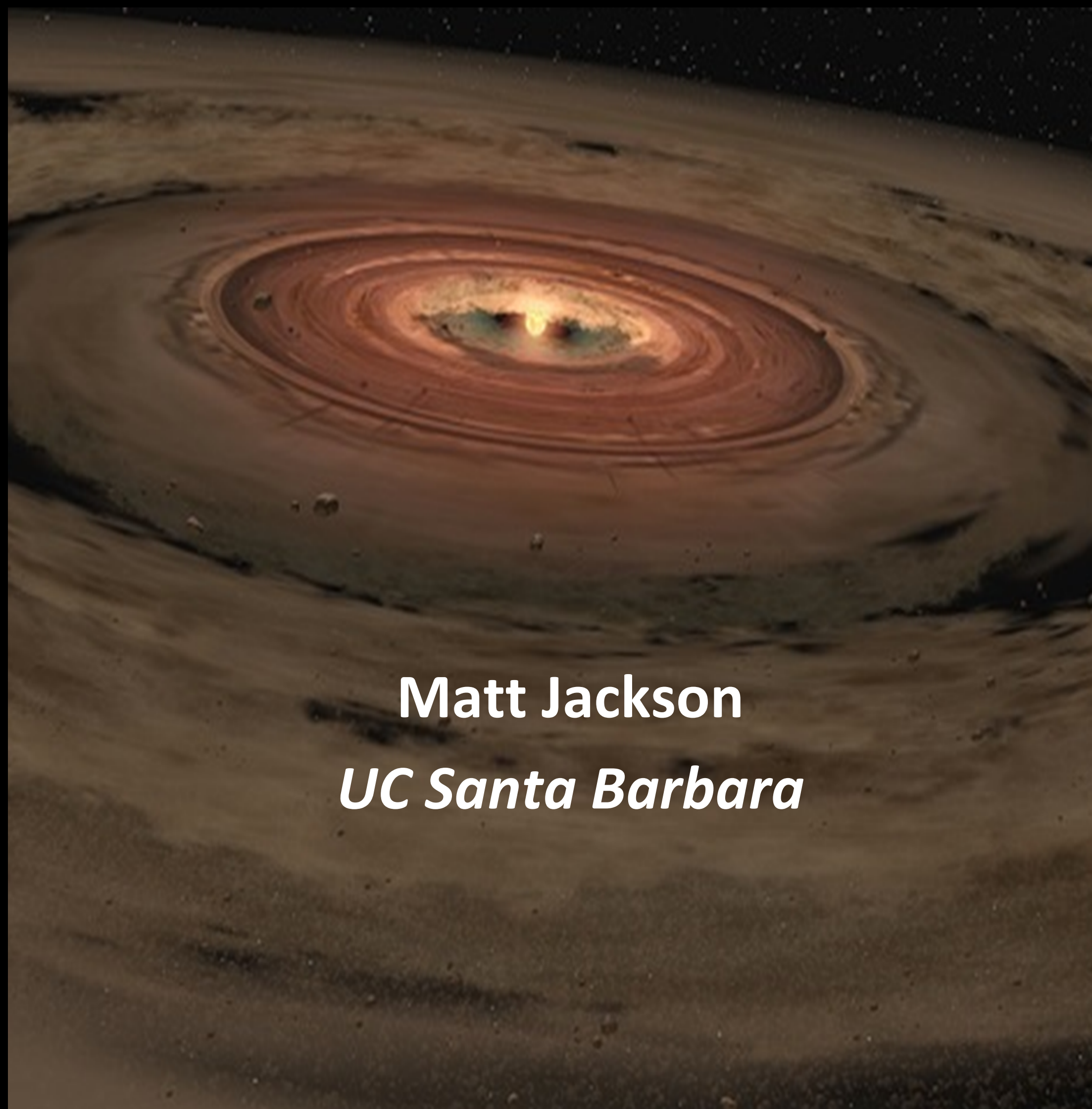
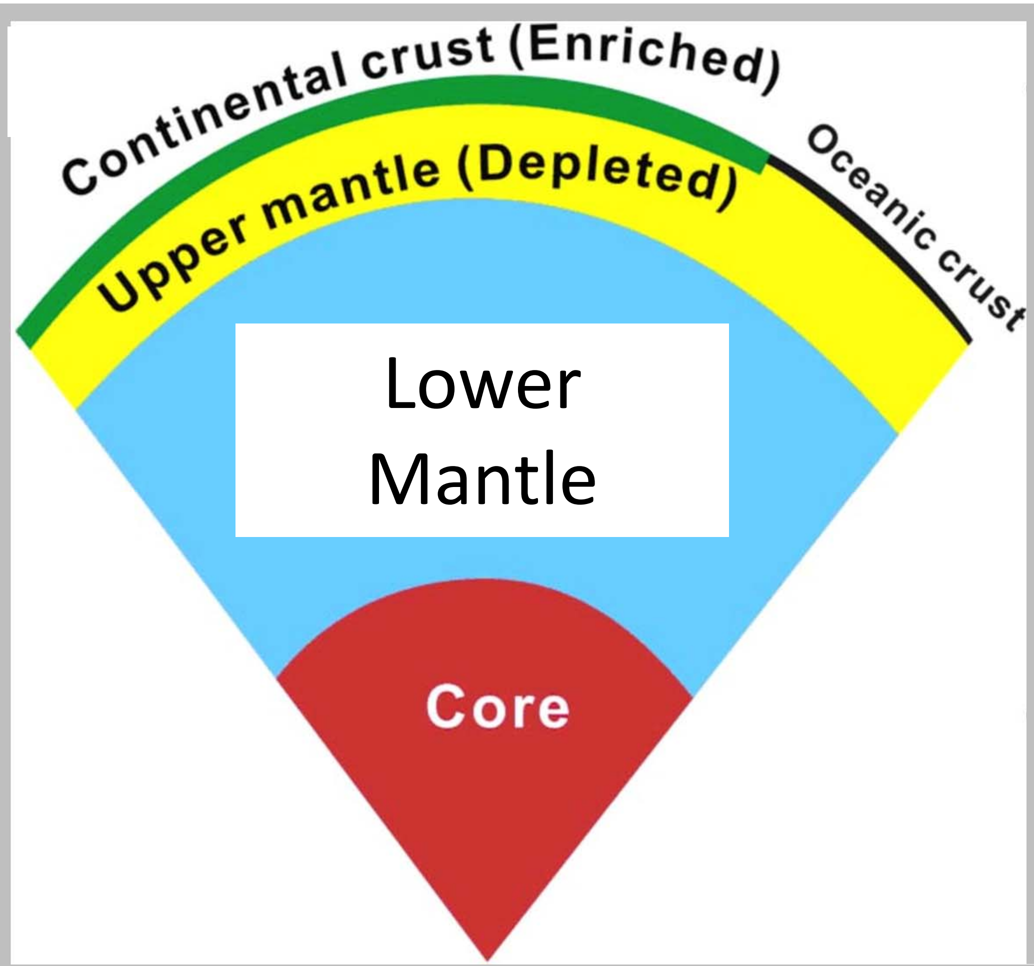
Radiogenic heating and geo-neutrinos from mantle



Courtesy of NASA/JPL-Caltech

Matt Jackson

UC Santa Barbara



--Continental crust extracted from the upper mantle by melting processes.

--The upper mantle is ***depleted*** in elements (like U, Th and K) that prefer to be in the melt relative to the solid mantle.

--Heat budget of the planet is **47 terawatts**:

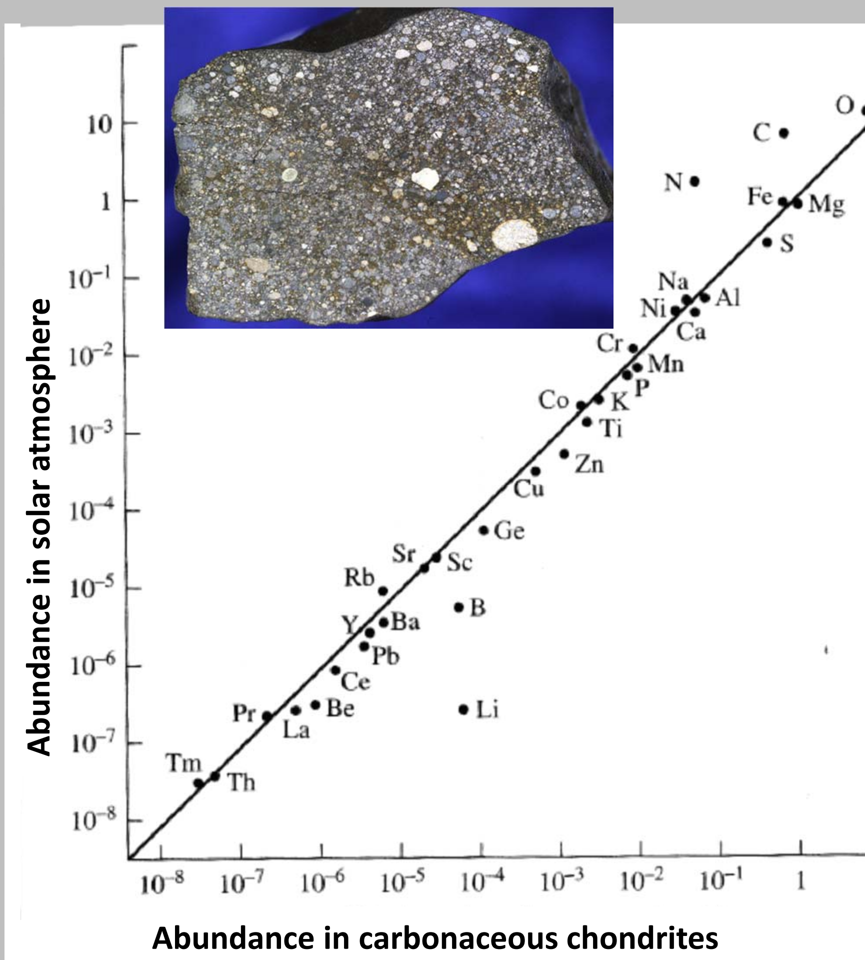
a.) 20 TW radioactive: 7 TW from crust + <u>13 TW from mantle</u>

b.) 27 TW primordial

God’s mortar and pestle

- We don’t know the composition of the Earth because the planet is so heterogeneous: Crust (continental & oceanic), mantle (upper and lower), core
- We need a **proxy** for the bulk composition of the Earth
- Such a proxy for the bulk Earth must be easily obtained and its constituent elemental abundances easily measured (the sun, clearly, is not a candidate!).
- Proxy = Carbonaceous chondrites

Starting composition of the Earth—Chondritic?



Comparison of solar-system abundances (relative to silicon) determined by solar spectroscopy and by analysis of carbonaceous chondrites (after Ringwood, 1979)

1.) Carbonaceous (C) chondrites ≈ Sun (Sun >99.9% of solar system's mass)

2.) C-chondrites and Earth came from the solar nebula.

3.) C-chondrites≈Earth (**for ratios of the non-volatile, lithophile elements, e.g. Sm,Nd**)

4.) $^{147}Sm \rightarrow {}^{143}Nd + {}^{4}He$ ($t_{1/2}$=106 **Gyr**)
$^{146}Sm \rightarrow {}^{142}Nd + {}^{4}He$ ($t_{1/2}$=68 **Myr**)

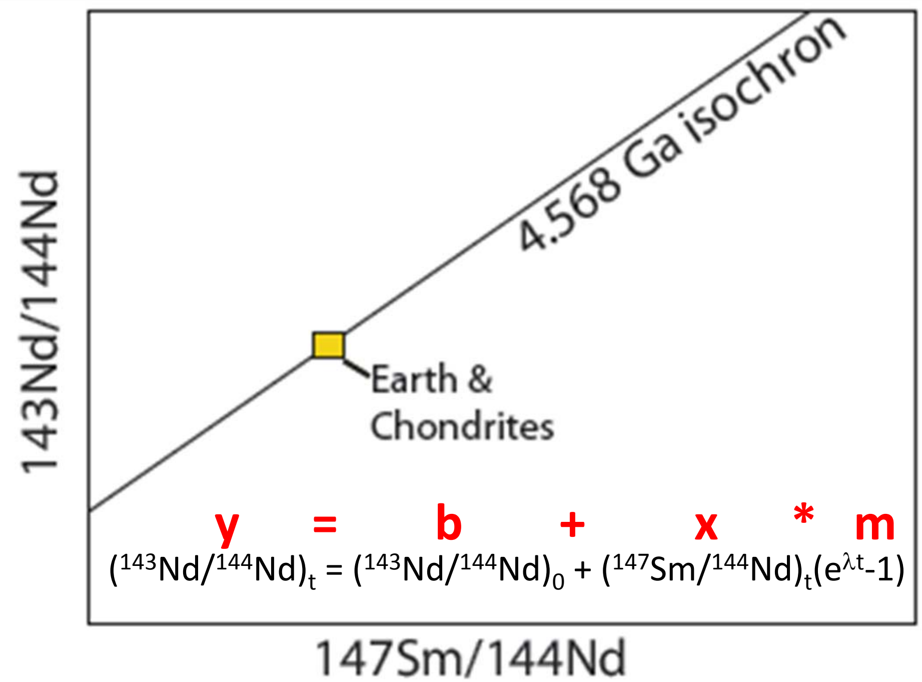
5.) If the Earth is a C-chondrite, then Earth and chondrites have the same Sm/Nd & $^{143}Nd/^{144}Nd$ & $^{142}Nd/^{144}Nd$.

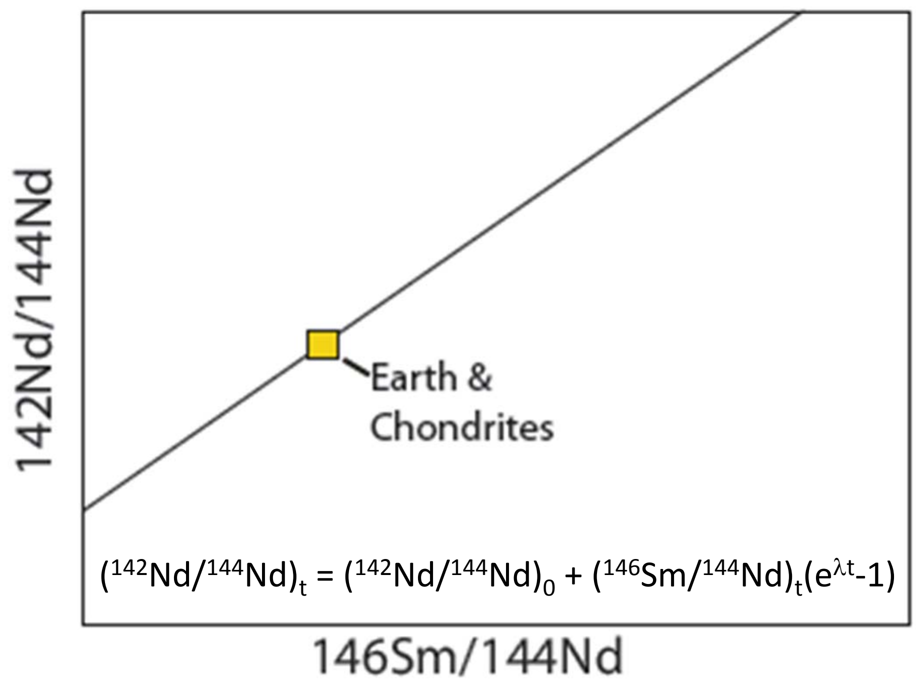
Standard Model (Earth is 'Chondritic')

$^{147}Sm \rightarrow {}^{143}Nd + {}^{4}He$ ($t_{1/2}$=106 Ga)

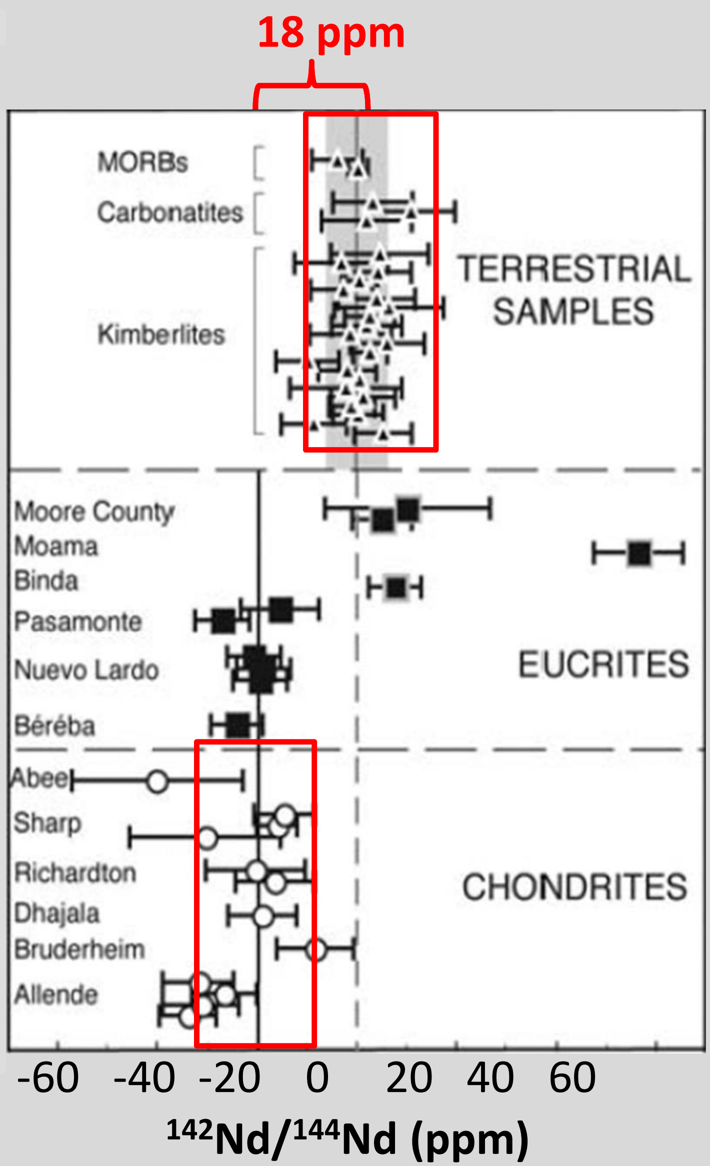
Isochrons 101:

1. Earth and chondrites should have the same Sm/Nd.
2. Earth and chondrites started with the same $^{142}Nd/^{144}Nd$ and $^{143}Nd/^{144}Nd$.
3. Therefore, Earth and chondrites should have the same present-day $^{143}Nd/^{144}Nd$ and $^{142}Nd/^{144}Nd$.
4. But $^{142}Nd/^{144}Nd$ not the same!





Implications from Neodymium-142



(Boyet and Carlson, Science, 2005)

- **Discovery:** ^{142}Nd/^{144}Nd ratios in accessible modern terrestrial lavas are 18±5 ppm higher than O chondrites (Boyet & Carlson, '05)

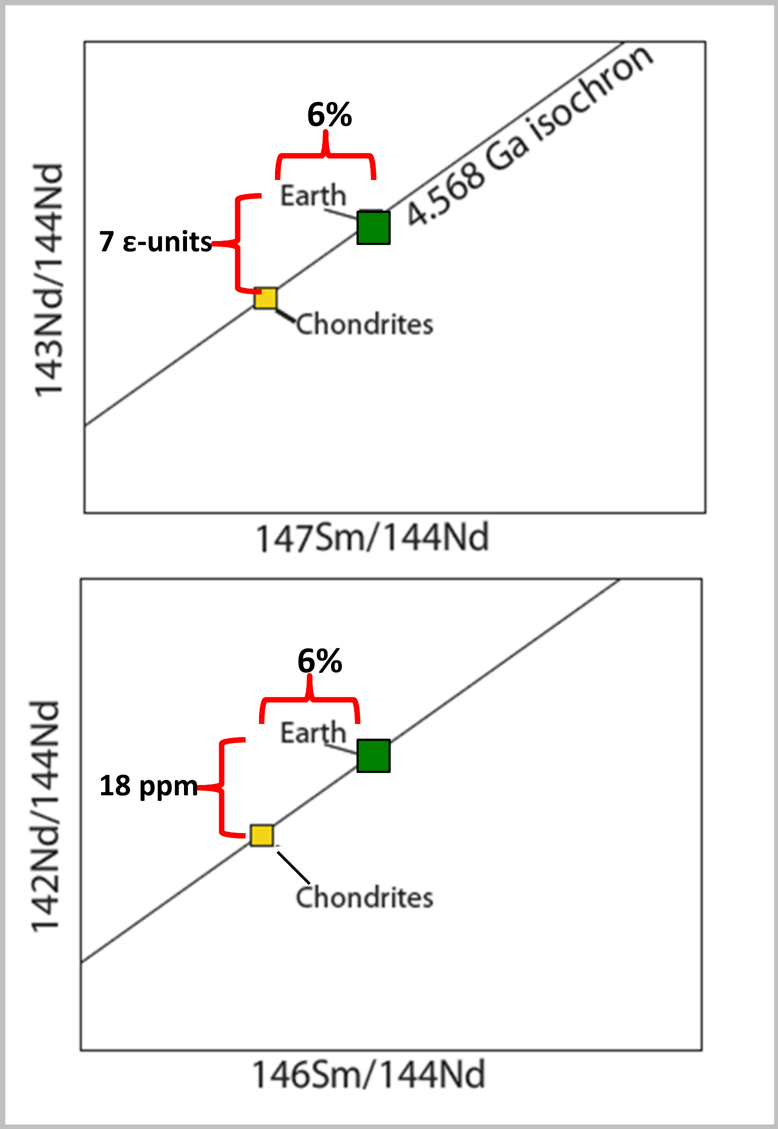
- **There are two interpretations of the new data:**

1. **^{142}Nd variation due to incomplete mixing of nucleosynthetic products.** ^{142}Nd variation has nothing to due with ^{146}Sm decay. Earth has chondritic *Sm/Nd and ^{143}Nd/^{144}Nd*.

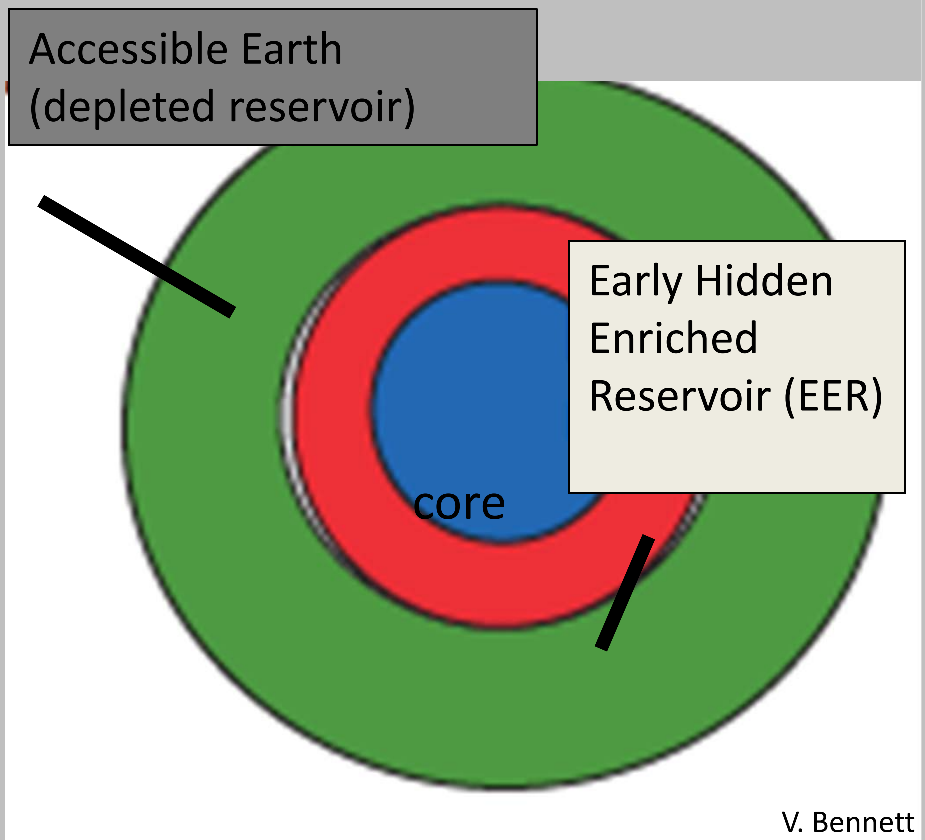
OR….

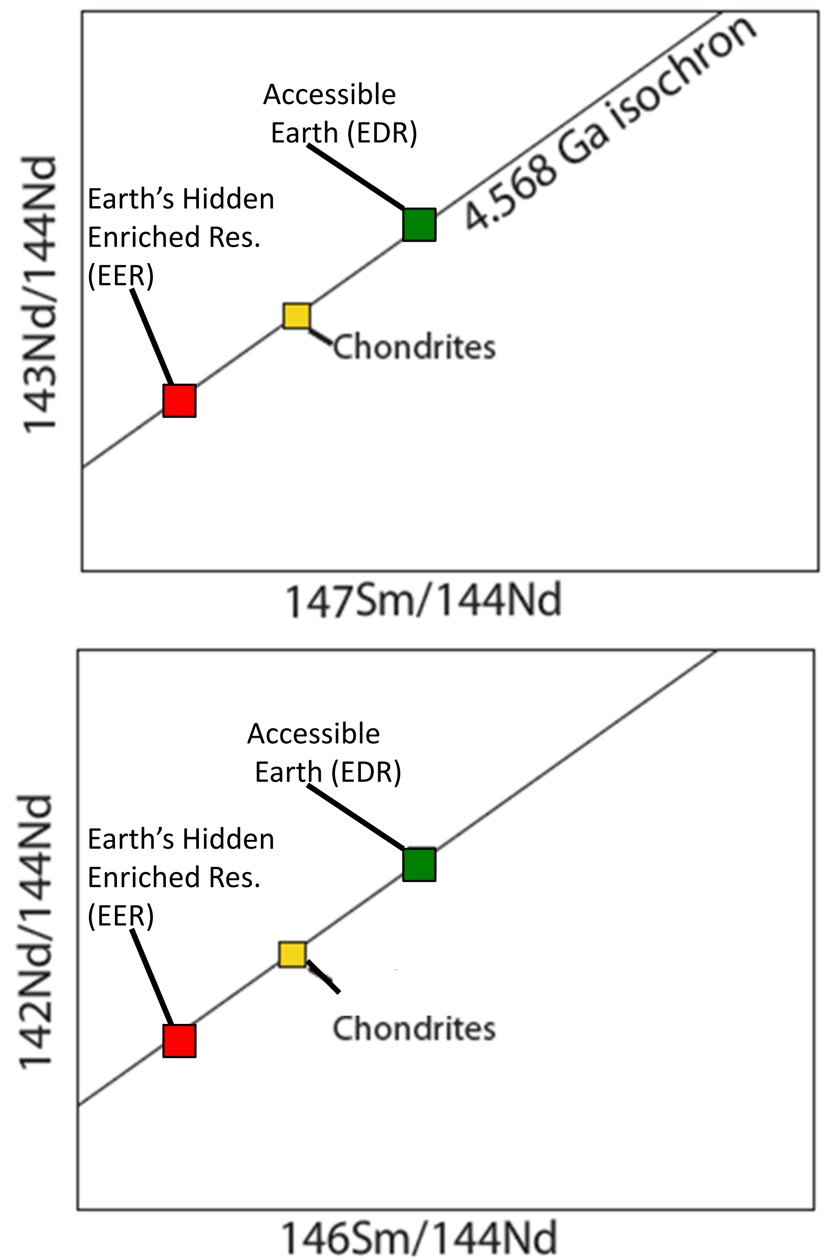
2. **^{142}Nd variation due to ^{146}Sm decay.** Accessible terrestrial mantle evolved from a reservoir with Sm/Nd ~6% higher than chondrites, resulting in *higher ^{143}Nd/^{144}Nd*!

What does $^{142}Nd/^{144}Nd$ discovery mean for $^{143}Nd/^{144}Nd$?



Dealing with the "fallout" from ^{142}Nd…. How to preserve the chondrite model?





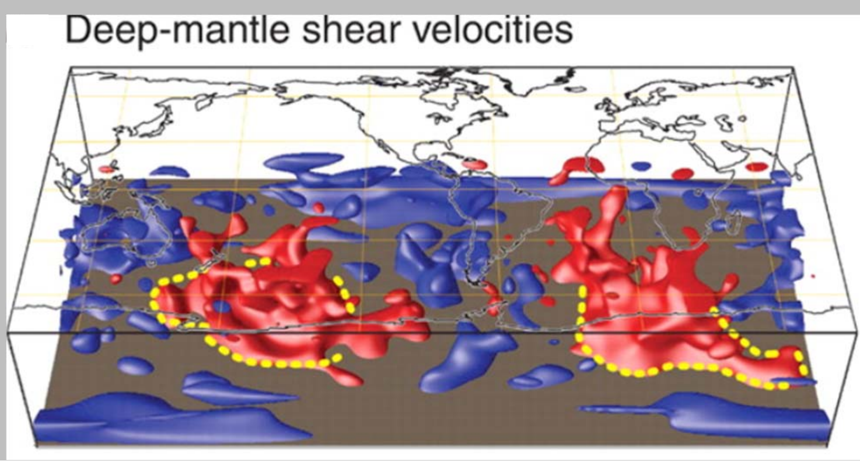
Hidden Enriched Reservoir: Has 30-48% of the budget of the planet's radioactive (heat-producing) elements

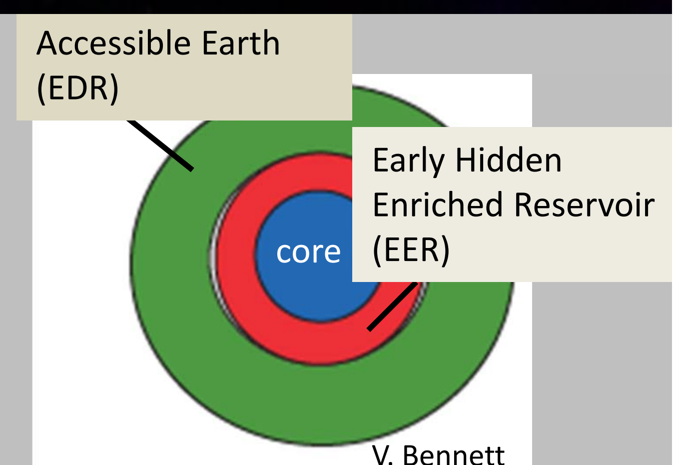
Survival of a “hidden” early enriched reservoir?

Hidden reservoir paradox #1:

A hidden reservoir is constrained (from ^{146}Sm-^{142}Nd and ^{182}W-^{182}Hf systematics) to have formed before the moon-forming giant impact.

How would a “hidden” reservoir remain *completely* hidden at the bottom of the mantle during a giant impact event?

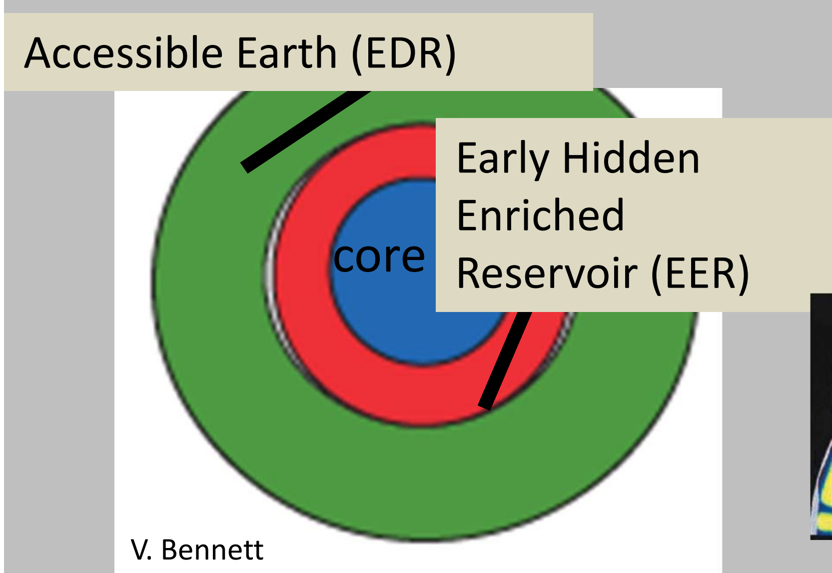


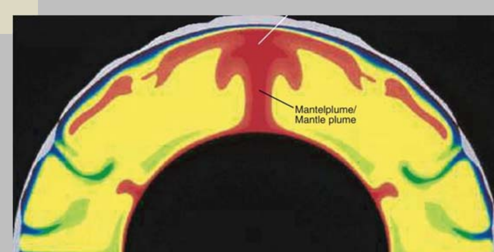


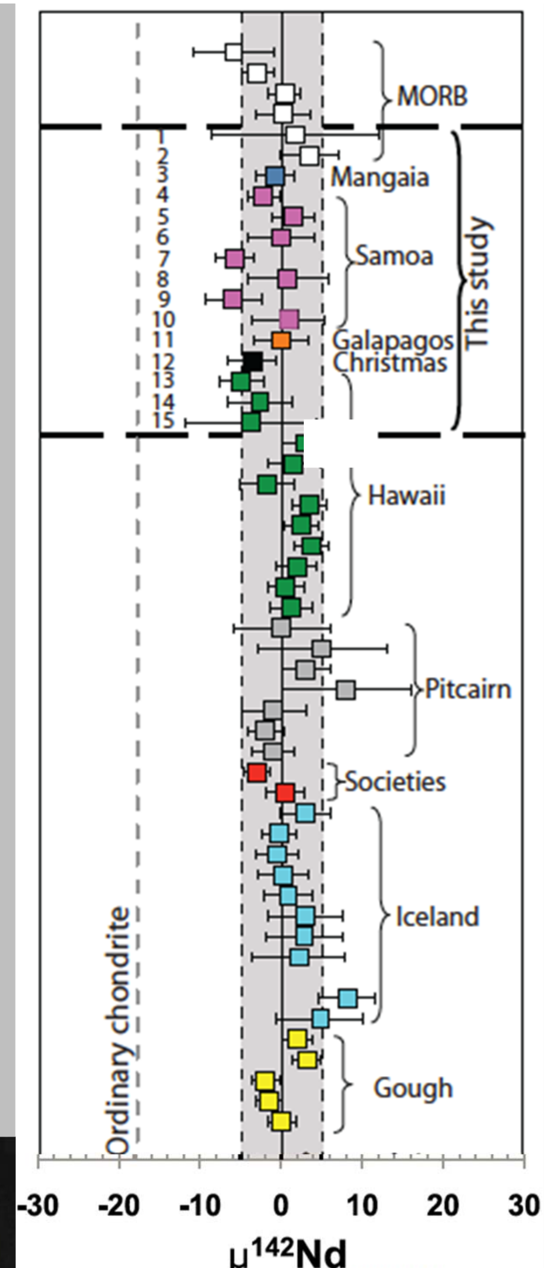
Paradox #2: How to keep a hidden <u>enriched</u> (U-Th-K) reservoir hidden?

$^{142}Nd/^{144}Nd$ in lavas sampling fed by putative mantle plumes:

There's no direct evidence for a hidden reservoir (with low $^{142}Nd/^{144}Nd$ in the deep mantle







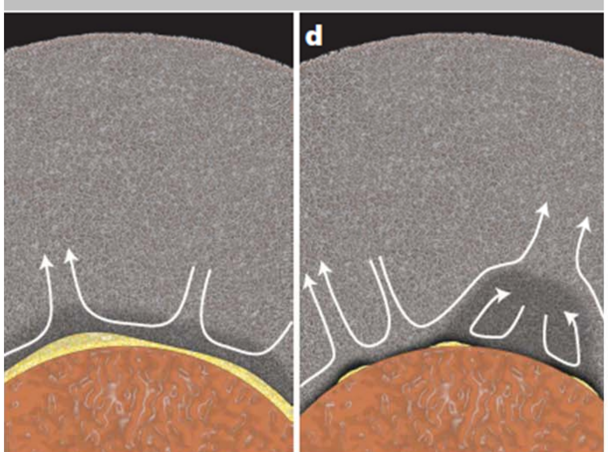
Jackson and Carlson (G-cubed 2012)

Paradox #3: $^{142}Nd/^{144}Nd$ in continental unchanged over 2.5 Ga:
No evidence of hidden enriched reservoir

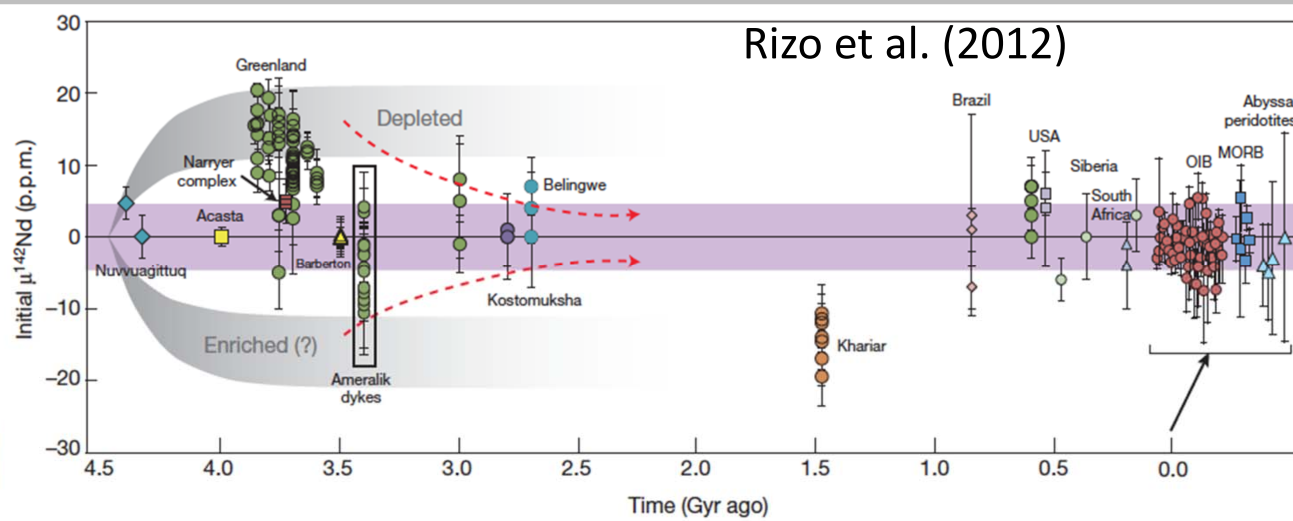
→If the hidden enriched reservoir is in the mantle, it is likely expressed as partially molten regions of the deep mantle called LLSVP's.

→If the enriched reservoir cools and solidifies over Earth history (*Labrosse et al, '07*), it becomes "entrainable", and the $^{142}Nd/^{144}Nd$ of the mantle (and continents) should decrease over time.

→It is possible to keep a deep reservoir hidden if it is molten (high viscosity contrast)…. But if the molten reservoir solidifies, viscosity contrast decreases and entrainment is more likely.



Labrosse et al. (2007)



Rizo et al. (2012)

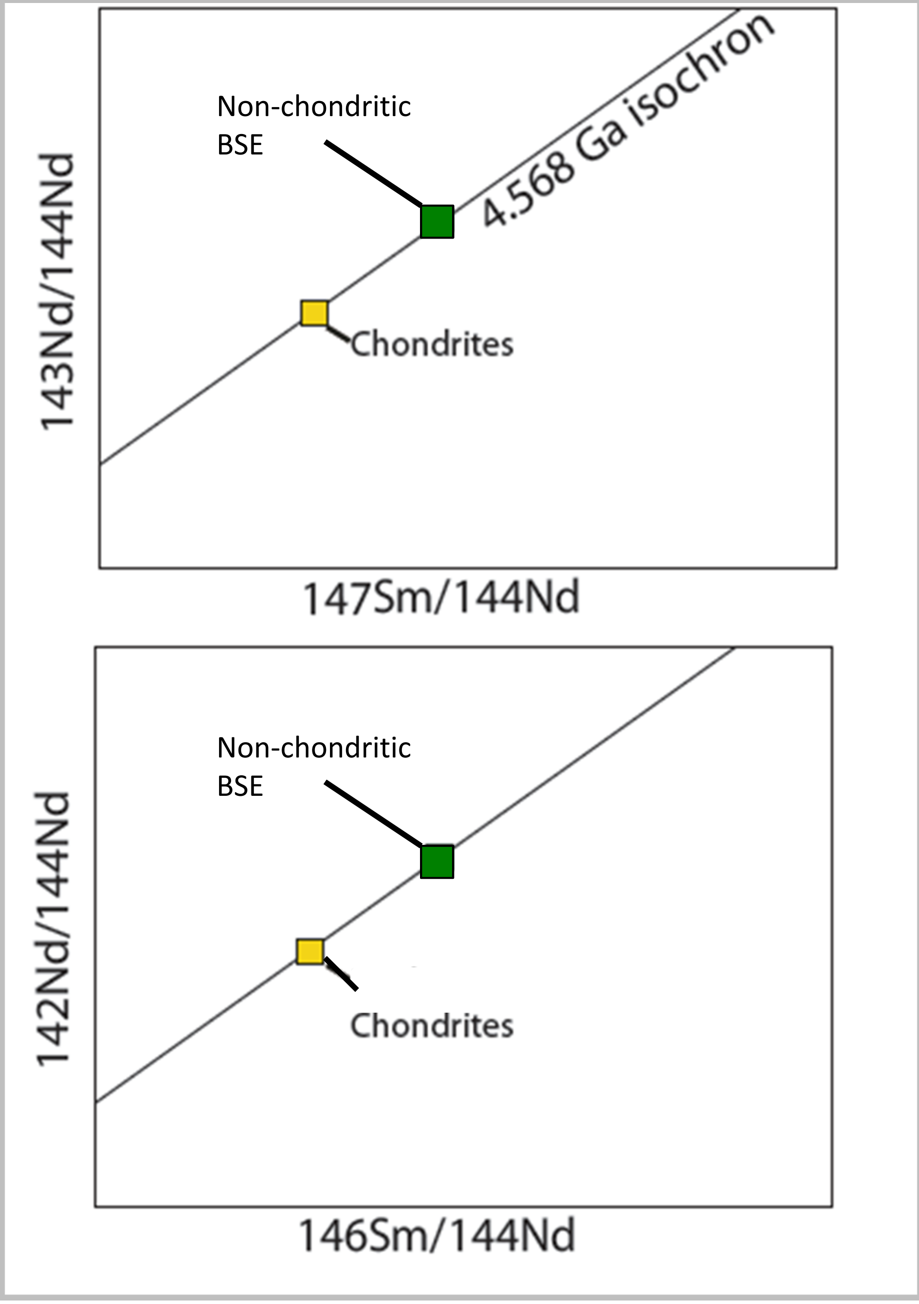
Summary

- It seems unlikely that a hidden enriched reservoir remains hidden in the deep mantle, and has not participated in mantle convection or geochemical evolution of the Earth for 4.5 Ga.

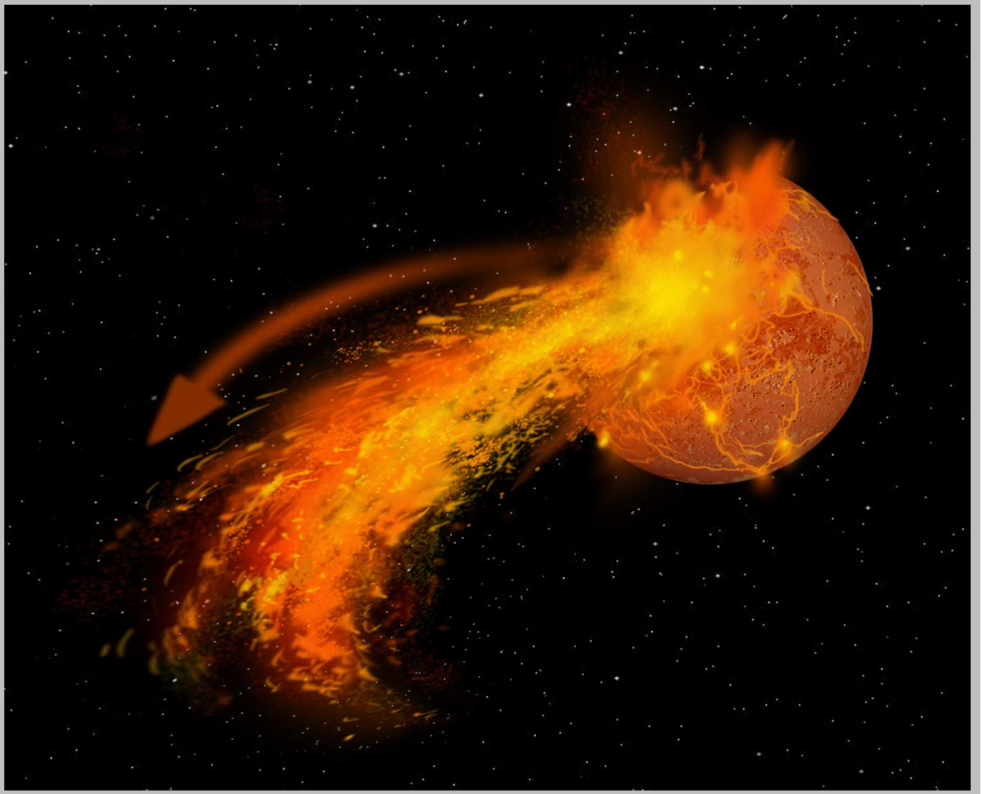
…..but I can't prove the "hidden" reservoir isn't there.

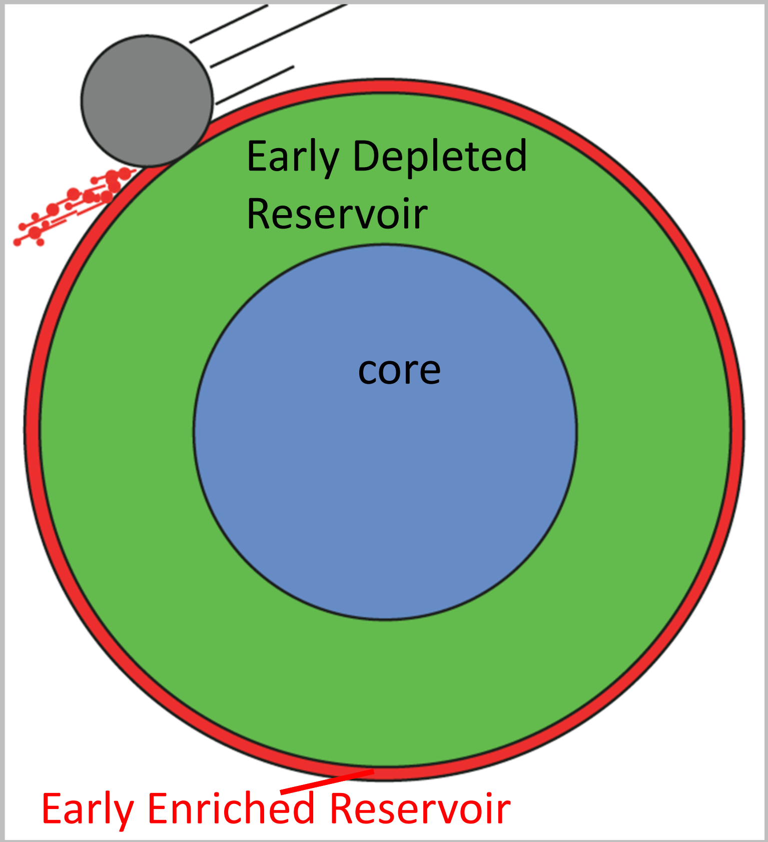
Non-chondritic Earth model

NO HIDDEN RESERVOIR



Impact erosion (and loss to space) of enriched early enriched crustal reservoir





If enriched reservoir was a crust located at the Earth's surface (instead of the bottom of the mantle). "Hit and run" collisions might erode the crust, leaving behind depleted (non-chondritic) mantle (O'Neill and Palme, 2008).

The bulk composition of a planet can evolve as enriched crust and depleted mantle are stripped from the planet in various proportions during giant impact events.

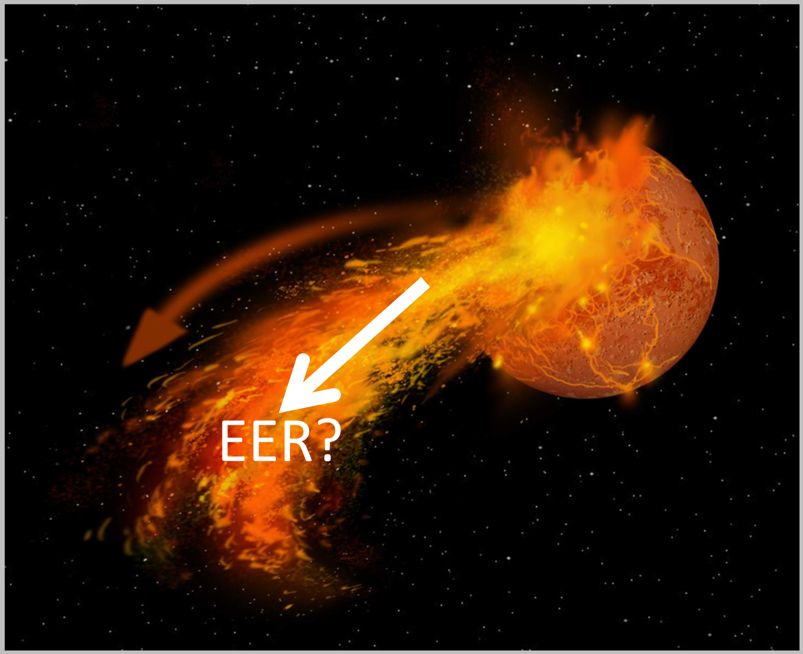
Fundamental question:

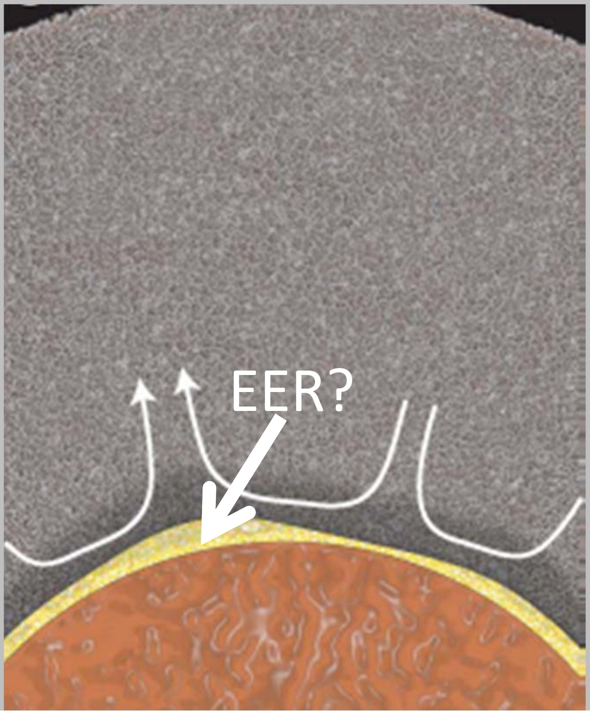
Was the enriched reservoir (with low $^{142}Nd/^{144}Nd$)
1.) hidden at the bottom of the mantle for all of geologic time, or
2.) was it lost to space?

How to detect this enriched reservoir if it is still in the Earth?

→Its U-Th-K budget is similar to the modern continents, and it will generate 6-9.5 TW of radioactive power

(Note: U-Th-K generate 99% of radioactive power in the Earth)





Put 6-9 terawatts (TW) into perspective:
It is 30-45% of radioactive power of planet

- Total surface heat flux from the planet is 47±2 TW.

→If the Earth has a composition tied to carbonaceous chondrites, then the radioactive power of the Earth is 20 TW. The remaining 27 TW is "primordial".

→Of the 20 TW of radioactive power:

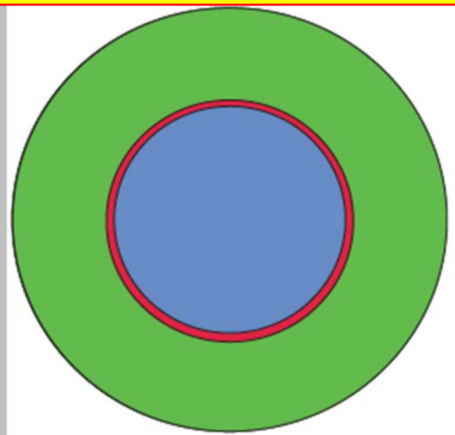
The continents generate: **5.6 to 7.5 TW**

The depleted mantle (if whole mantle): **2.8 to 5.3 TW**

± Hidden enriched reservoir: **6 to 9.5 TW.**

Is the "hidden enriched reservoir" at the bottom of the mantle, or lost to space? 6-9 TW of radioactive power are at stake!

Radioactive power of planet is
20 TW

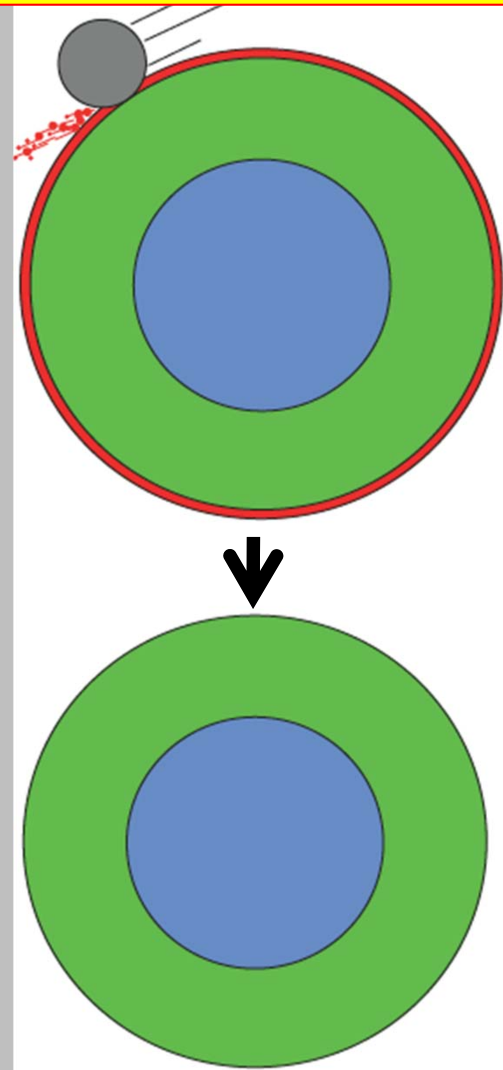


Hidden reservoir at the bottom of the mantle

(30-48% of radioactive power focused at bottom of mantle)

OR

Radioactive power of planet is
10.5-14 TW

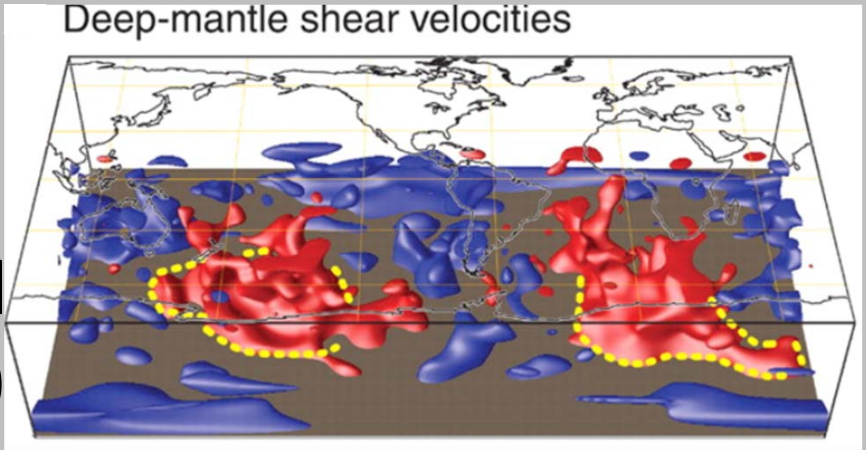


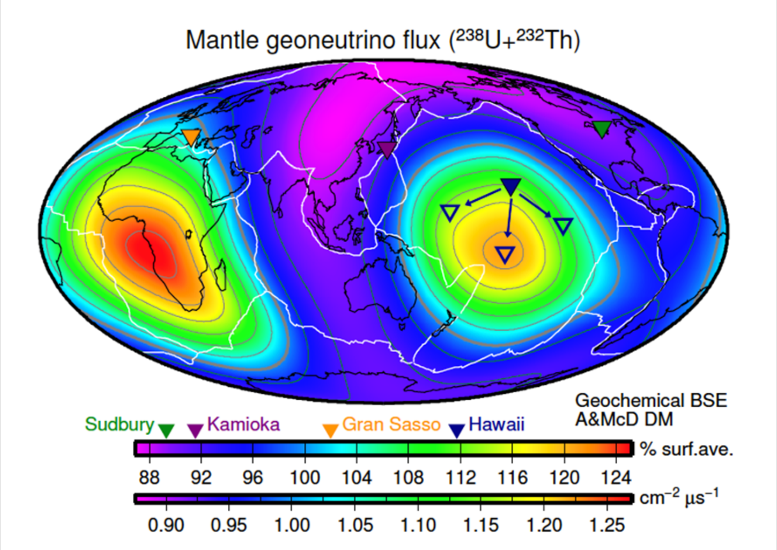
Hidden reservoir lost to space

Dave Stegman wants
~35 TW !

Geo-neutrinos

- If there is a "hidden" **enriched** reservoir at the bottom of the mantle, it will be **enriched in U and Th** (30-48% of planet's budget)
- 10-year deployment of a submerged, mobile geo-neutrino detector is $300 million.





Sramek et al. (2012)