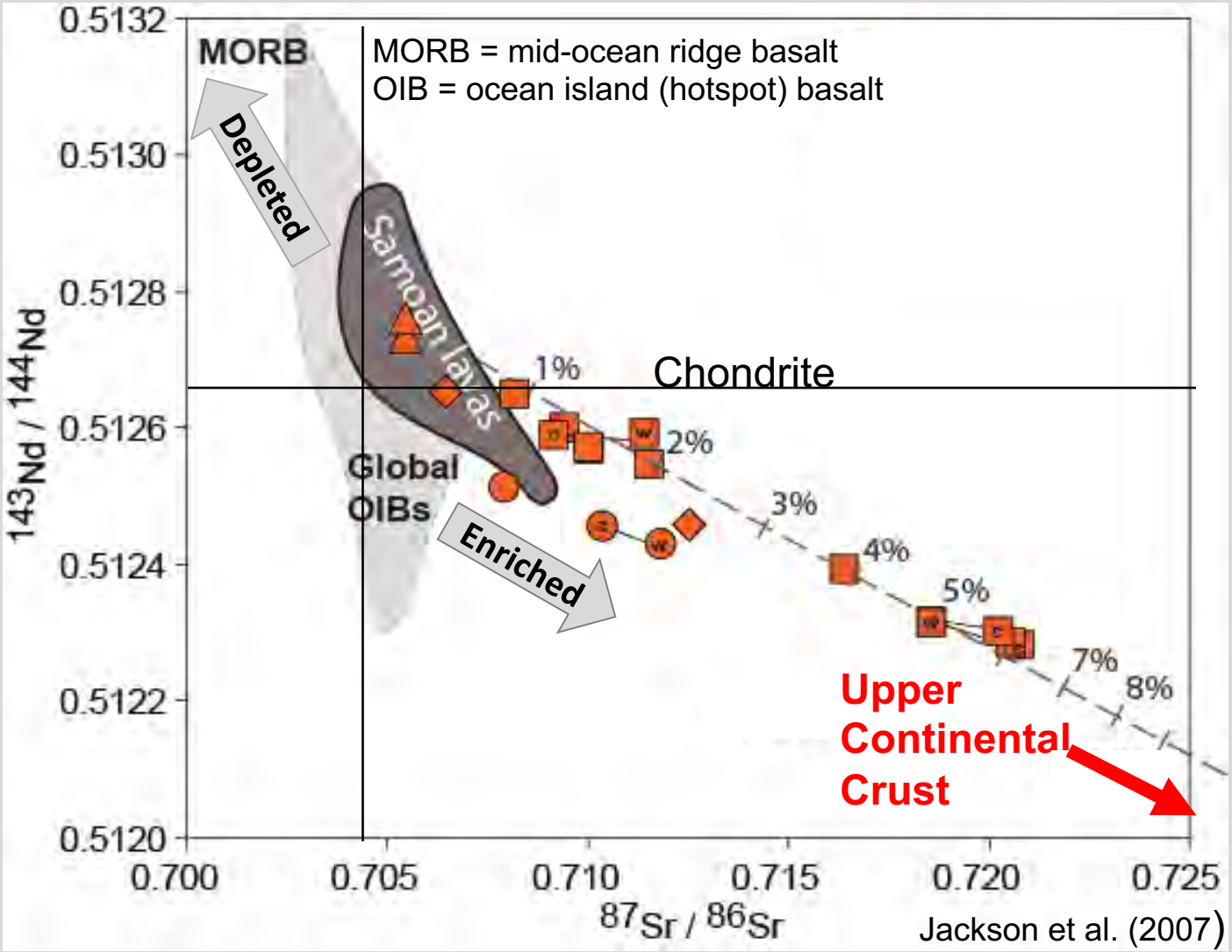


Brandenburg et al. (EPSL 2008)

3. **When** did various geochemical reservoirs form in the chaotically-convecting mantle? *4.56 Ga? 2.5 Ga? 0.65 Ga?*

4. **Where** are the different geochemical domains located in the mantle?

Origin of EM2: Tracing continental crust cycling through the mantle



Jackson et al. (2007)

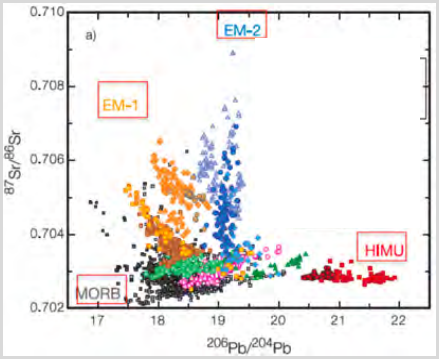
Samoa (2005)

Sigsbee (1880)

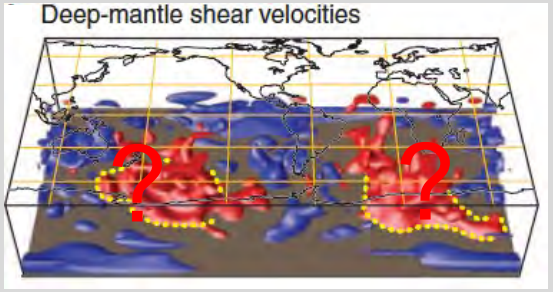
Many mantle "species" resulting from recycling oceanic and continental crust… But ***where*** are they?

- **The analogy of the zookeepers**

Geochemical "zookeepers" know which "animals" are in the mantle zoo, but they don't know where the cages are.



Seismological "zookeepers" know where the "cages" are, but they don't know which animals are in the cages!



Ed Garnero

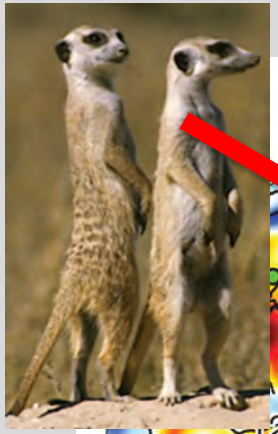
Geoneutrino "zookeepers" wanted! What if the "animals" had high geoneutrino luminosity? Then we could tell where the different animals are!

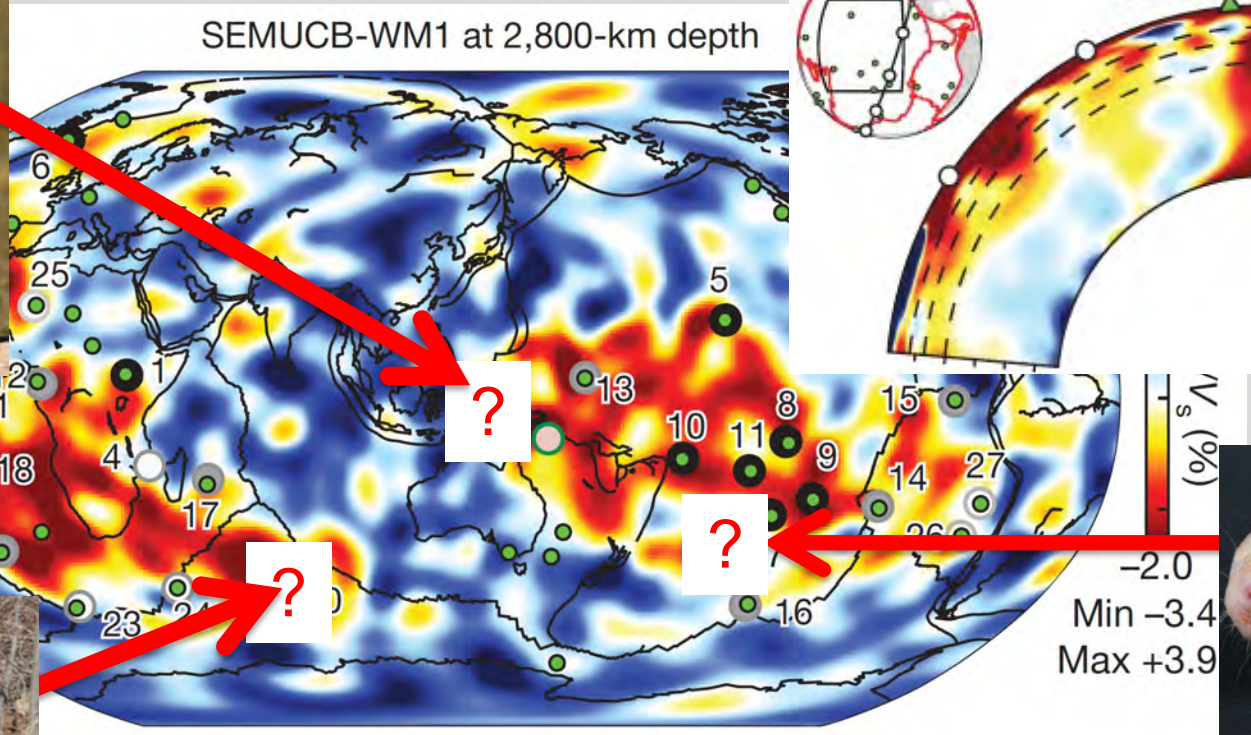
Where is EM? Where is HIMU?

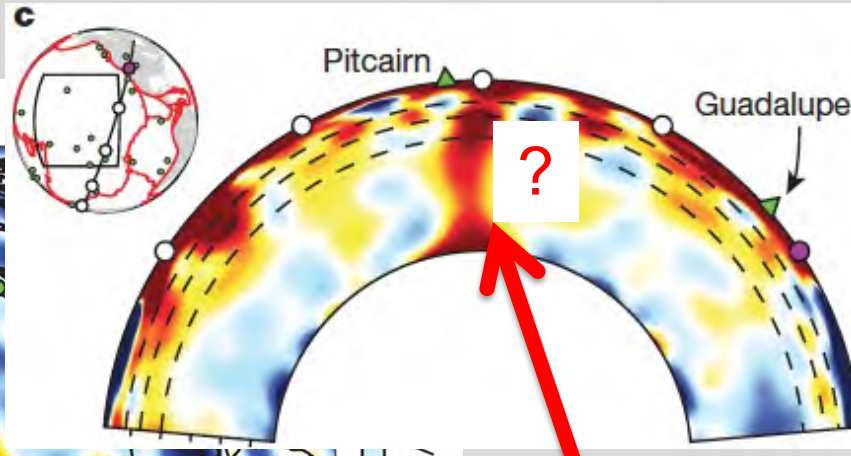
A multi-messenger geophysical approach is needed:

Constraints from seismology and geochemistry are insufficient.

Addition of geoneutrinos will revolutionize deep Earth science!



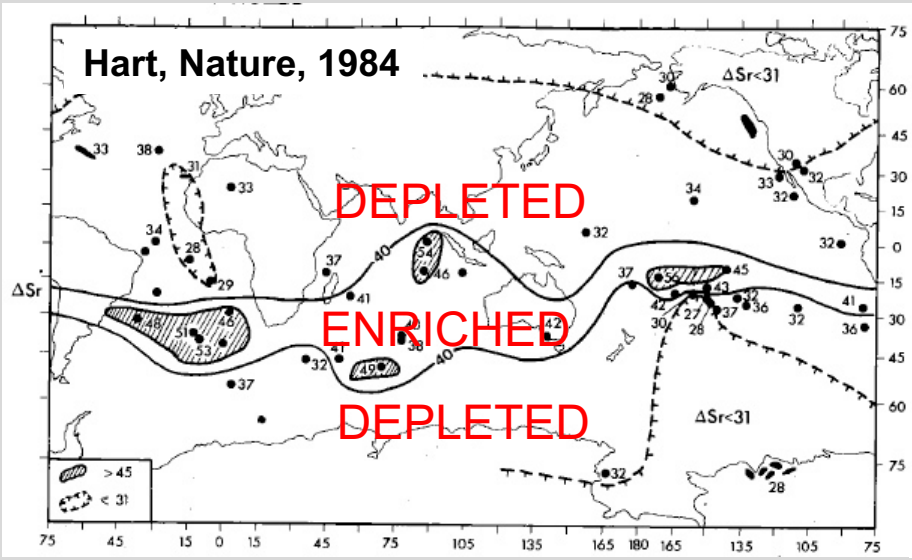




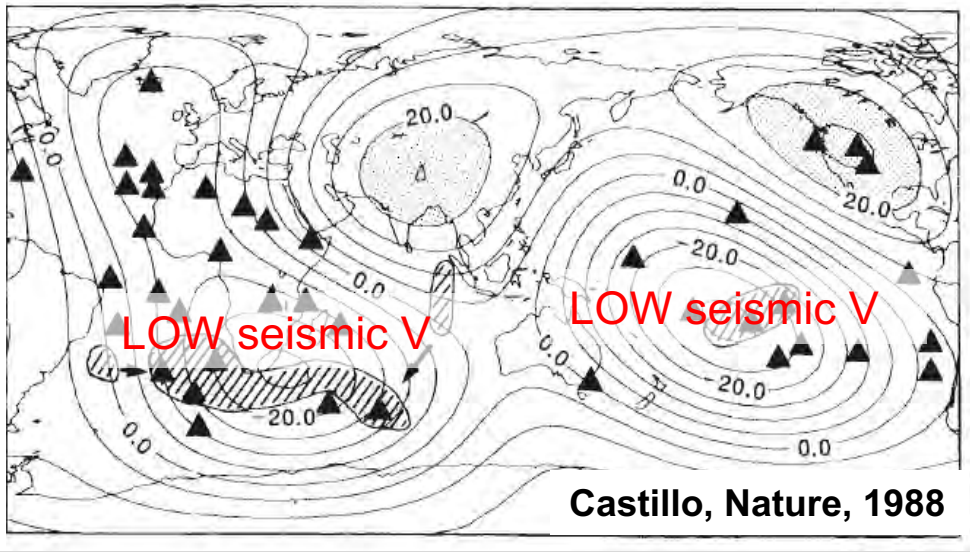
French & Romanowicz, 2015

Two messengers: Connecting hotspot geochemistry with the seismic Large Low Shear Wave Velocity Provinces (LLSVPs)

Geochemical DUPAL anomaly



Geochemical DUPAL vs seismic low velocity anomalies

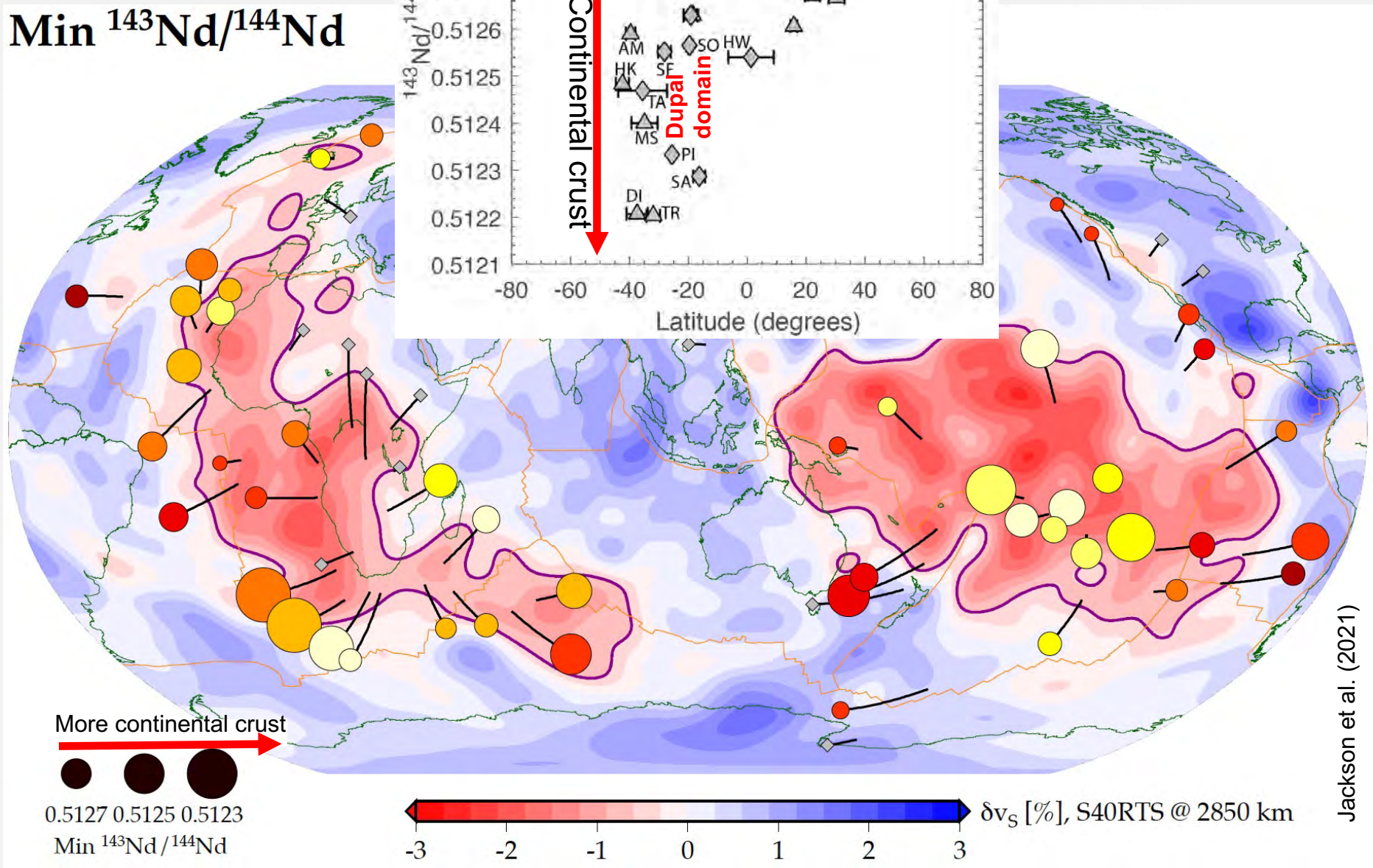


DUPAL = **Dup**ré+**Al**lègre **LLSVP** = **L**arge **L**ow **S**hear-wave **V**elocity **P**rovince

Over the past 30+ years,
global seismic velocity models and
geochemical databases have improved dramatically.

Comparing geochemistry and seismology: lava with lowest $^{143}Nd/^{144}Nd$ shown for 46 oceanic hotspots.

Continental $^{143}Nd/^{144}Nd$ associated with <u>southern regions</u> of LLSVPs.



Low $^{143}Nd/^{144}Nd$ in austral hotspots means continental crust subduction focused in austral hemisphere

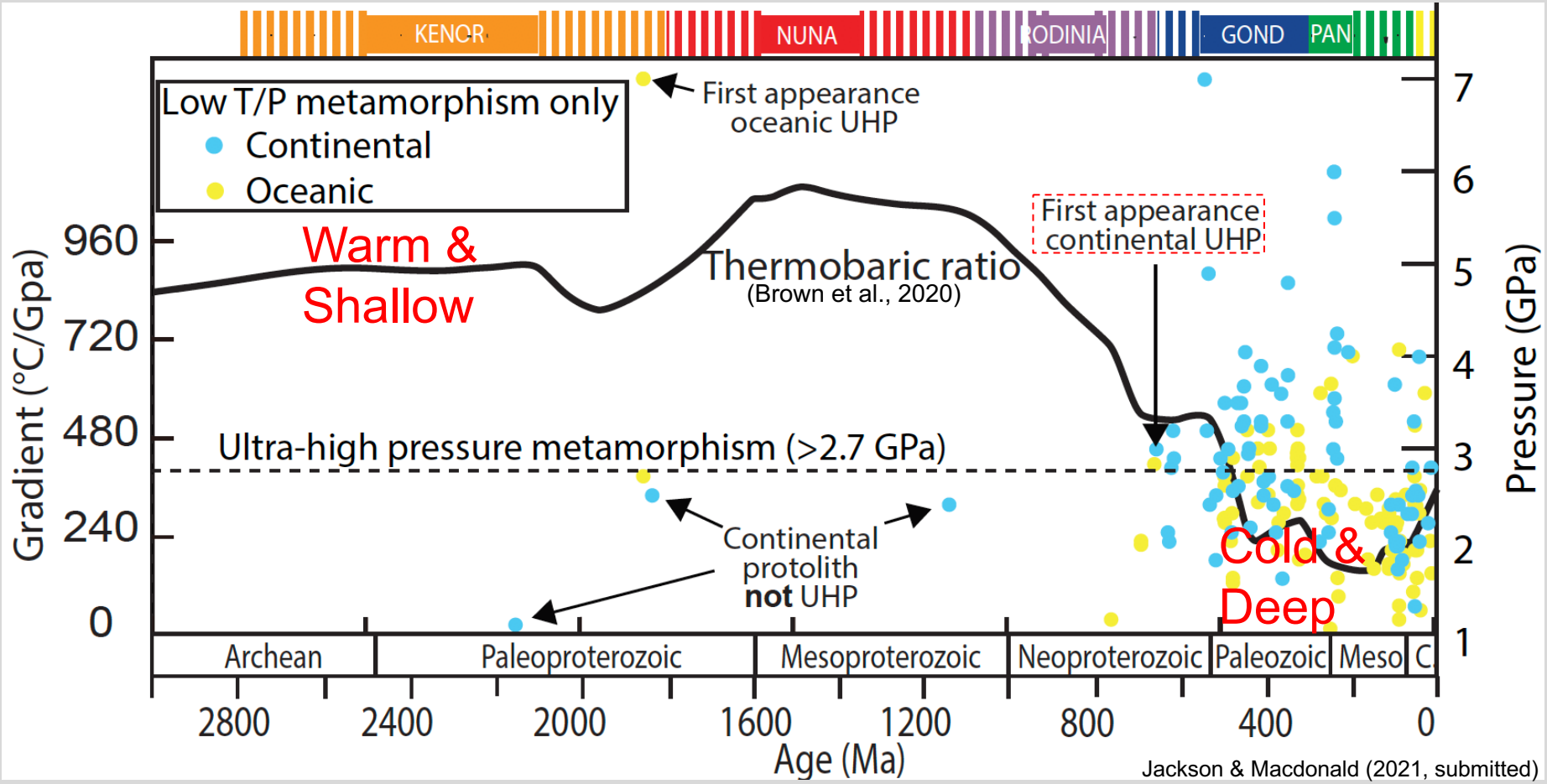
Hypothesis: Gondwana assembly (ca. **650-300 Ma**) from continental collisions in southern hemisphere resulted in continental subduction into austral mantle.

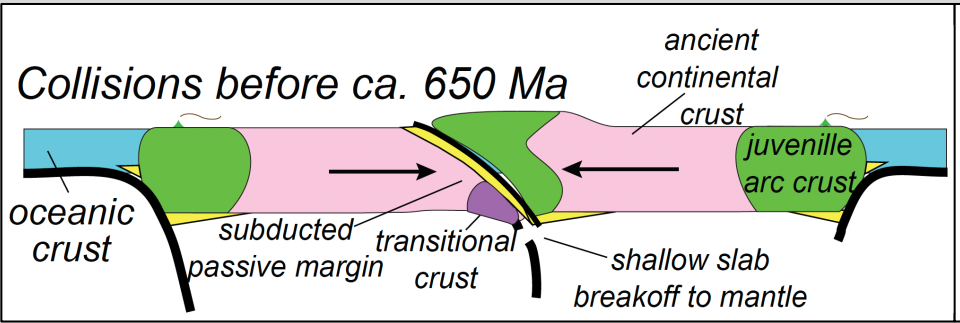
Jackson & Macdonald, 2021 (submitted)

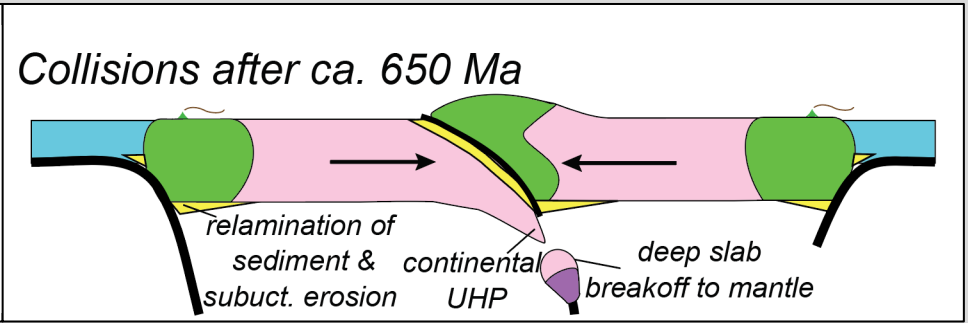
Problem: During the Precambrian, continental assembly and subduction occurred at all latitudes, so we might expect to see continental crust signatures in hotspots at all latitudes.

Solution? A mechanism is needed in which deep continental crust subduction ”turned on” when Gondwana started to assemble in the southern hemisphere.

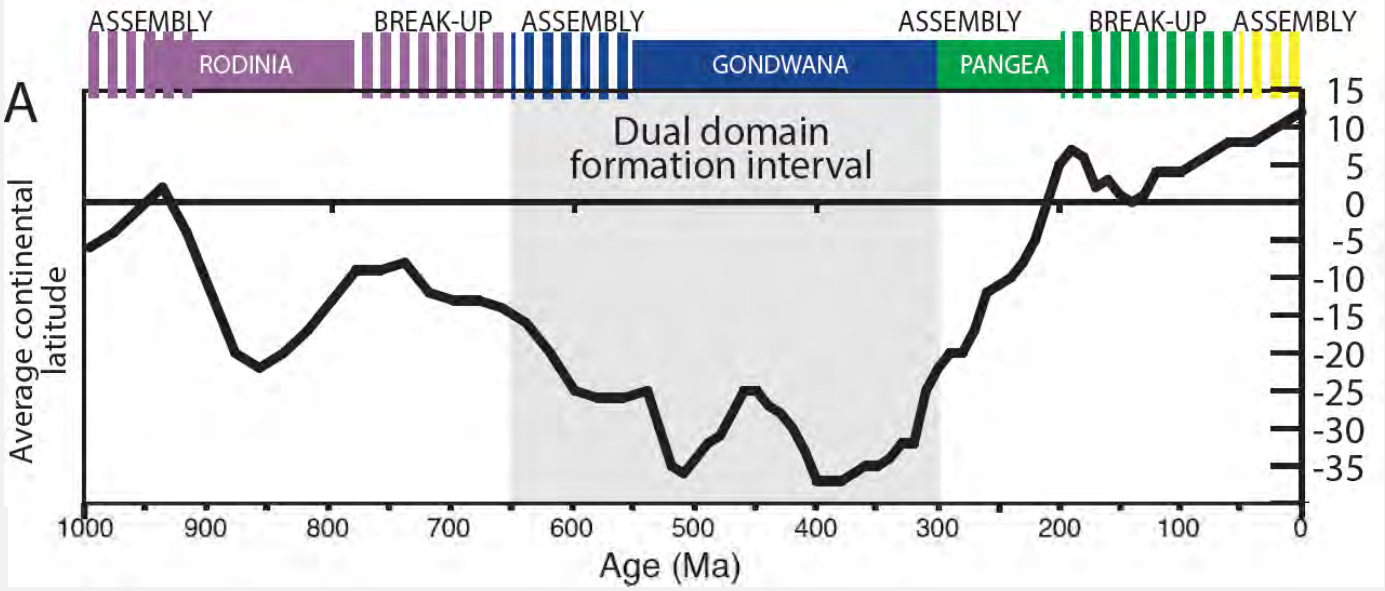
First observed *continental* ultrahigh pressure at ~650 Ma: Onset of deep slab breakoff and deep continental subduction?





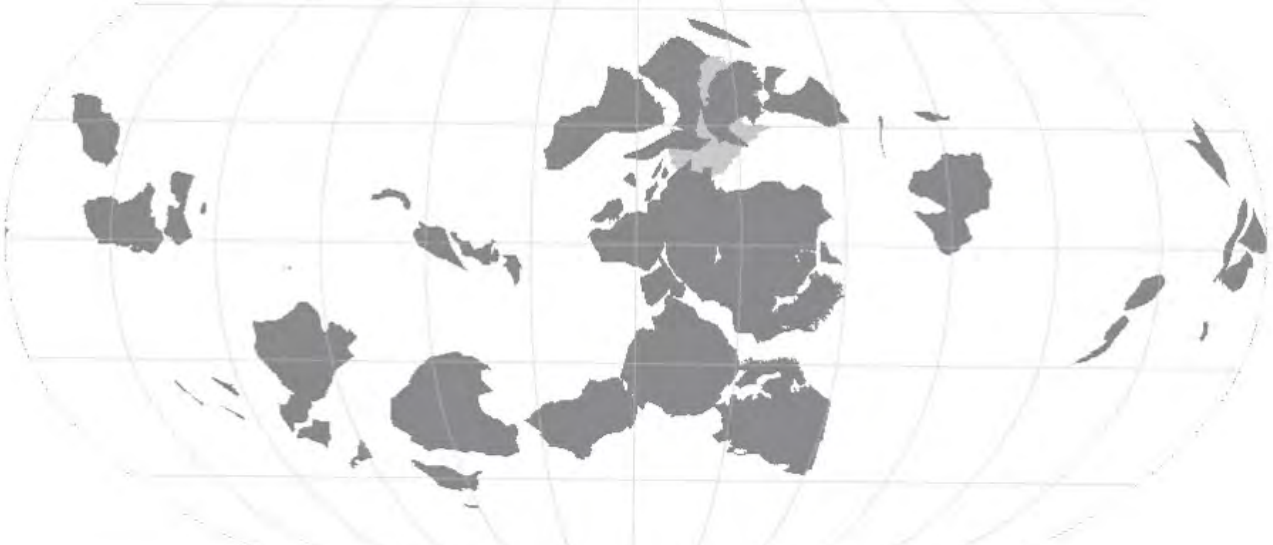


Two ingredients needed to explain Dupal formation:
Timing and latitude of continental crust subduction



1,000.00 Ma

Continents focused in Southern Hemisphere from 650-300 Ma

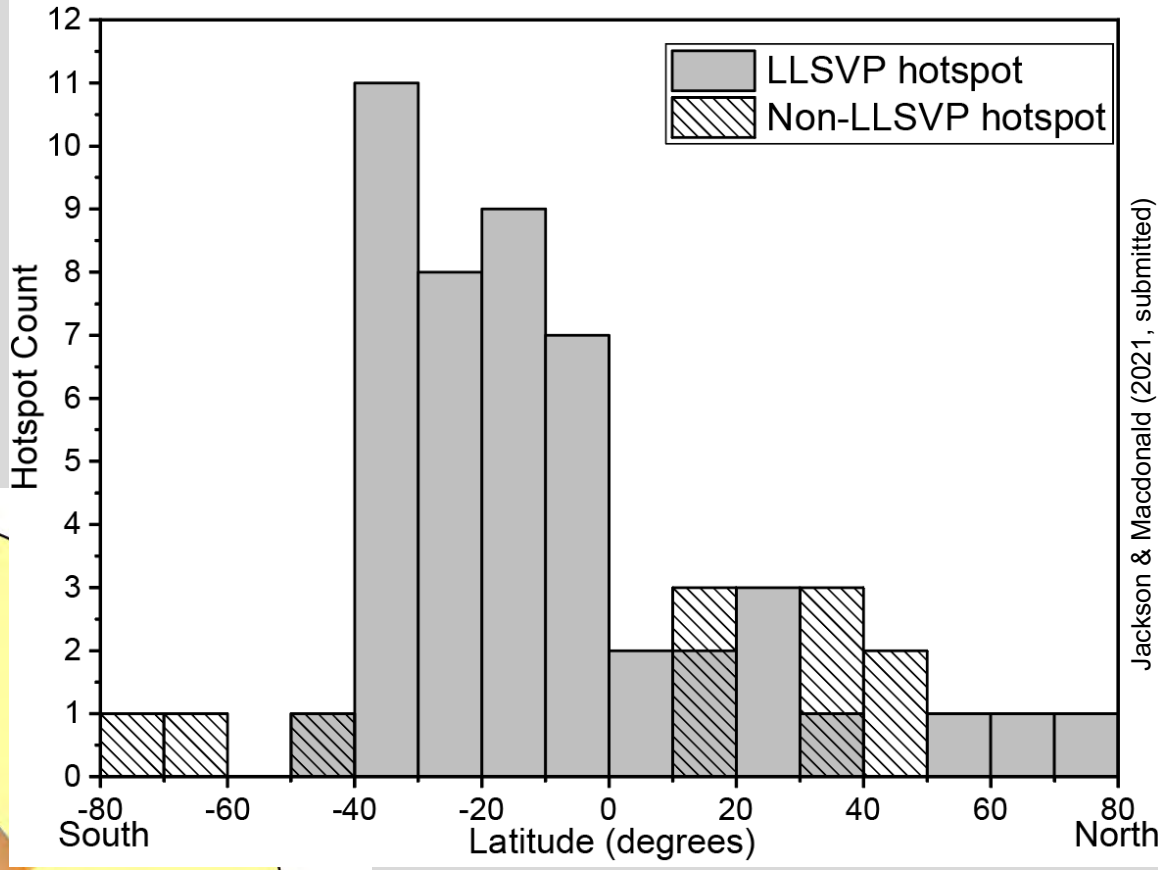


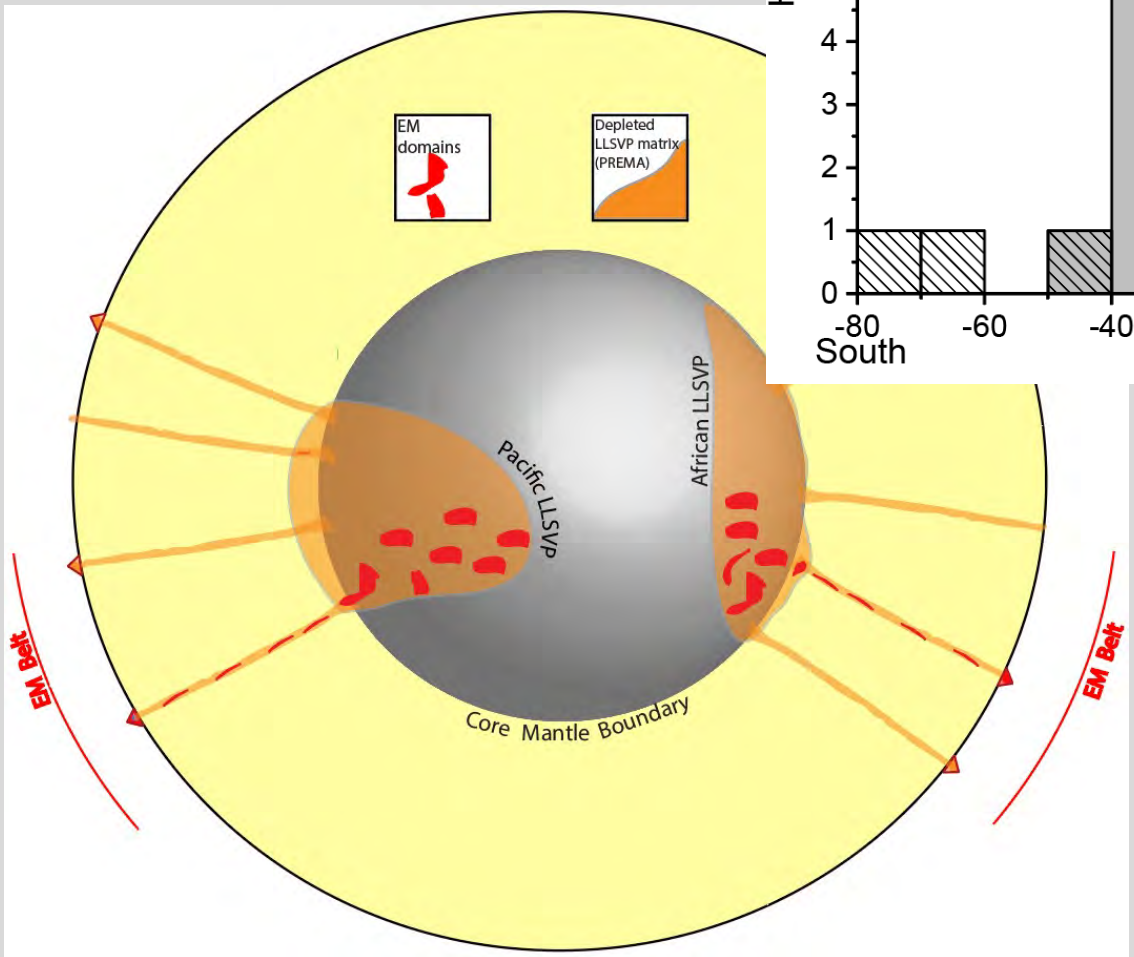
Reconstruction based on Merdith et al. (*Earth Sci. Rev.*, 2020).

But, what about continental crust subducted from 300 Ma to the present?

It takes ~200 Ma for subducted crust to reach the core-mantle boundary, and then another 100 Ma for a plume to rise.

Geodynamic consequence of continental crust in the southern hemisphere mantle:
More austral radiogenic heating and, thus, more austral plumes!





The radiogenic power balances:

→Radiogenic power carried by all mantle plumes is ≥2 TW.

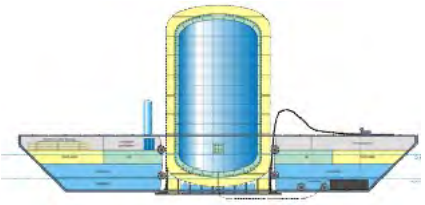
→2 TW generated by a subducted mass of continental crust equivalent to ~1/3 of the mass of modern continents.

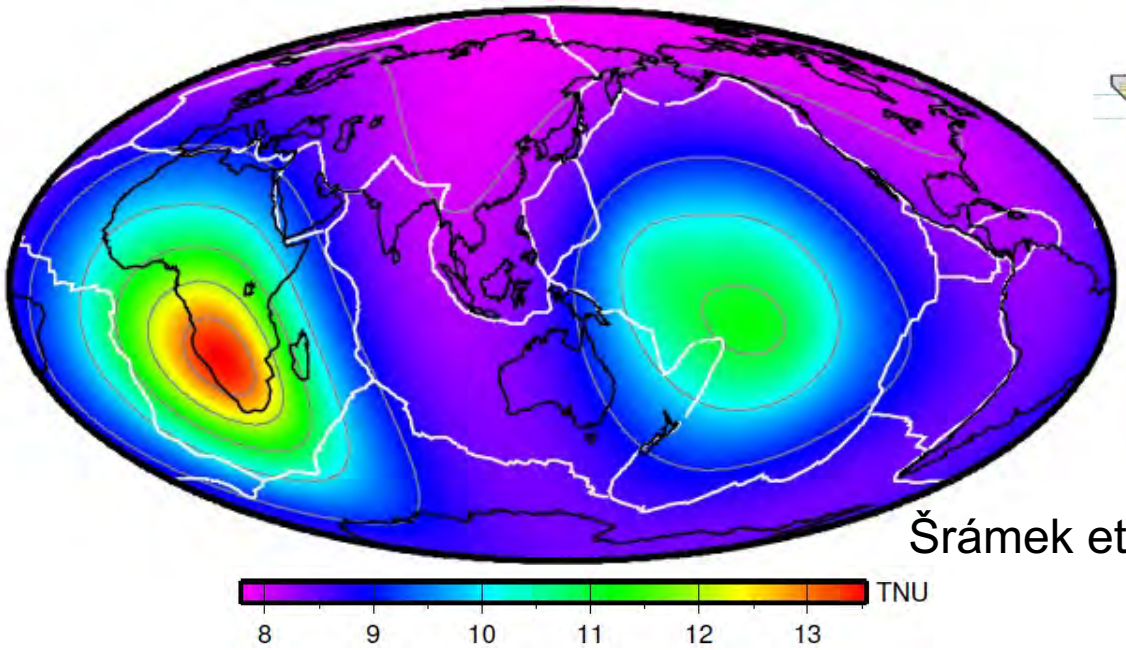
Continental crust in the deep southern hemisphere mantle?

Multi-messenger geophysics—seismology, geochemistry, geoneutrinos—makes this a testable hypothesis.

→The continental crust has nearly 2 orders of magnitude higher U & Th concentrations than ambient mantle; continents host 1/3 of U & Th in the Earth.
→The southern hemisphere regions of LLSVPs are host to continental crust, perhaps 1/3 of mass of continental crust at the surface.

Hypothesis: *The southern hemisphere regions of LLSVPs should have high geoneutrino luminosities.*

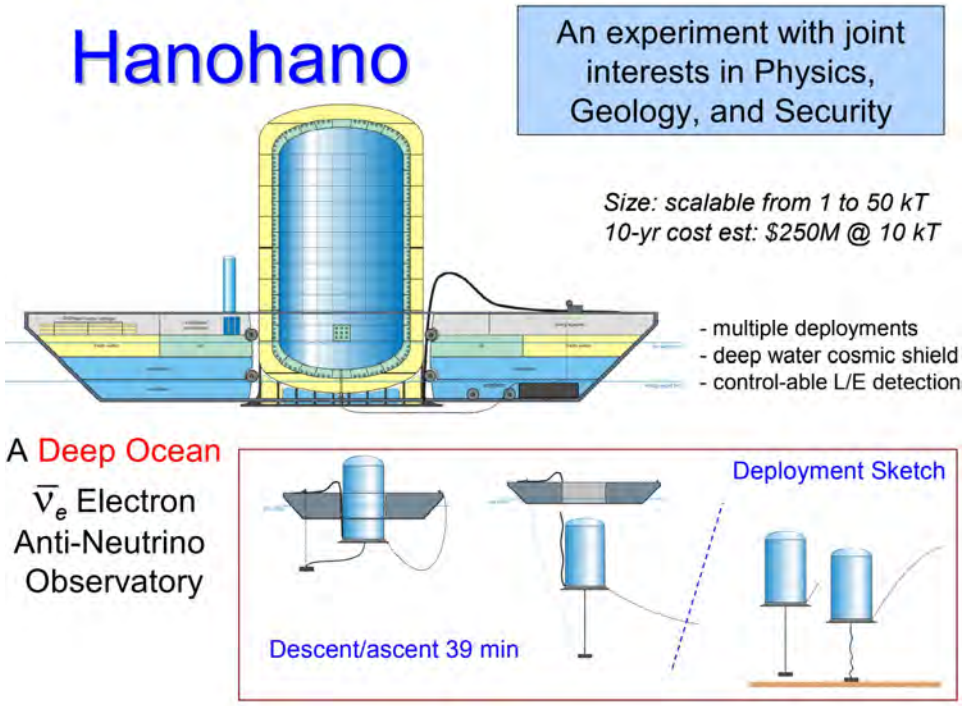




Šrámek et al

Mobile oceanic geoneutrino detector

- **Detector must be in an oceanic setting.** If in continental setting, then geoneutrino signal from deeply subducted crust will be obscured by shallow crustal geoneutrinos.
- **Detector should be mobile** to be able to "map out" distribution of U and Th rich regions of mantle.



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