Mantle Isotope Geochemistry

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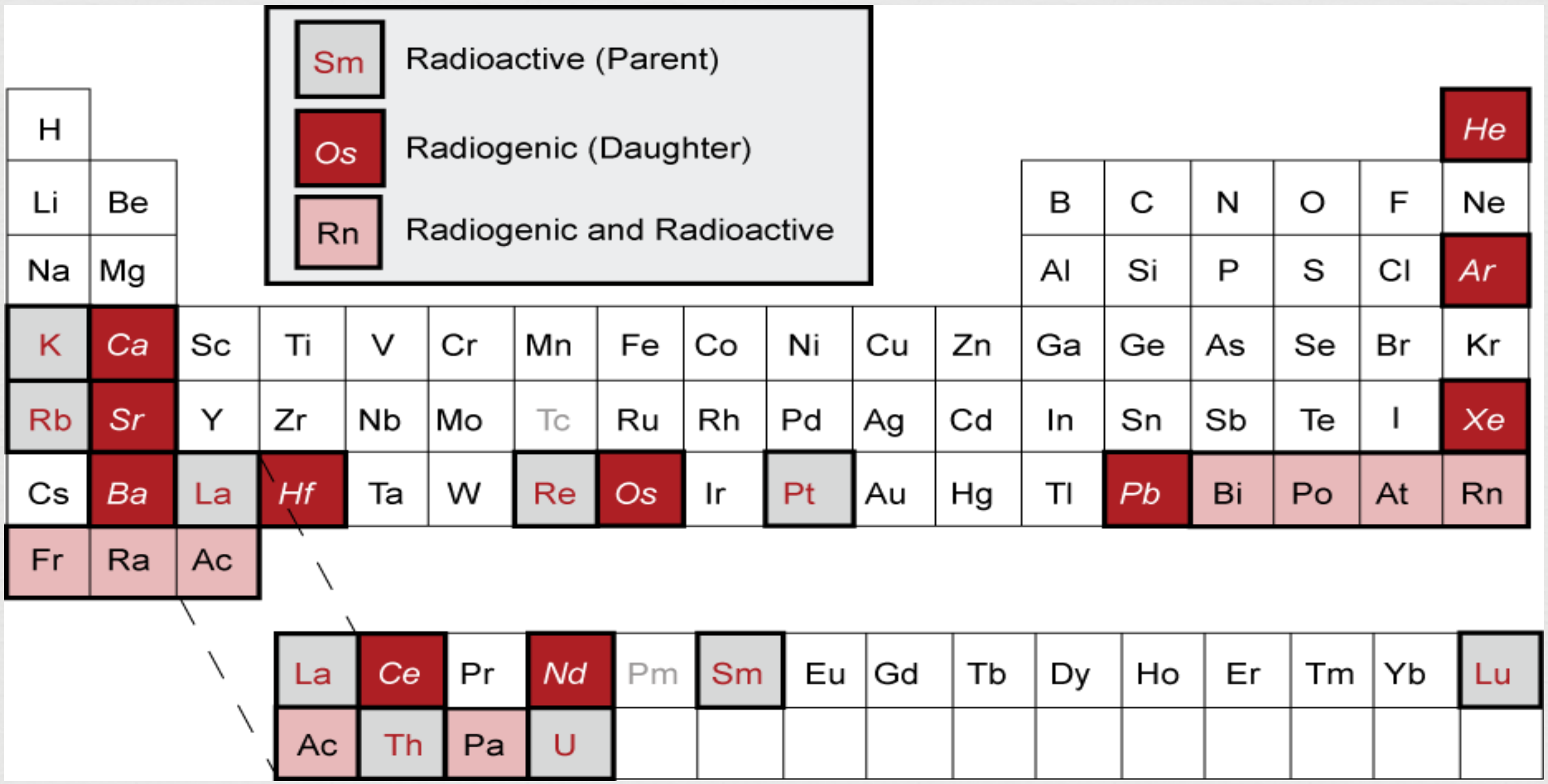
Radiogenic Isotope Geochemistry



Isotope Geochemistry

$$\frac{^{87}Sr}{^{86}Sr} = \left(\frac{^{87}Sr}{^{86}Sr}\right)_0 + \frac{^{87}Rb}{^{86}Sr}(e^{\lambda_{87}t} - 1)$$

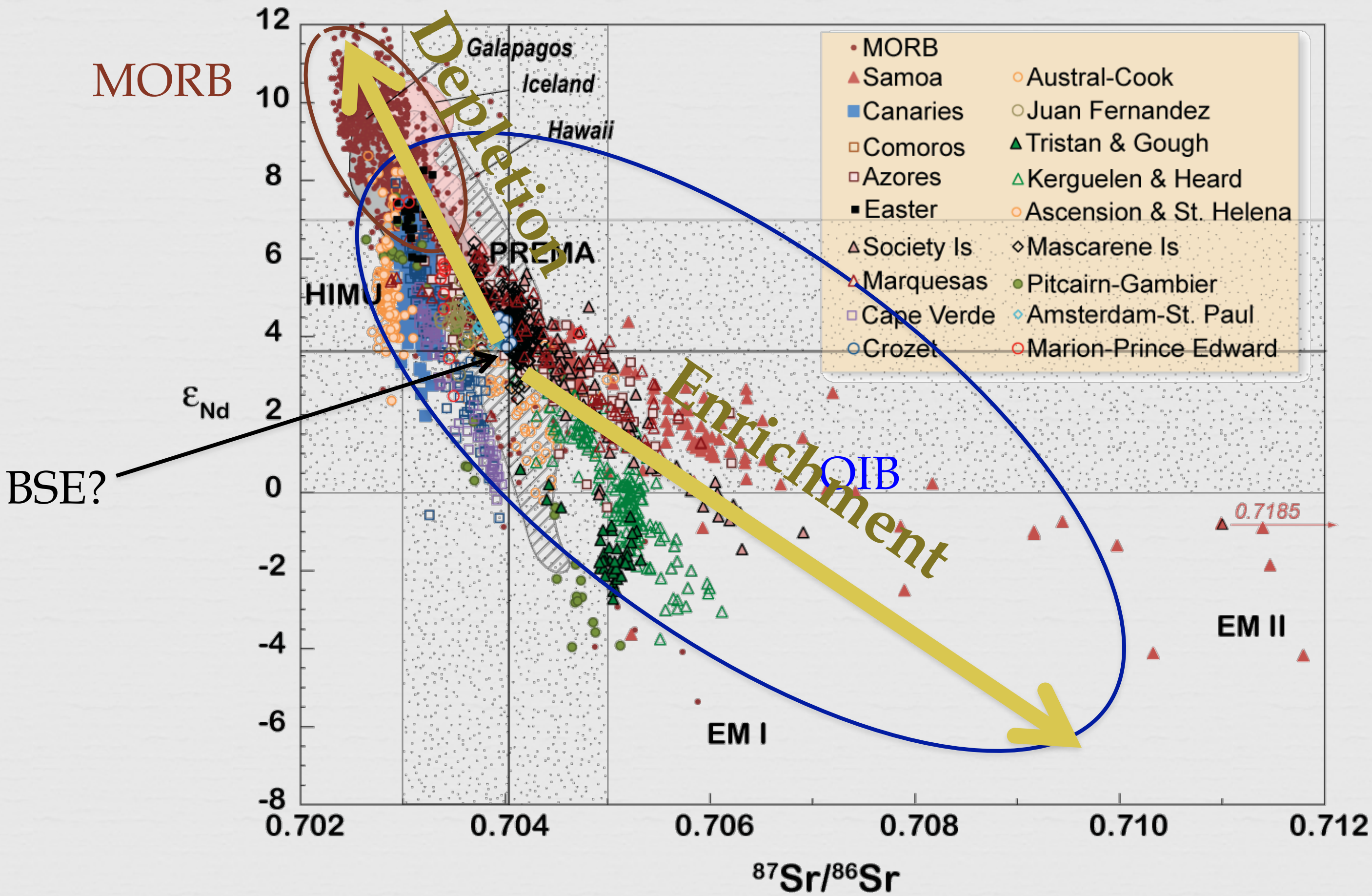
Gast (1960):

- *In a given chemical system the isotopic abundance of ^{87}Sr is determined by four parameters: the isotopic abundance at a given initial time, the Rb/Sr ratio of the system, the decay constant of ^{87}Rb, and the time elapsed since the initial time. The isotopic composition of a particular sample of strontium, whose history may or may not be known, may be the result of time spent in a number of such systems or environments. In any case the isotopic composition is the <u>time-integrated</u> result of the Rb/Sr ratios in all the past environments. Local differences in the Rb/Sr will, in time, result in local differences in the abundance of ^{87}Sr. Mixing of material during processes will tend to homogenize these local variations. Once homogenization occurs, the isotopic composition is not further affected by these processes.*
  - *This statement applies to other decay systems, many of which were 'developed' well after 1960.*

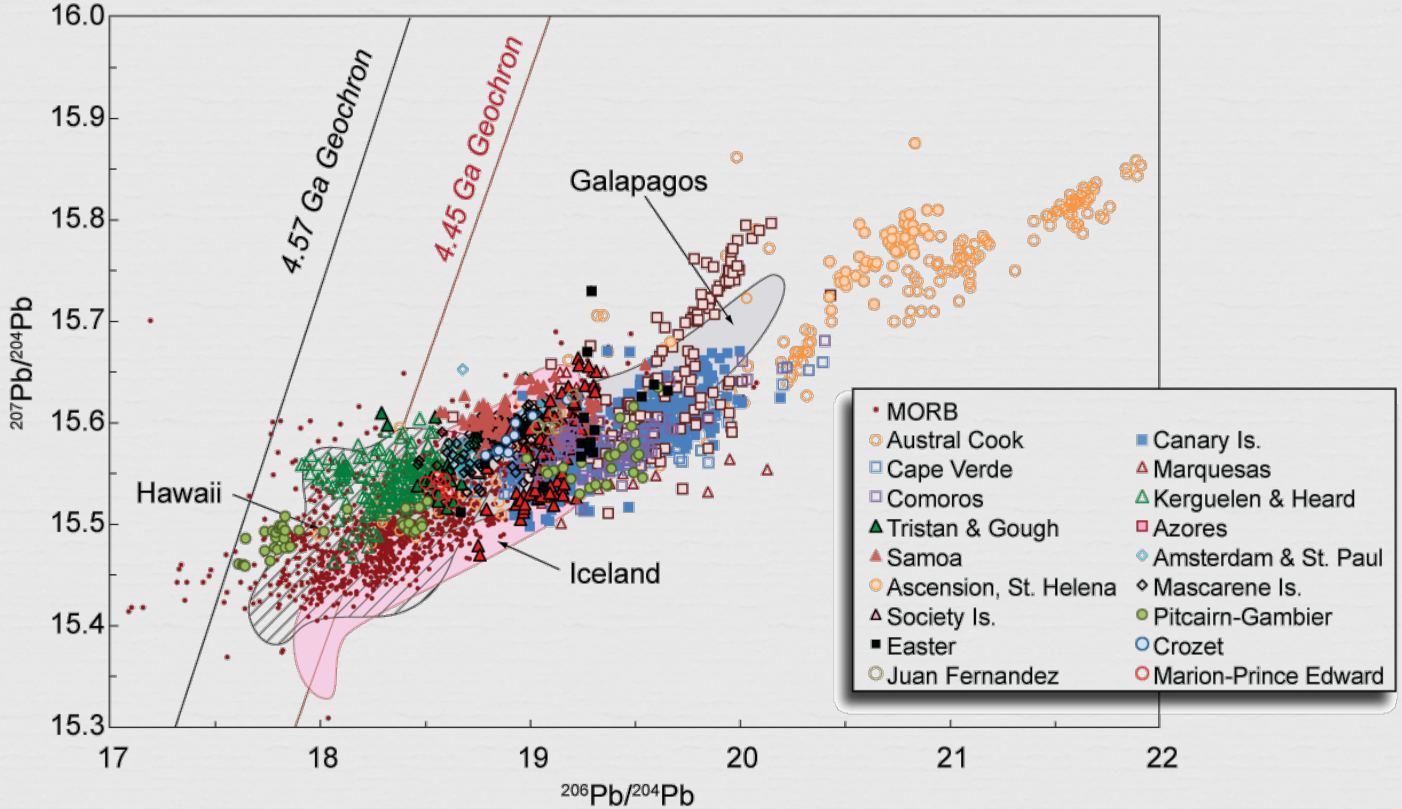
Bottom Line

Radiogenic isotope ratios are *time-integrated* measure of elemental ratios such as Rb/Sr, Sm/Nd, U/Pb, Lu/Hf, and Re/Os.

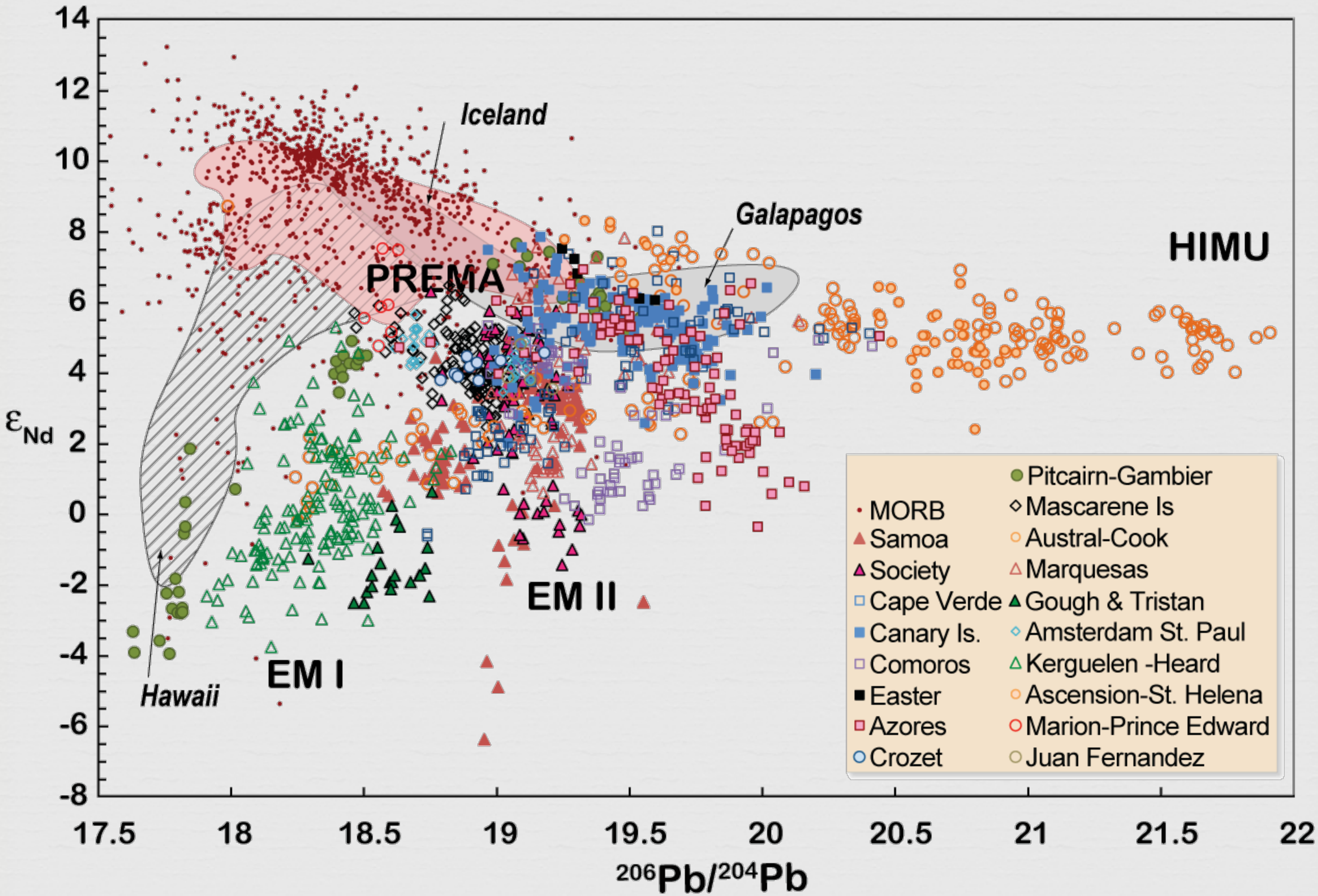
Oceanic Basalt Data Set



Pb Isotopes



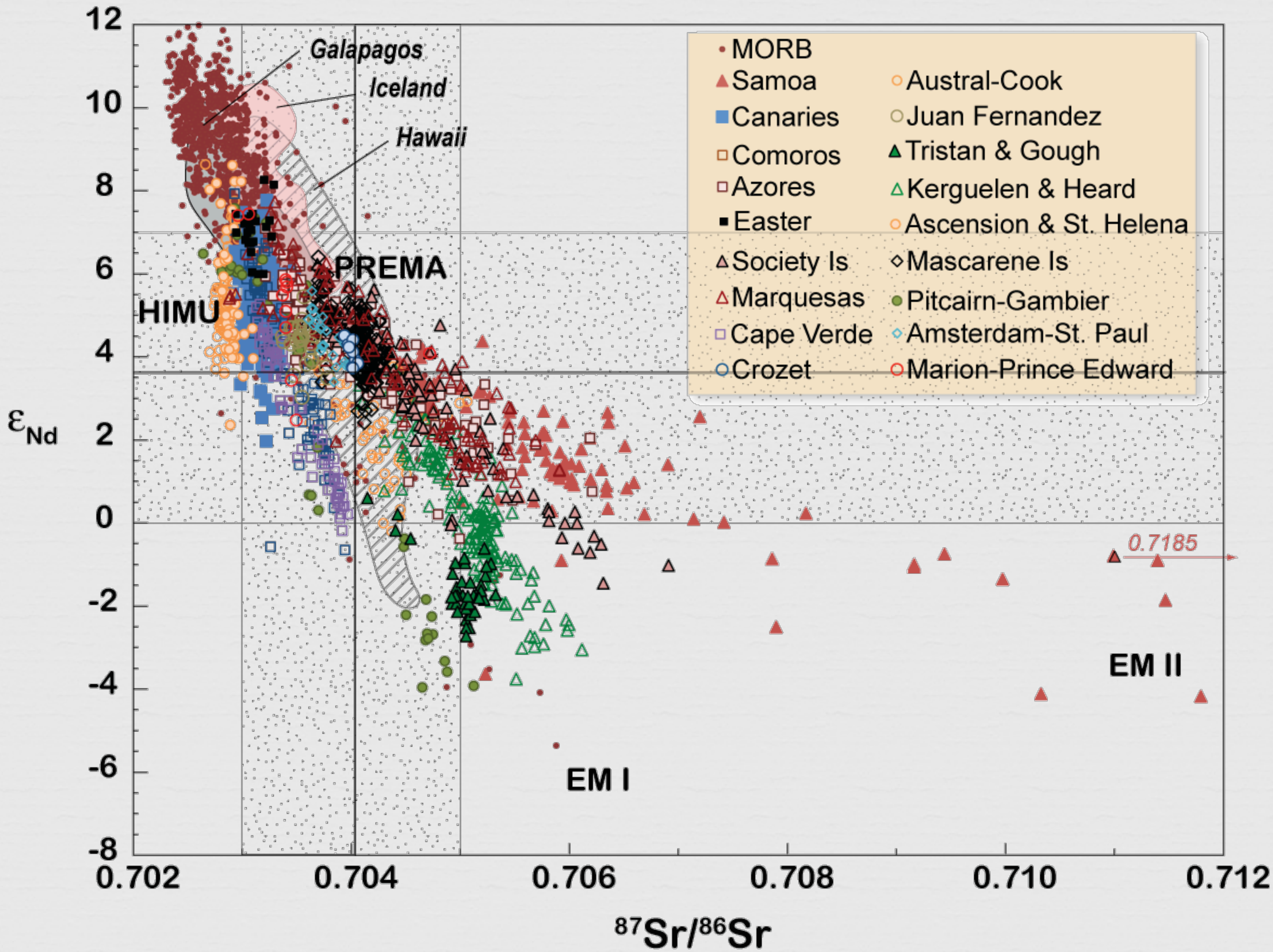
^{206}Pb is the decay product of ^{238}U ($t_{1/2}$ =4.5 Ga), ^{207}Pb is the decay product of ^{235}U ($t_{1/2}$ = 700 Ma). Slopes on this plot have age significance.



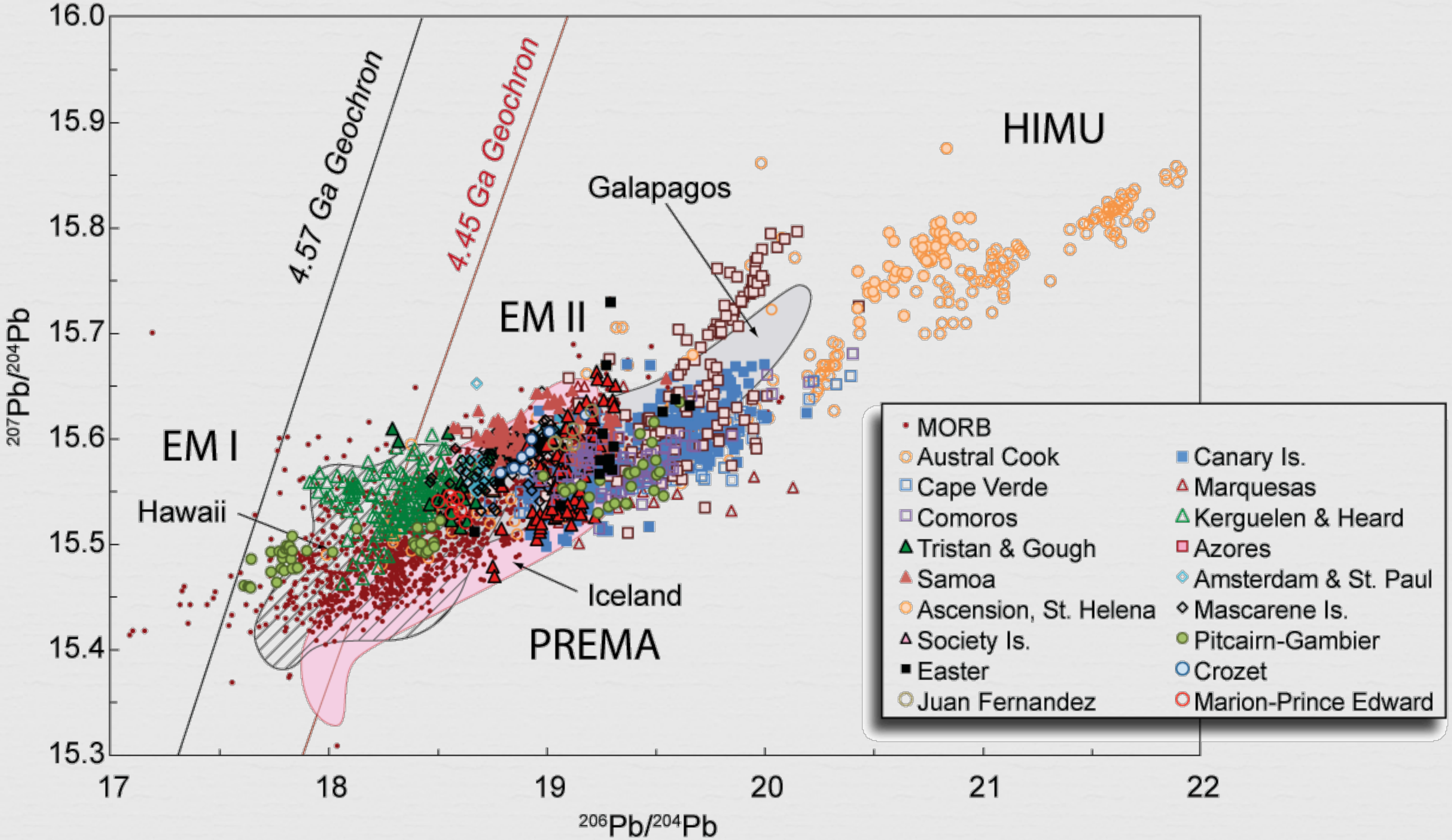
14
12
10
8
6
4
2
0
-2
-4
-6
-8
ε_{Nd}
17.5
18
18.5
19
19.5
20
20.5
21
21.5
22
$^{206}Pb/^{204}Pb$
Iceland
Galapagos
HIMU
PREMA
EM II
EM I
Hawaii
Pitcairn-Gambier
MORB
Mascarene Is
Samoa
Austral-Cook
Society
Marquesas
Cape Verde
Gough & Tristan
Canary Is.
Amsterdam St. Paul
Comoros
Kerguelen -Heard
Easter
Ascension-St. Helena
Azores
Marion-Prince Edward
Crozet
Juan Fernandez

Mantle Taxonomy

- There are some systematic variations that allows us to divide oceanic island basalts (and presumably the plumes that generate them) into several varieties. (I like to think of them as genera, some of which can have several species). These are:
  - DMM (Depleted MORB Mantle); mantle source of MORB
  - EM I: Type examples are Kerguelen and Tristan da Cunha
  - EM II: Type examples are Society Is. & Samoa
  - HIMU: restricted to St. Helena, Ascension, and Australs.
  - PREMA (aka FOZO, C, PHEM): appears to be present as a mixing end-member in many plumes.



MORB
Samoa
Canaries
Comoros
Azores
Easter
Society Is
Marquesas
Cape Verde
Crozet
Austral-Cook
Juan Fernandez
Tristan & Gough
Kerguelen & Heard
Ascension & St. Helena
Mascarene Is
Pitcairn-Gambier
Amsterdam-St. Paul
Marion-Prince Edward
Galapagos
Iceland
Hawaii
PREMA
HIMU
EM I
EM II
0.7185
ε_{Nd}
$^{87}Sr/^{86}Sr$
12
10
8
6
4
2
0
-2
-4
-6
-8
0.702
0.704
0.706
0.708
0.710
0.712



16.0
15.9
15.8
15.7
15.6
15.5
15.4
15.3
17
18
19
20
21
22
$^{207}Pb/^{204}Pb$
$^{206}Pb/^{204}Pb$
4.57 Ga Geochron
4.45 Ga Geochron
HIMU
Galapagos
EM II
EM I
Hawaii
Iceland
PREMA
MORB
Austral Cook
Cape Verde
Comoros
Tristan & Gough
Samoa
Ascension, St. Helena
Society Is.
Easter
Juan Fernandez
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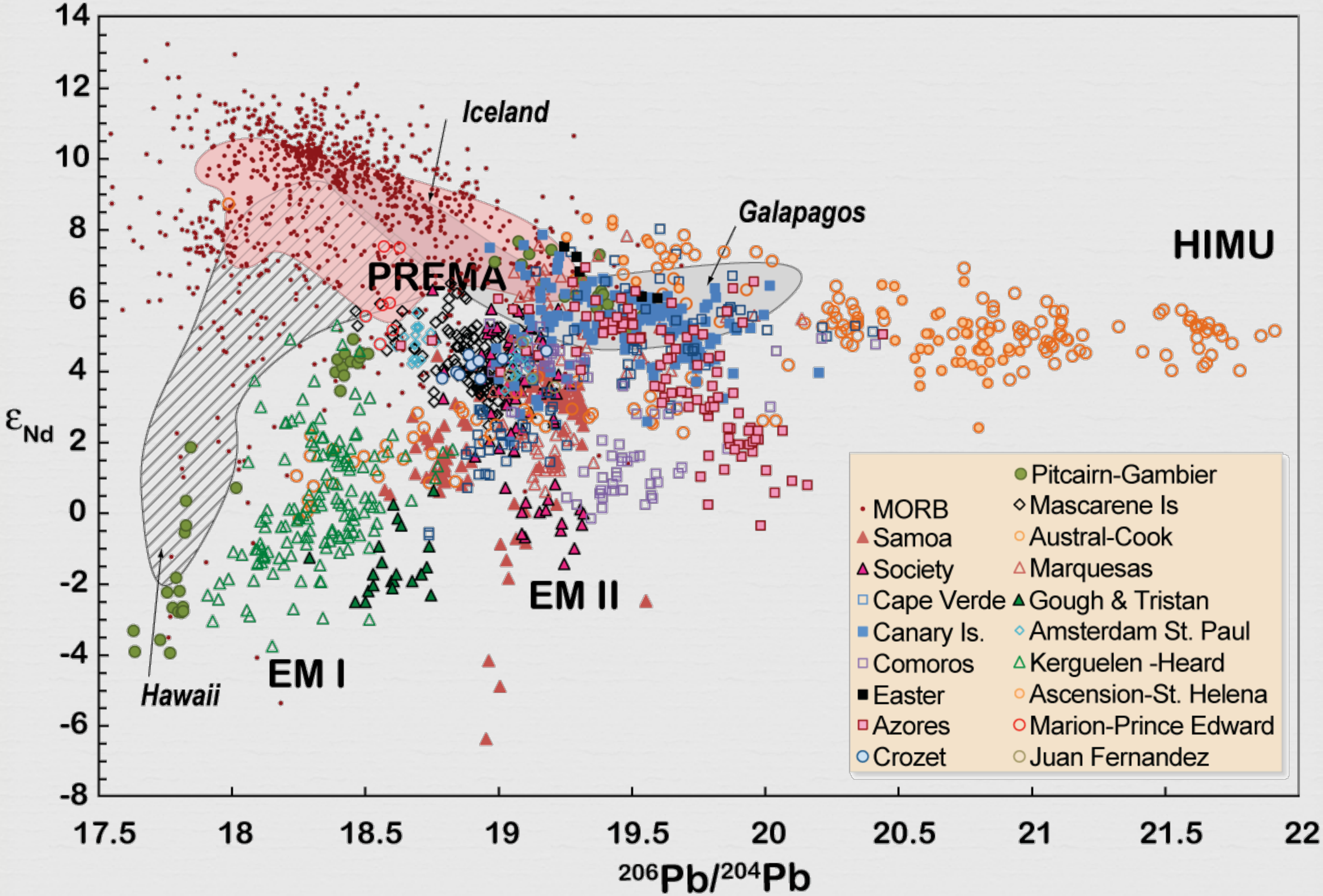
Azores
Amsterdam & St. Paul
Mascarene Is.
Pitcairn-Gambier
Crozet
Marion-Prince Edward



Iceland
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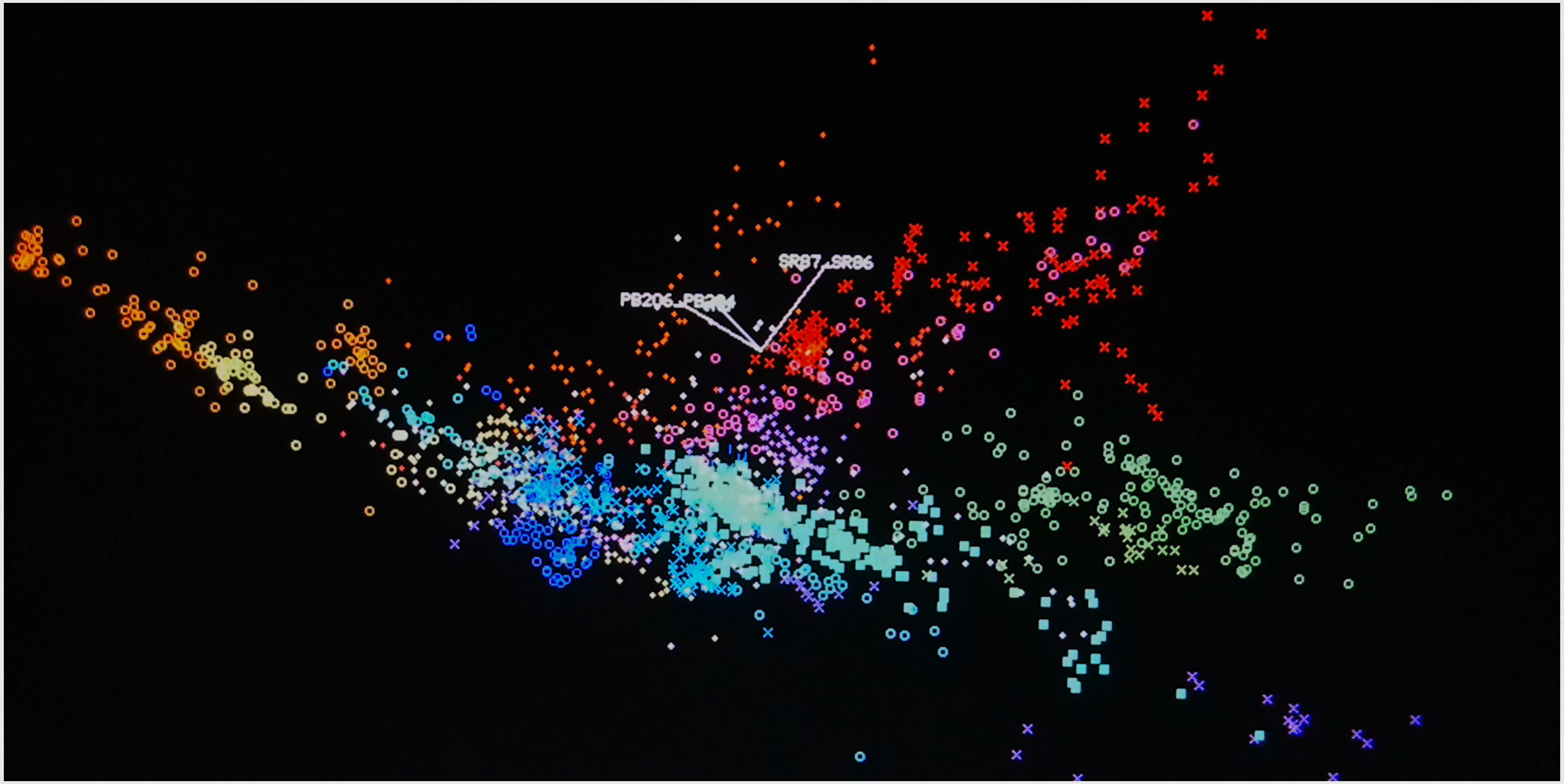
What are they?

- Unique components contained in spatially distinct reservoirs that then mix?
  - Probably true of DMM (upper mantle; although we can identify Pacific, Atlantic and Indian species); possibly true of PREMA & HIMU
- Simply ‘reservoirs’ that have chemically evolved in a similar way?
  - Most likely for EM I and EM II.

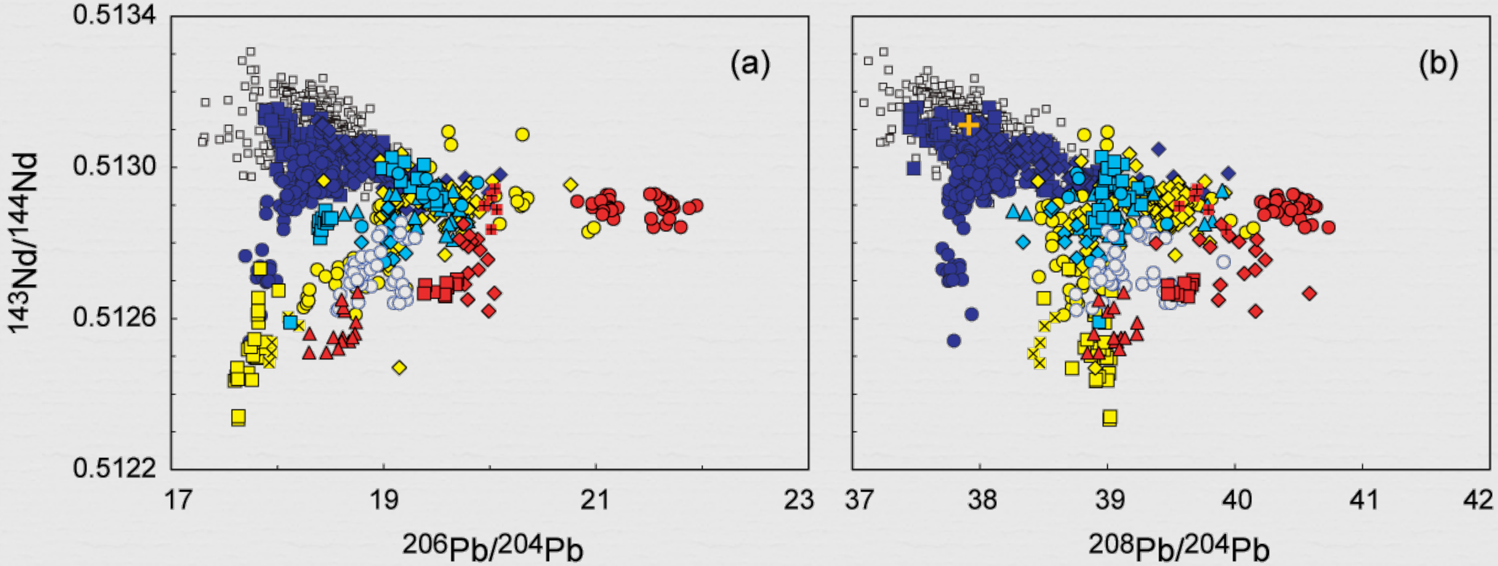
Many Distinct Species



The Big Question

How have these genera evolved and what does this tell us about the mantle?

$^3He/^4He$ in OIB



PREMA may be the closest thing to unprocessed "Primitive Mantle" as still exists in the Earth.

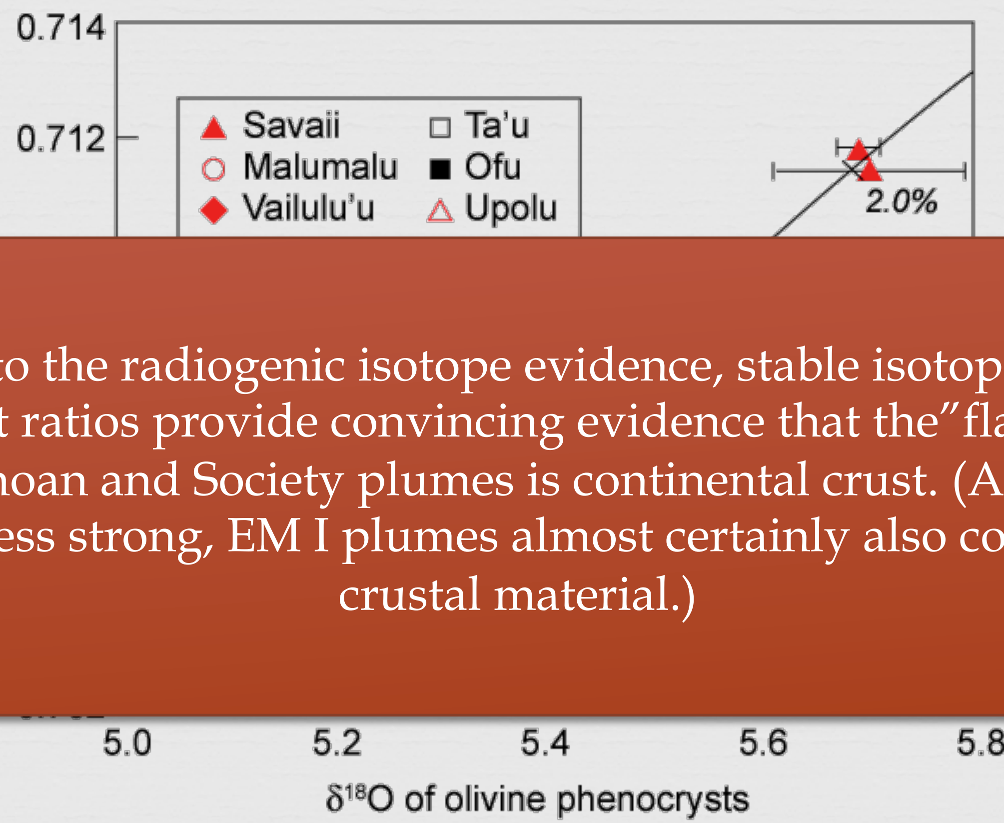
Stable Isotopes

Stable isotope ratios are generally reported as *per mil deviations from a standard*, e.g., $\delta^{18}O_{SMOW}$ (Standard Mean Ocean Water).

Ratios of stable isotopes, e.g., $^{18}O/^{16}O$, vary due to the slight effect of nuclear mass on bond strength, reactivity, and diffusivity.

These effects decrease with the inverse square of temperature and usually are negligible at mantle temperatures. Thus stable isotopes fractionate only at the surface of the Earth.

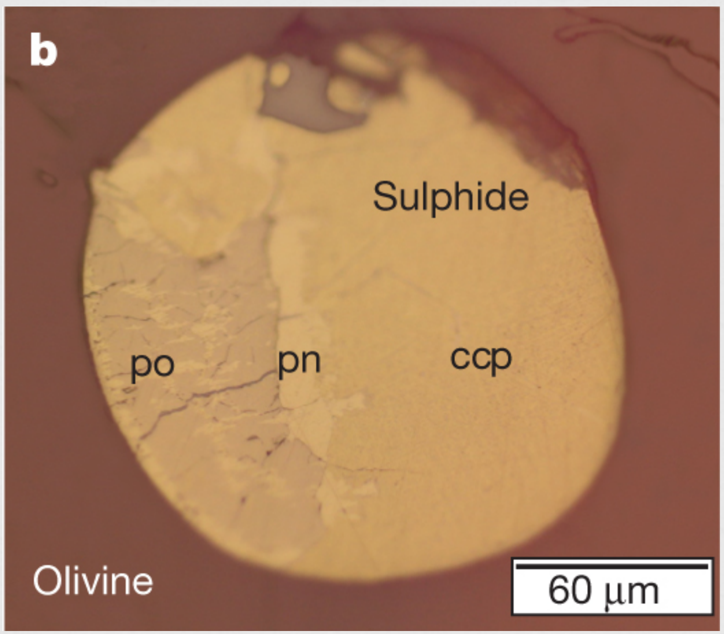
δ ^{18}O in Samoan (EM II) Lavas



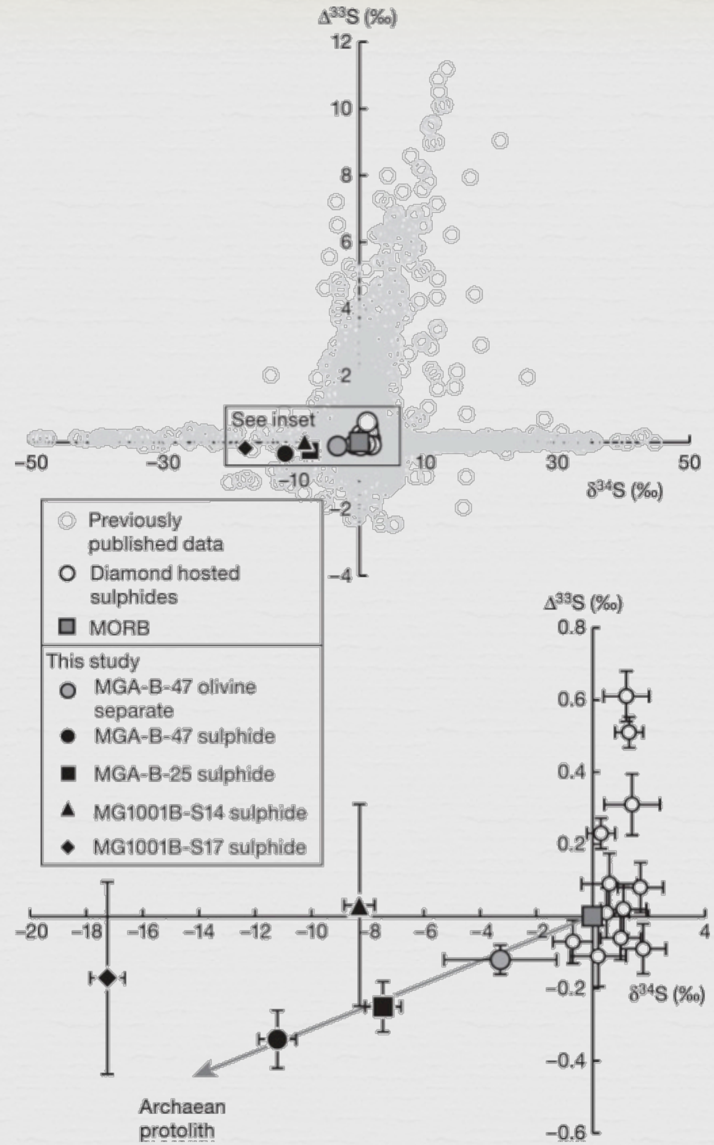
In addition to the radiogenic isotope evidence, stable isotopes and certain trace element ratios provide convincing evidence that the"flavoring agent" in the Samoan and Society plumes is continental crust. (Although the evidence is less strong, EM I plumes almost certainly also contain recycled crustal material.)

from Workman et al. (2008)

'MIF' Sulfur in Mangaia (Australs) Olivine Sulfide Inclusion Lava



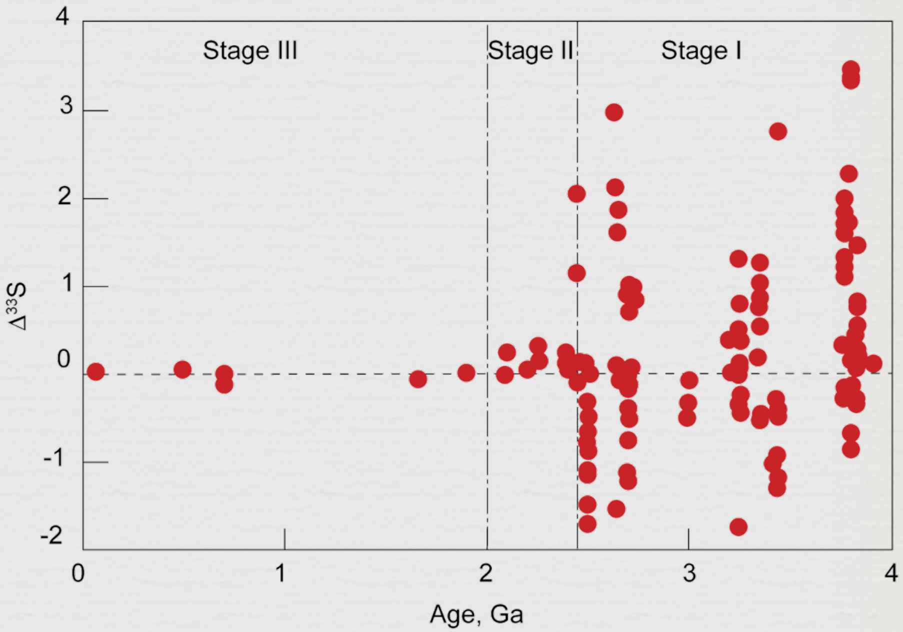
Reflected-light photomicrographs of sulphide inclusions.



From: Cabral *et al*. *Nature* (2013)

MIF Sulfur

- Mass Independent Fractionation (MIF) is a rare phenomenon that generally involves photodissociation. It occurs in the modern stratosphere.
- mass independent fractionation of sulfur is restricted to time before 2.3 Ga when UV radiation could penetrate an oxygen- and ozone-free atmosphere.



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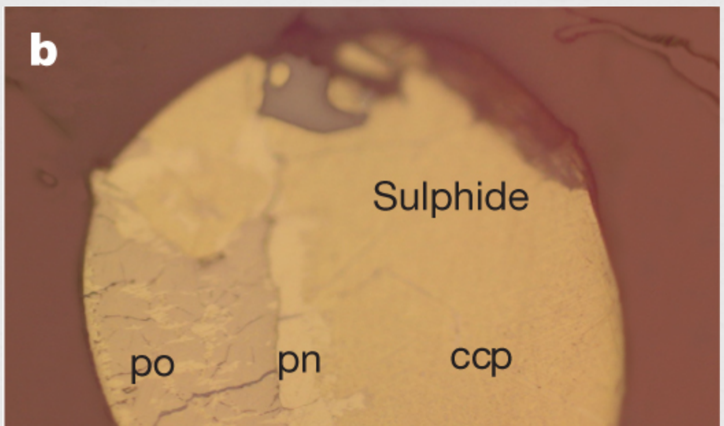

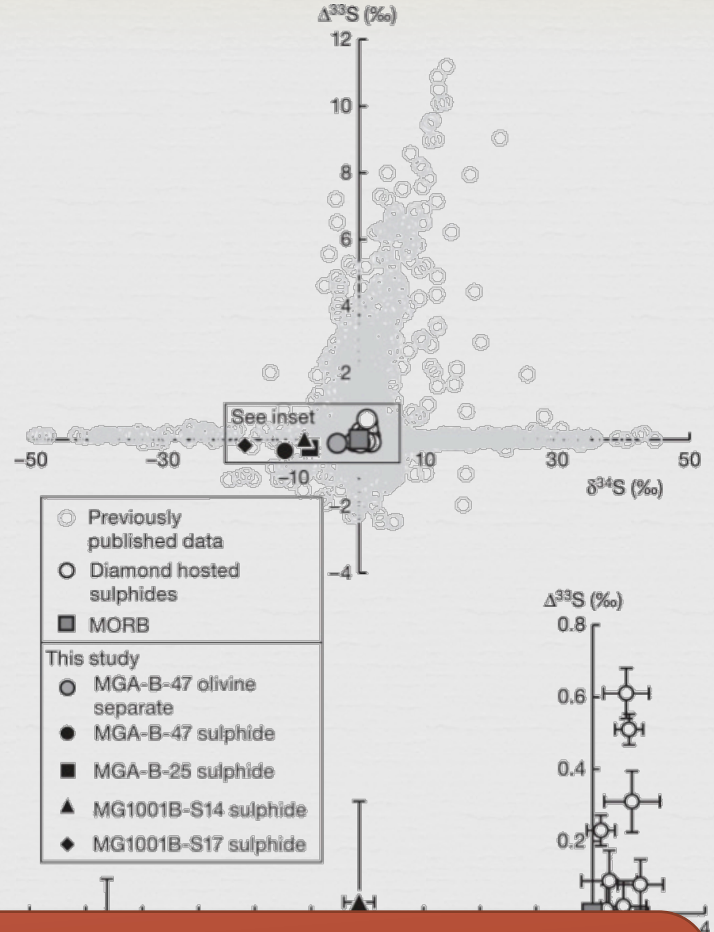

HIMU too must also contain recycled crustal material

From: Cabral *et al*. *Nature* (2013)