マントル内物質循環の「年代」に関する二つの制約

Age of mantle reservoirs formed by slab subduction

Raivavae, Austral Islands, French Polynesia

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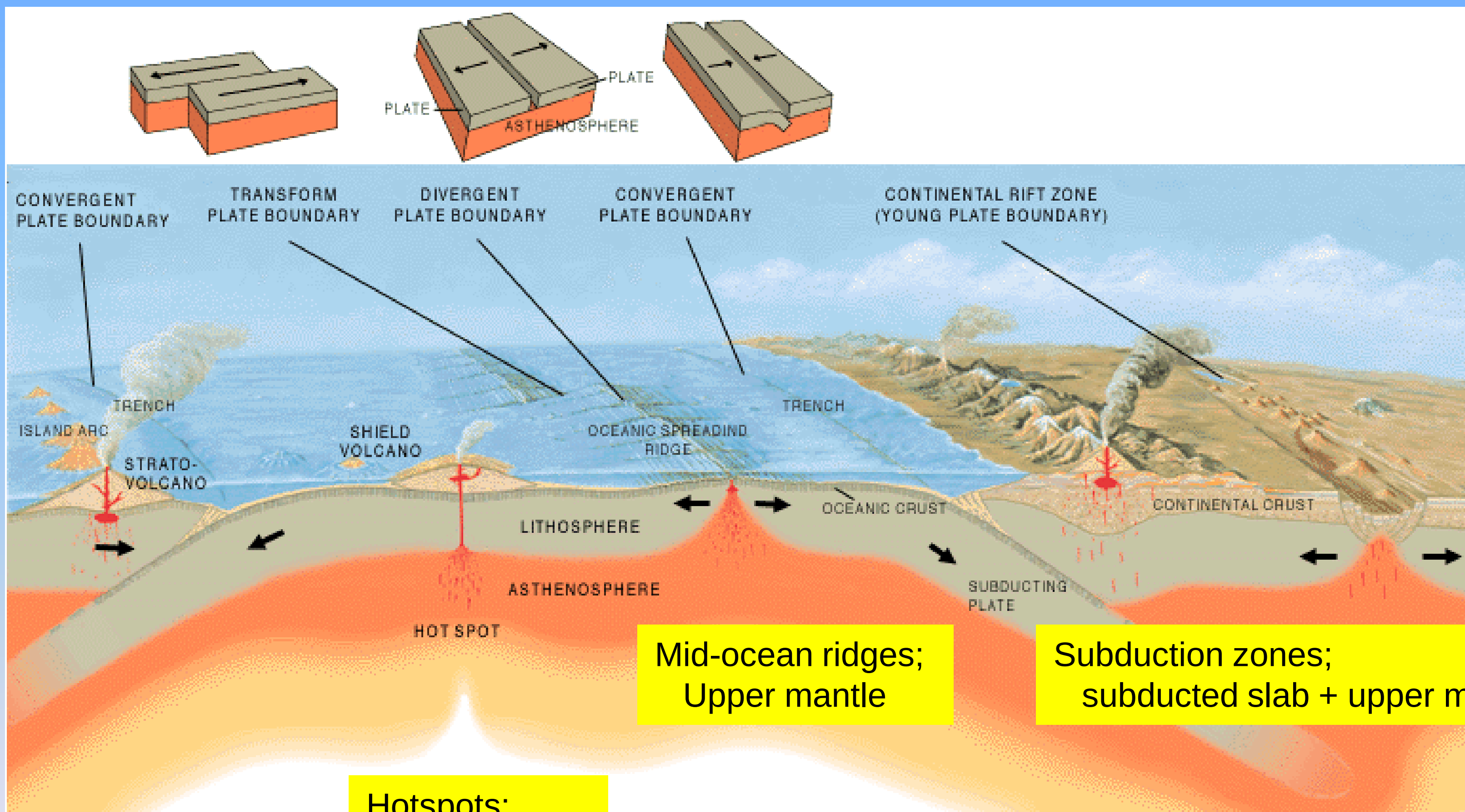
Outline of today’s talk

1. Introduction
   – Mantle geochemical heterogeneity and significance of HIMU

2. What we studied on HIMU ocean island basalts
   – Recent progress

3. Age of the HIMU mantle reservoir
   – Implications to crustal recycling in the mantle

Hotspot – a window to the deep mantle

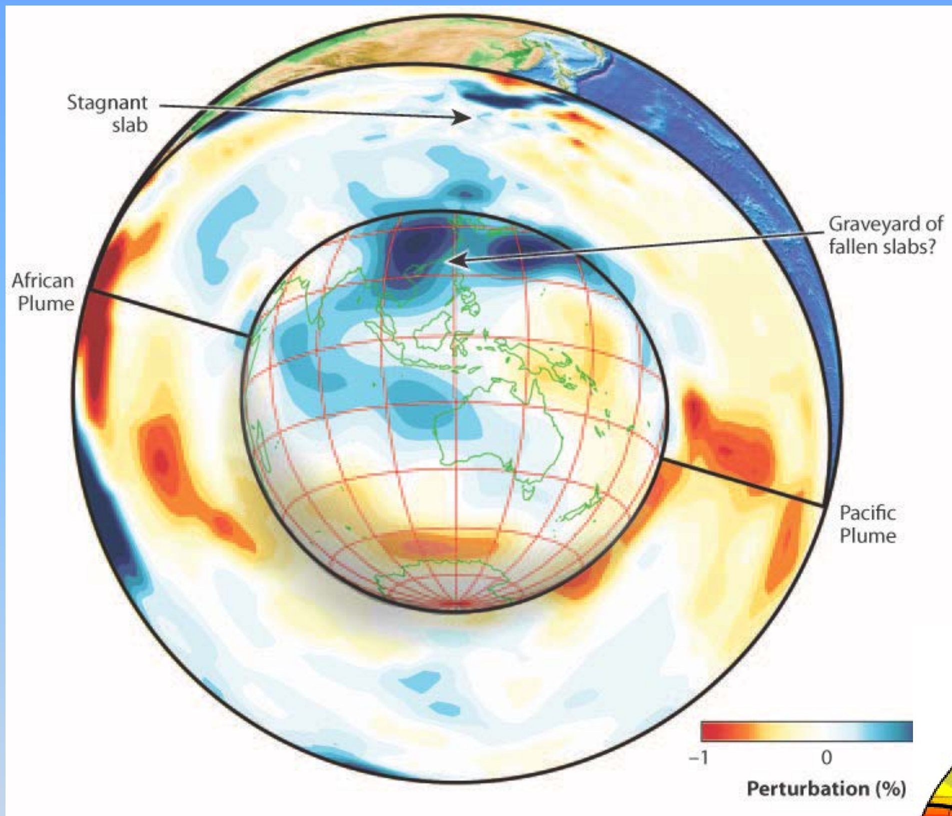


Mid-ocean ridges;
Upper mantle

Subduction zones;
subducted slab + upper mantle

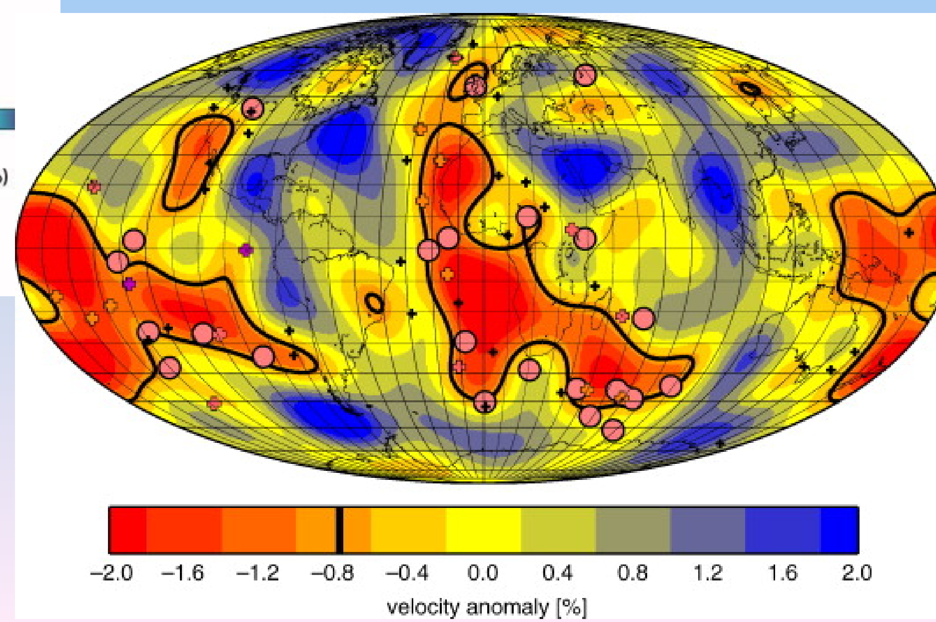
Hotspots;
Lower mantle

Hotspot – a window to the deep mantle



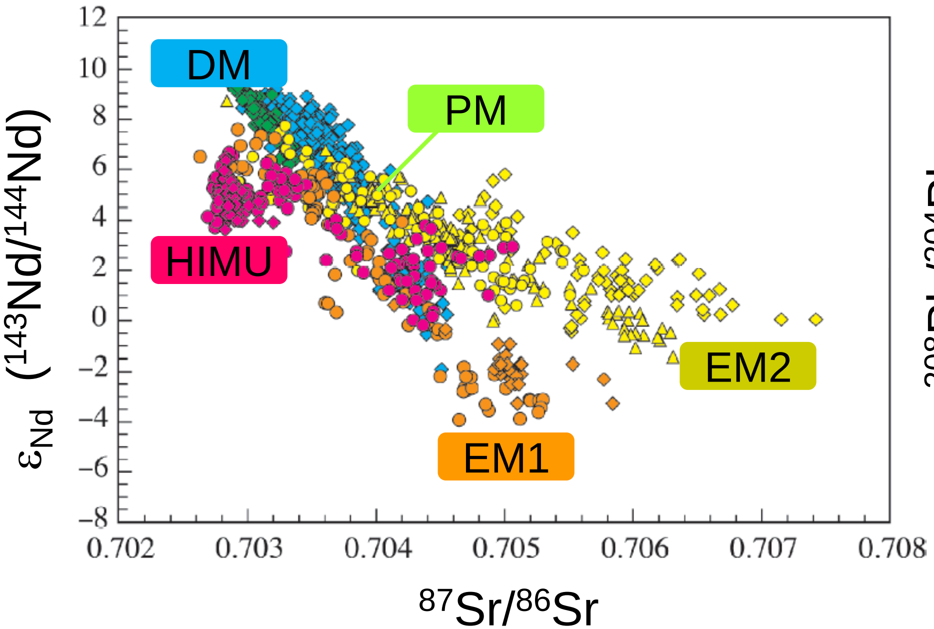
Fukao Y, et al. 2009.
Annu. Rev. Earth Planet. Sci. 37:19–46

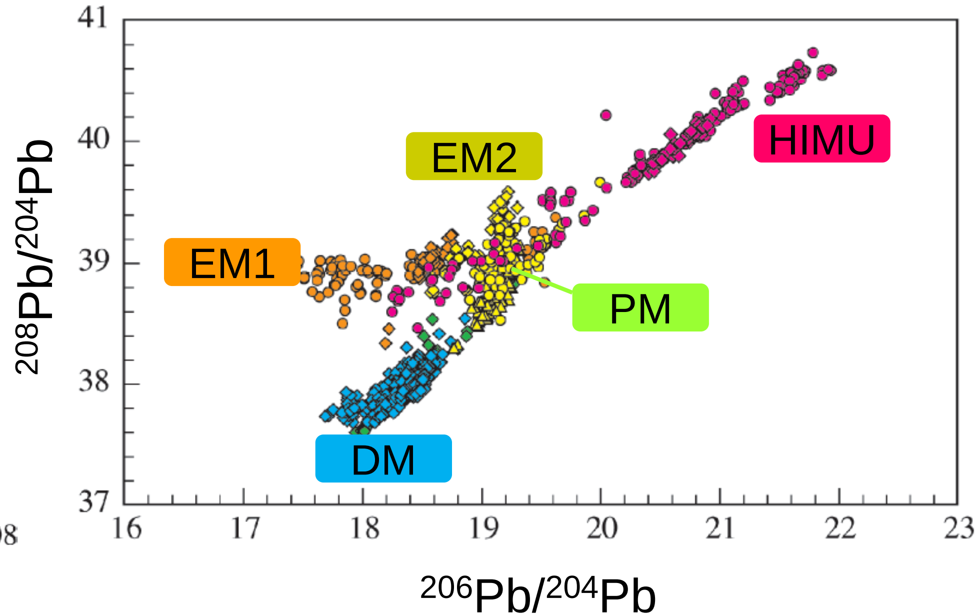
Burke et al. (2008)



Mantle geochemical heterogeneity

Isotopic variation of mantle derived rocks (MORB, OIB)



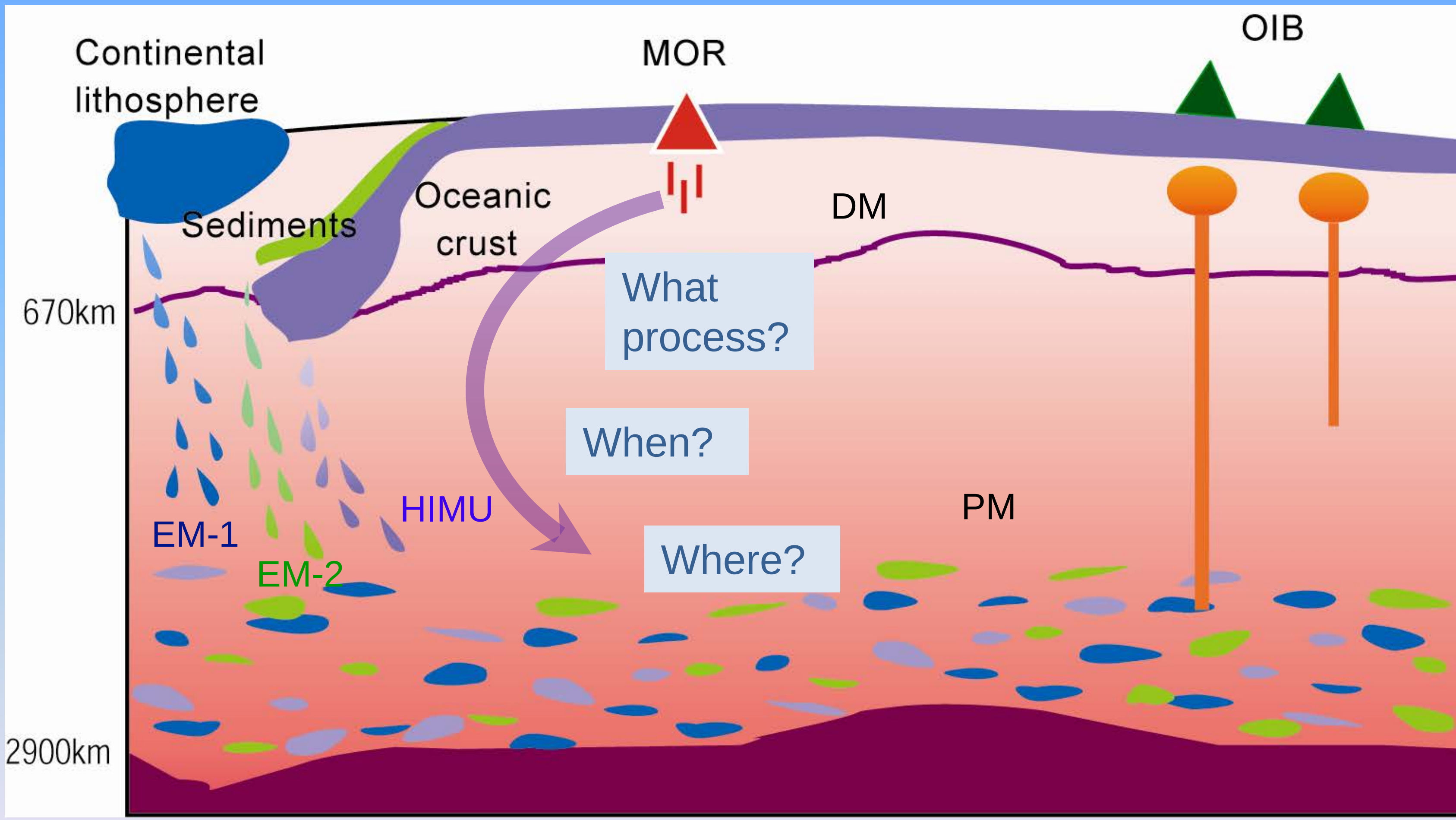


Hofmann (2003)

Rb/Sr; $^{87}Rb \rightarrow ^{87}Sr$ (48.9 Byr; half life)
Sm/Nd; $^{147}Sm \rightarrow ^{143}Nd$ (106 Byr)
Lu/Hf; $^{176}Lu \rightarrow ^{176}Hf$ (37.1 Byr)

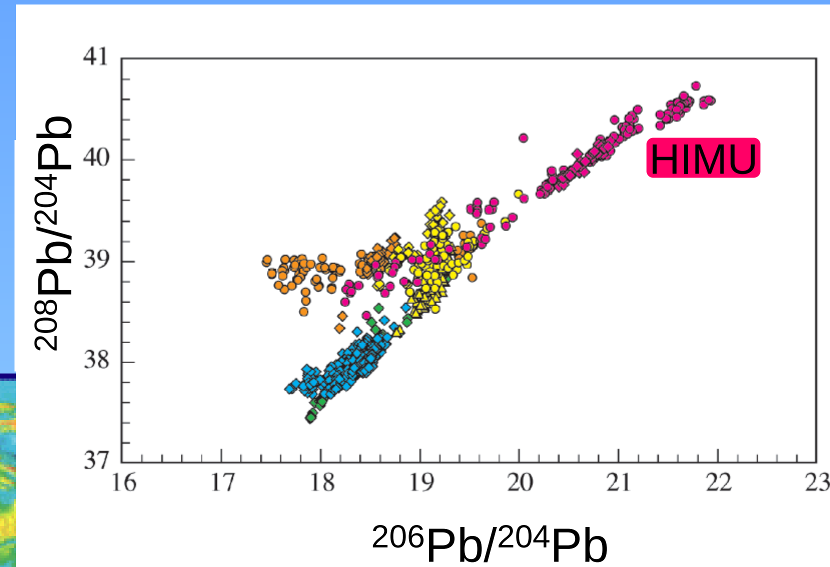
U/Pb; $^{238}U \rightarrow ^{206}Pb$ (4.47 Byr)
$^{235}U \rightarrow ^{207}Pb$ (0.704 Byr)
Th/Pb; $^{232}Th \rightarrow ^{208}Pb$ (14.0 Byr)

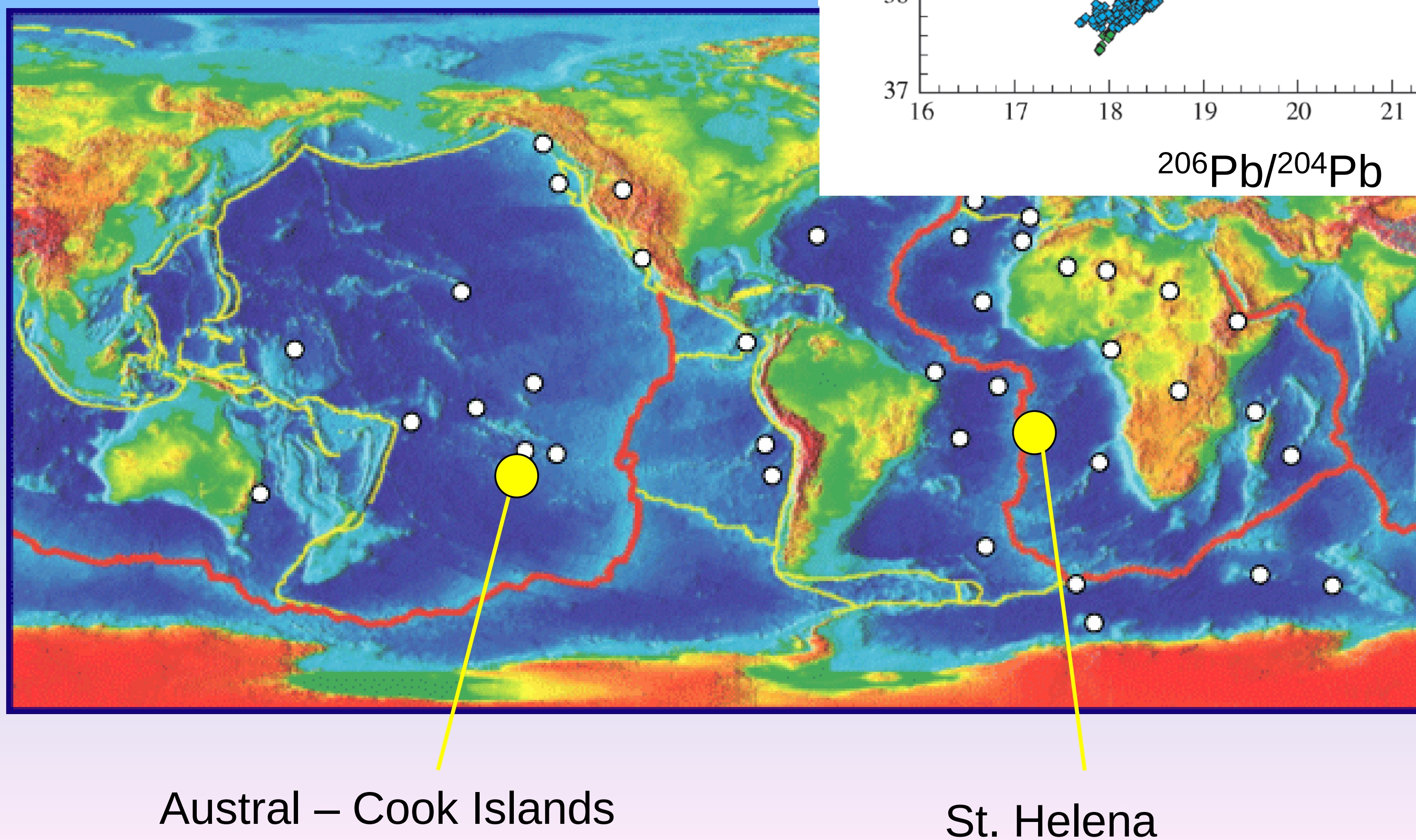
Mantle geochemical heterogeneity



What is HIMU?

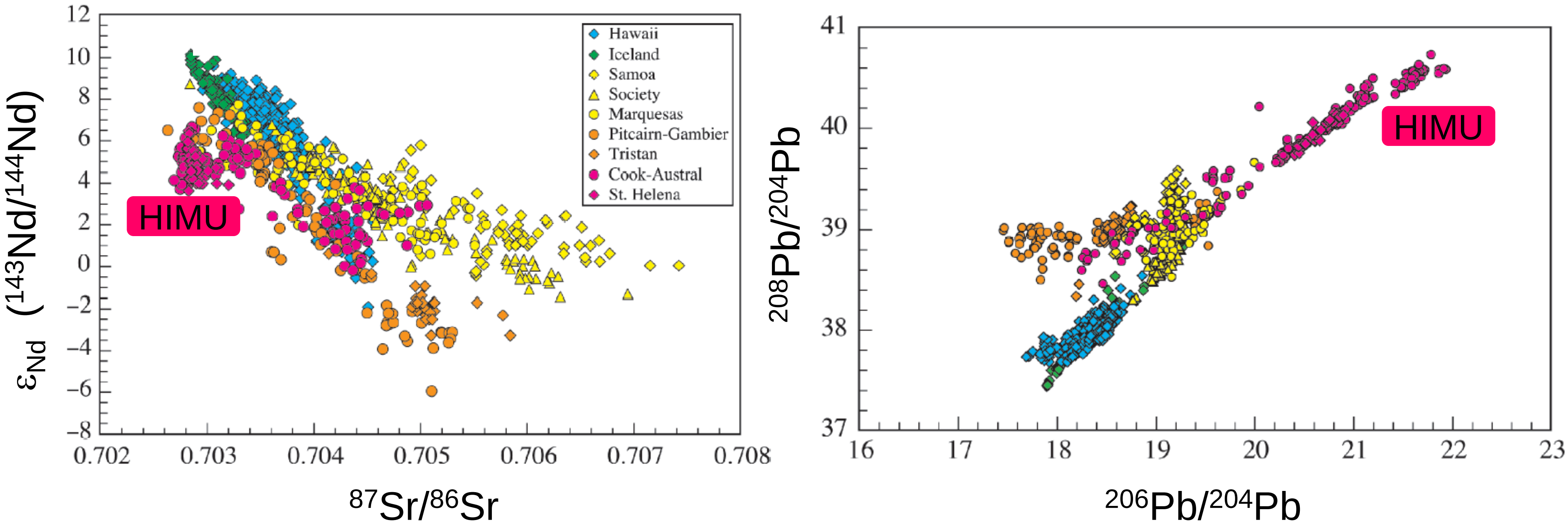
Occurrence of “pure” HIMU basalts is limited…





What is HIMU?

Isotopic variation of mantle derived rocks (MORB, OIB)



Hofmann (2003)

Low Rb/Sr, High U/Pb, Th/Pb

(high $\mu = {}^{238}U/{}^{204}Pb$)

What is HIMU?

Proposed HIMU models

(1) Recycle model

- Subducted dehydrated oceanic crust

(Zindler and Hart, 1986; Chauvel et al., 1992)

- Subducted metasomatized lithosphere

(Niu and O'Hara, 2003; Pilet et al., 2005)

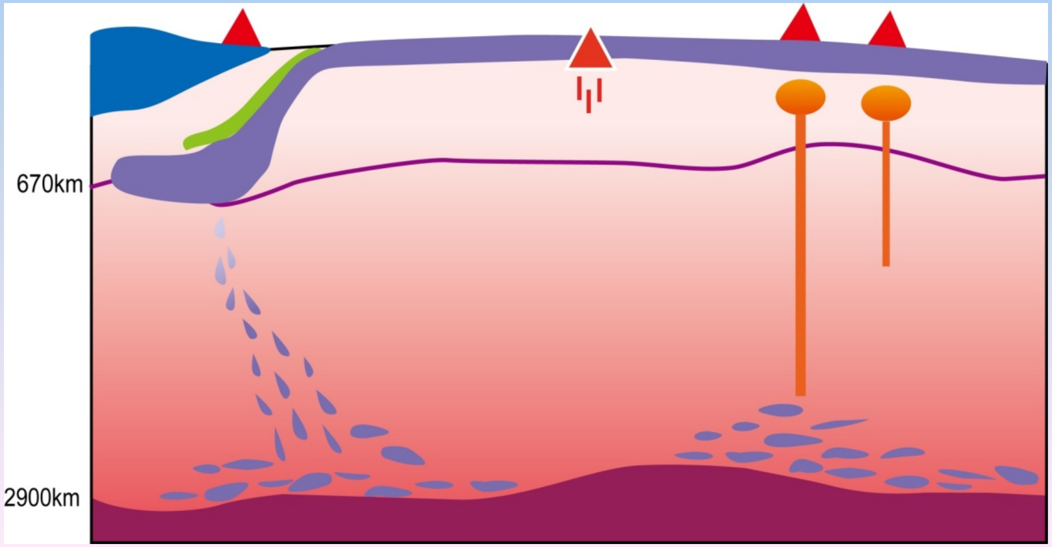
(2) Non-recycle model

- Partial melting in the lower mantle

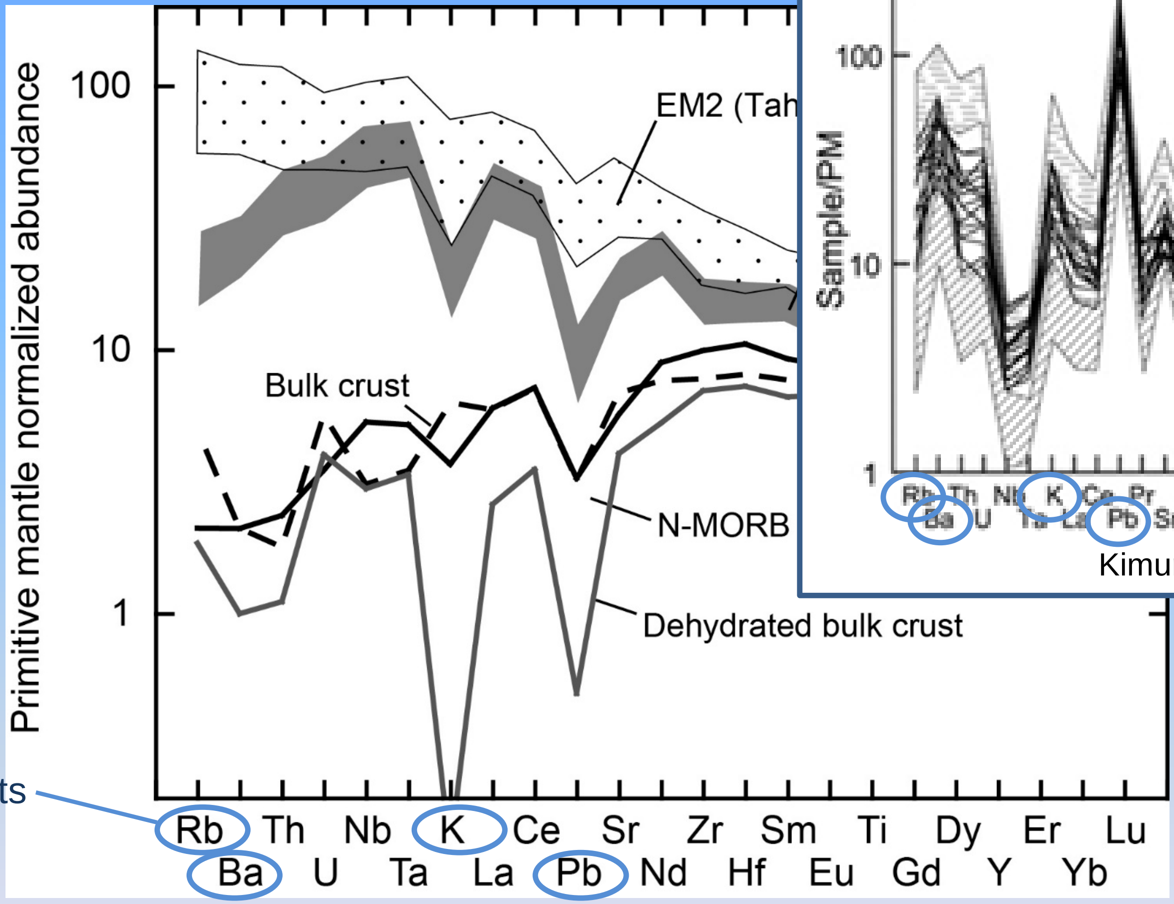
(Collerson et al., 2010)

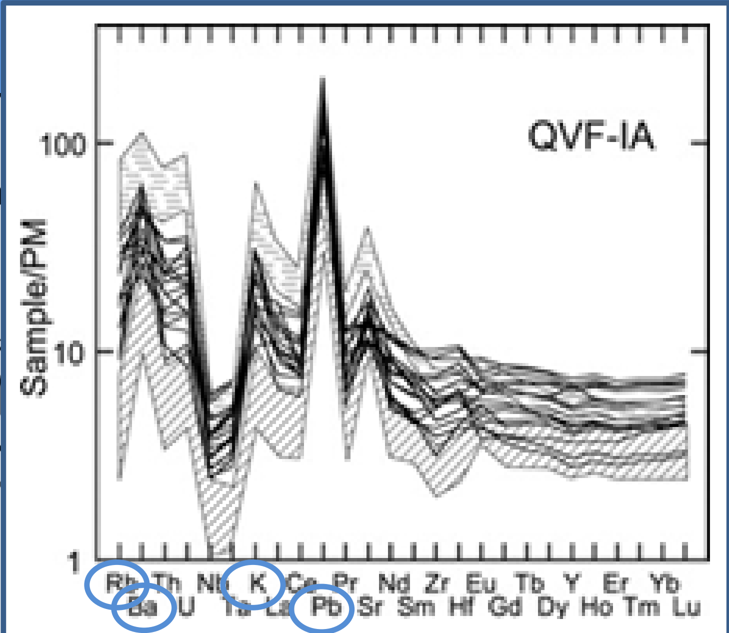
- Interaction with core material

(Allegre et al., 1980)



What is HIMU?





Kimura and Yoshida (2006)

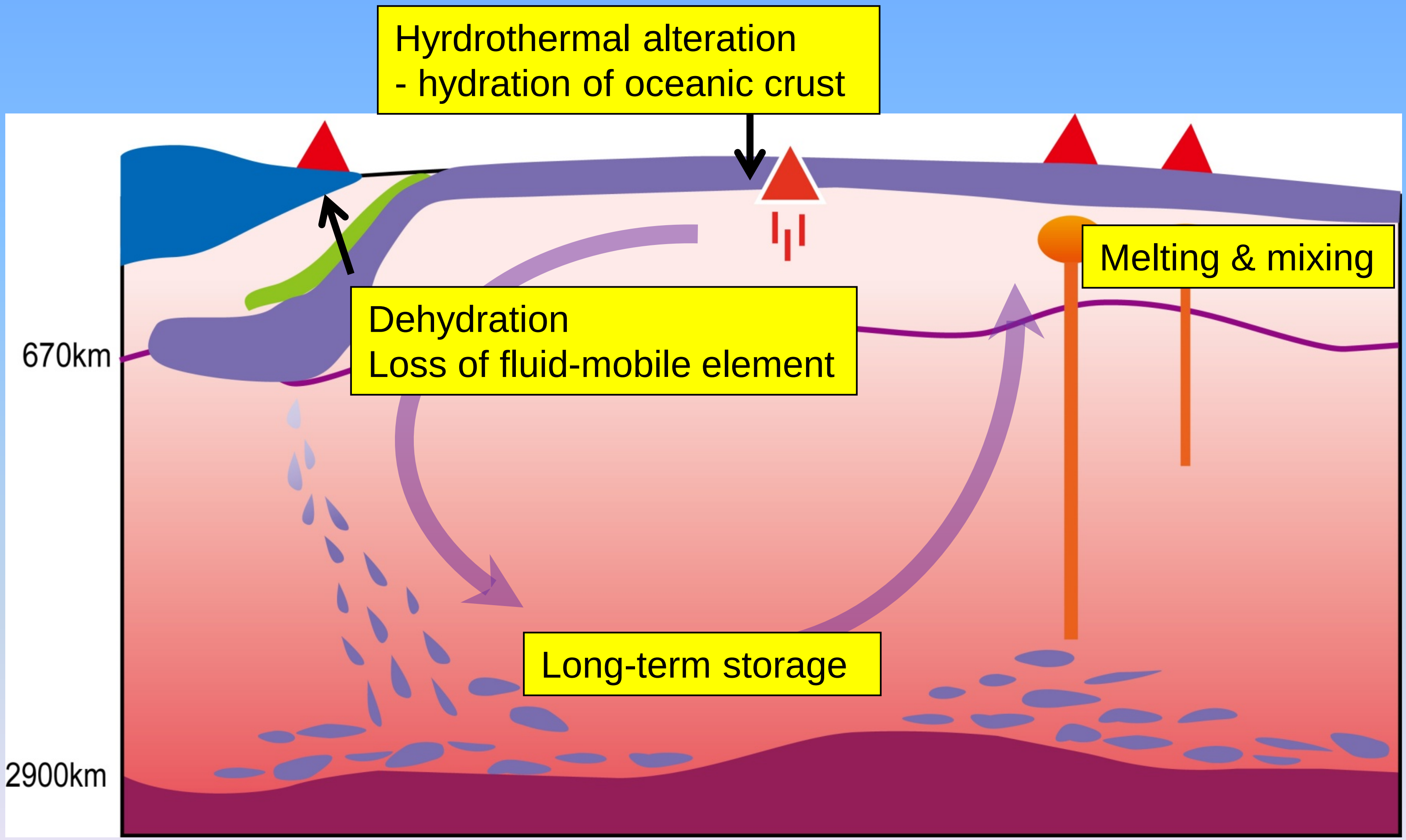
Fluid-mobile elements

Suetsugu and Hanyu (2013)

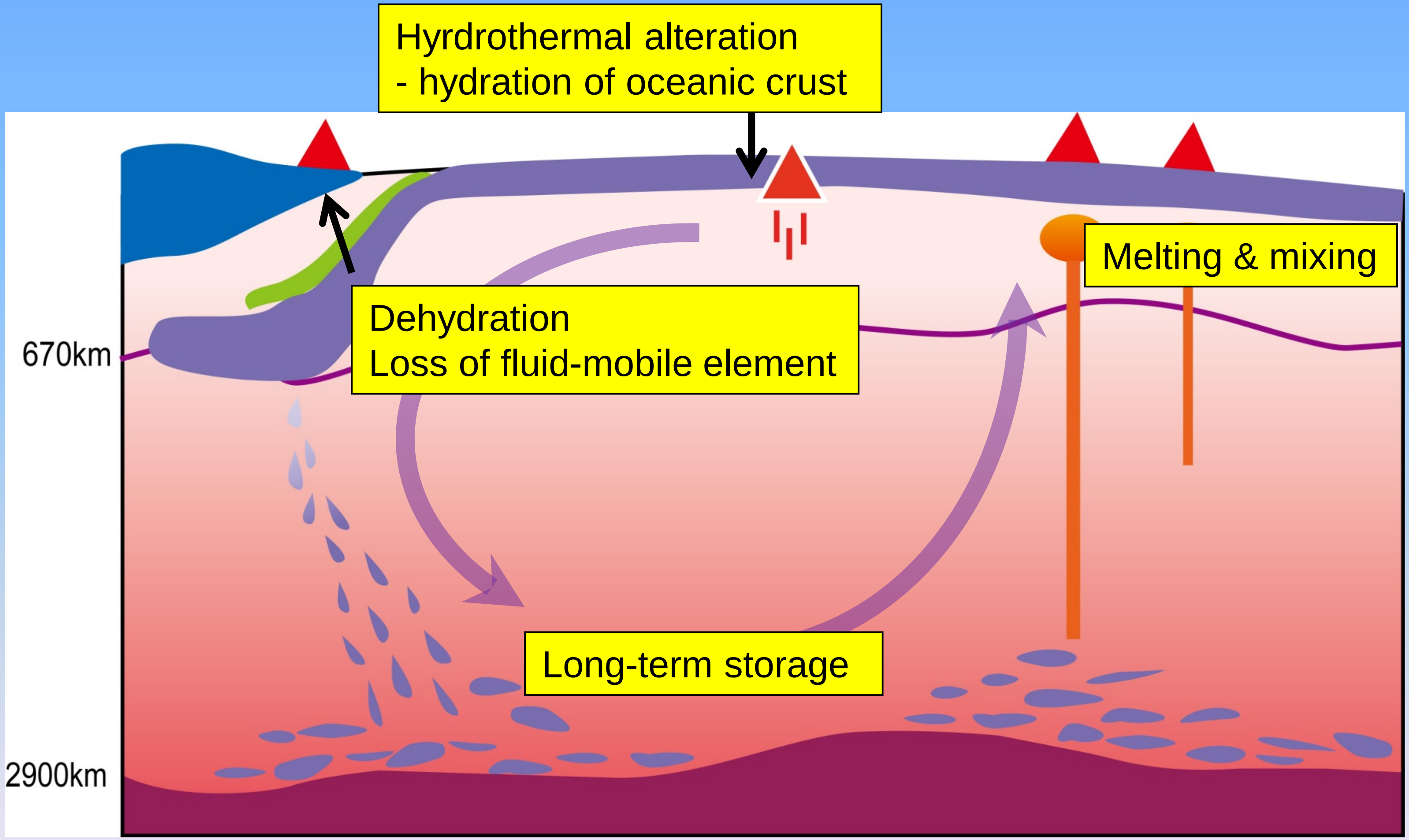
Concentrated in melt

Concentrated in residue

What is HIMU?

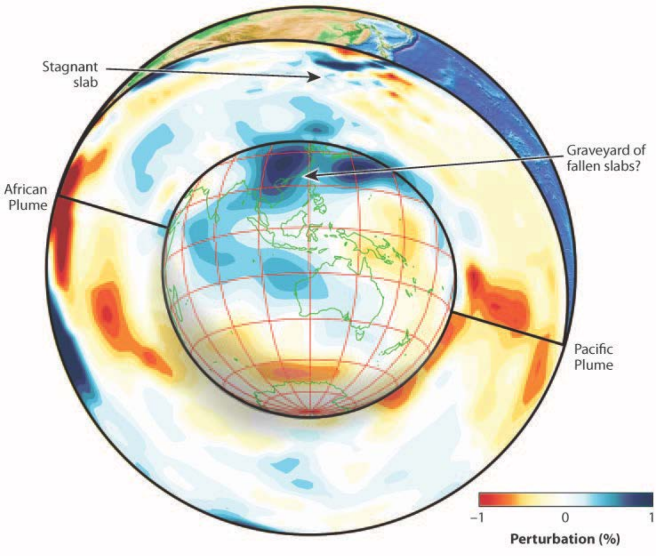

Hyrdrothermal alteration
- hydration of oceanic crust
670km
Dehydration
Loss of fluid-mobile element
Melting & mixing
Long-term storage
2900km

Age of HIMU reservoirs



Pacific HIMU vs Atlantic HIMU

Occurrence of “pure” HIMU basalts
is limited…



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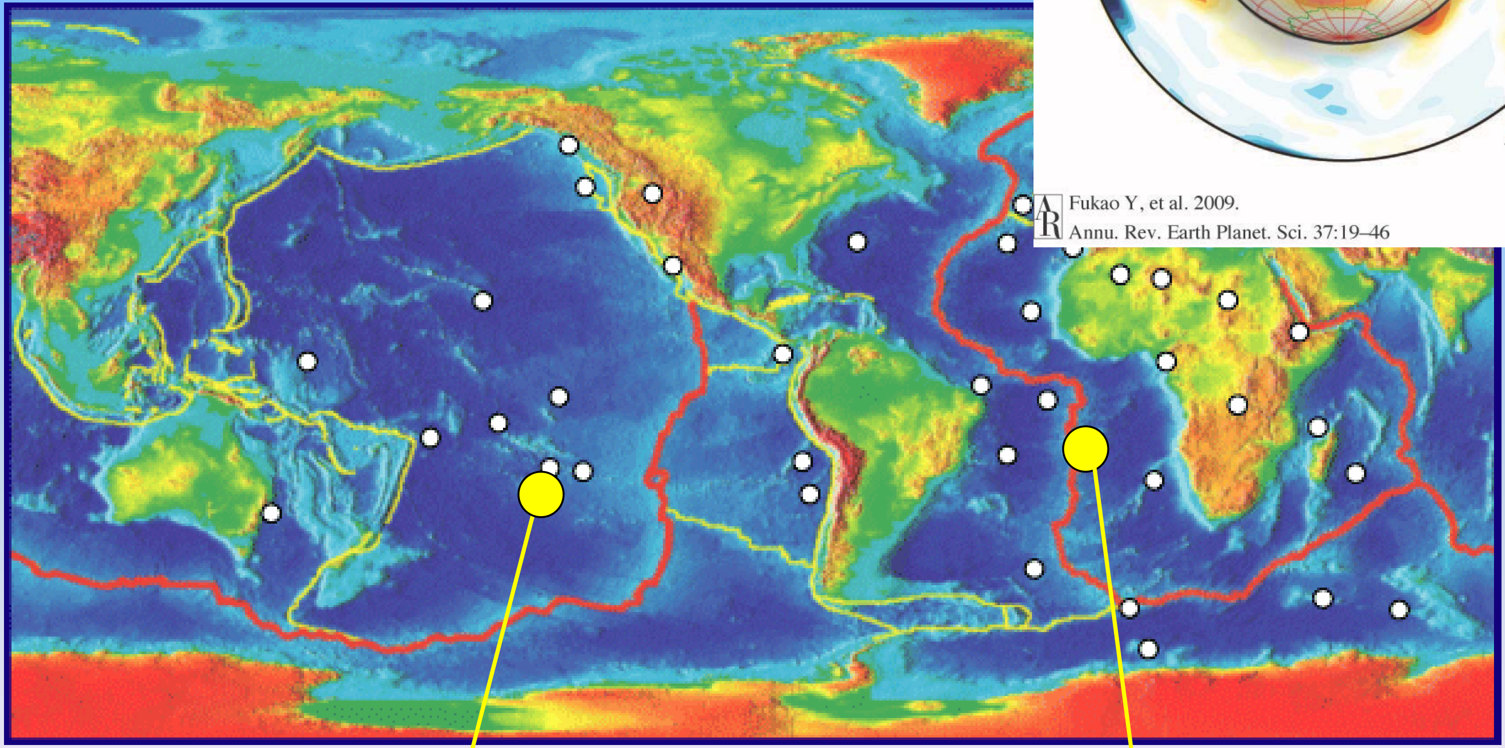
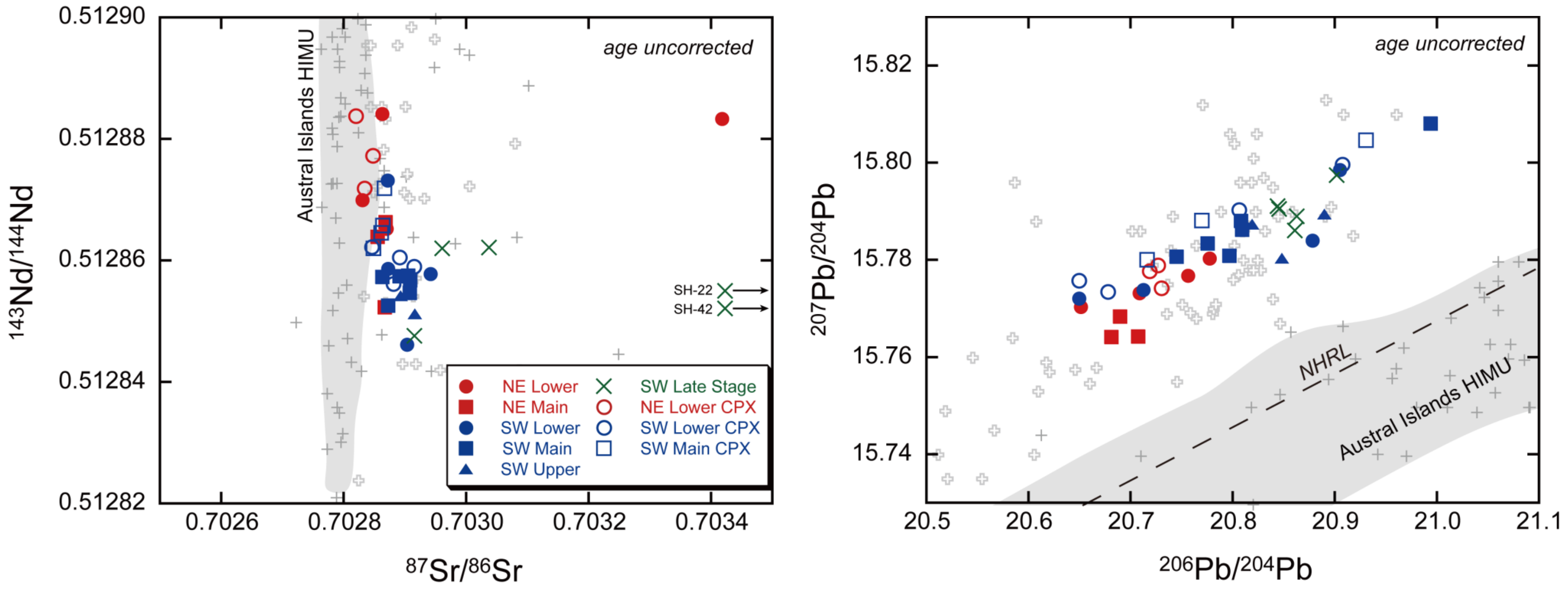


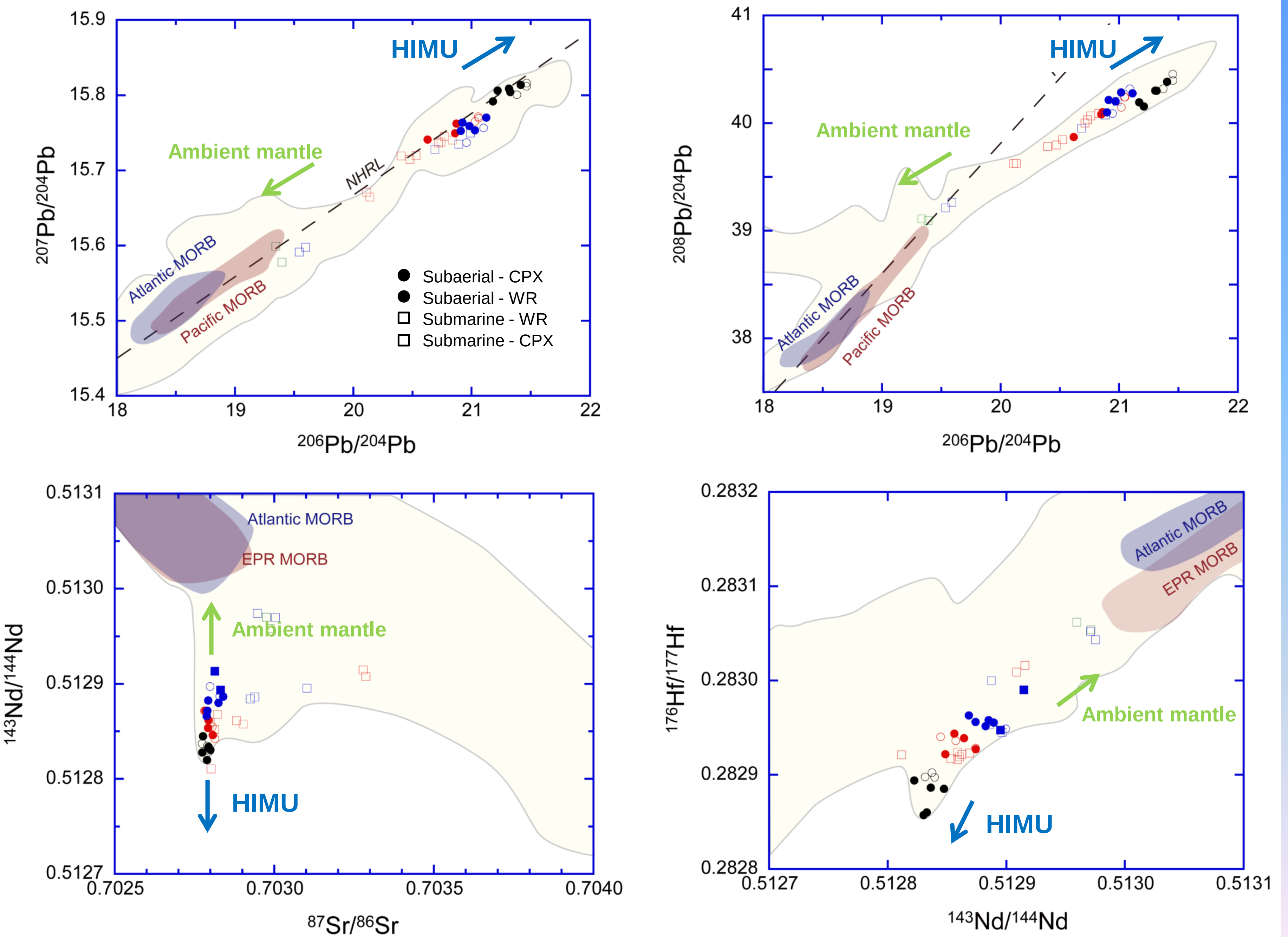
Austral – Cook Islands

St. Helena

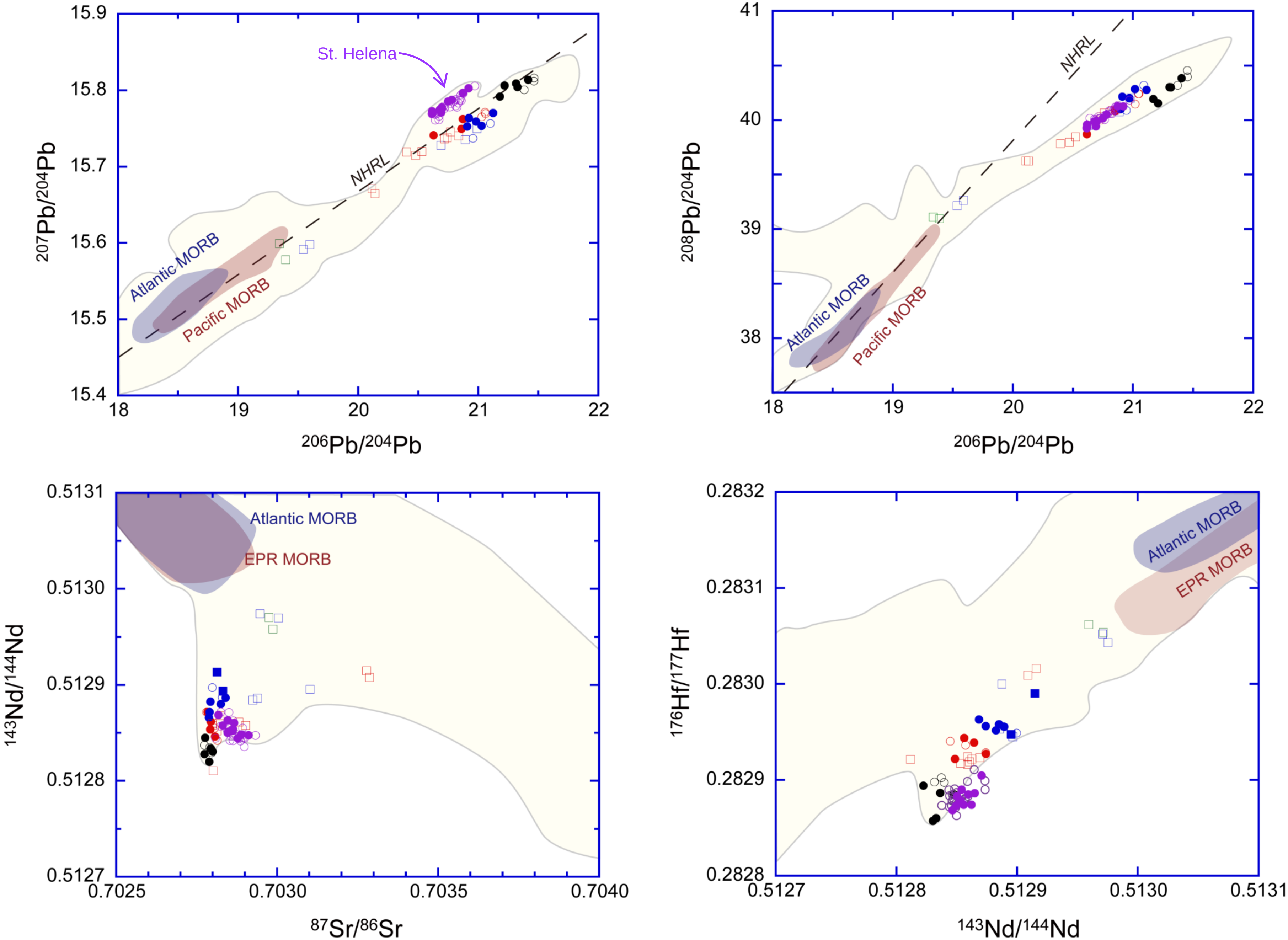
Pacific HIMU vs Atlantic HIMU



Hanyu et al. (2014)

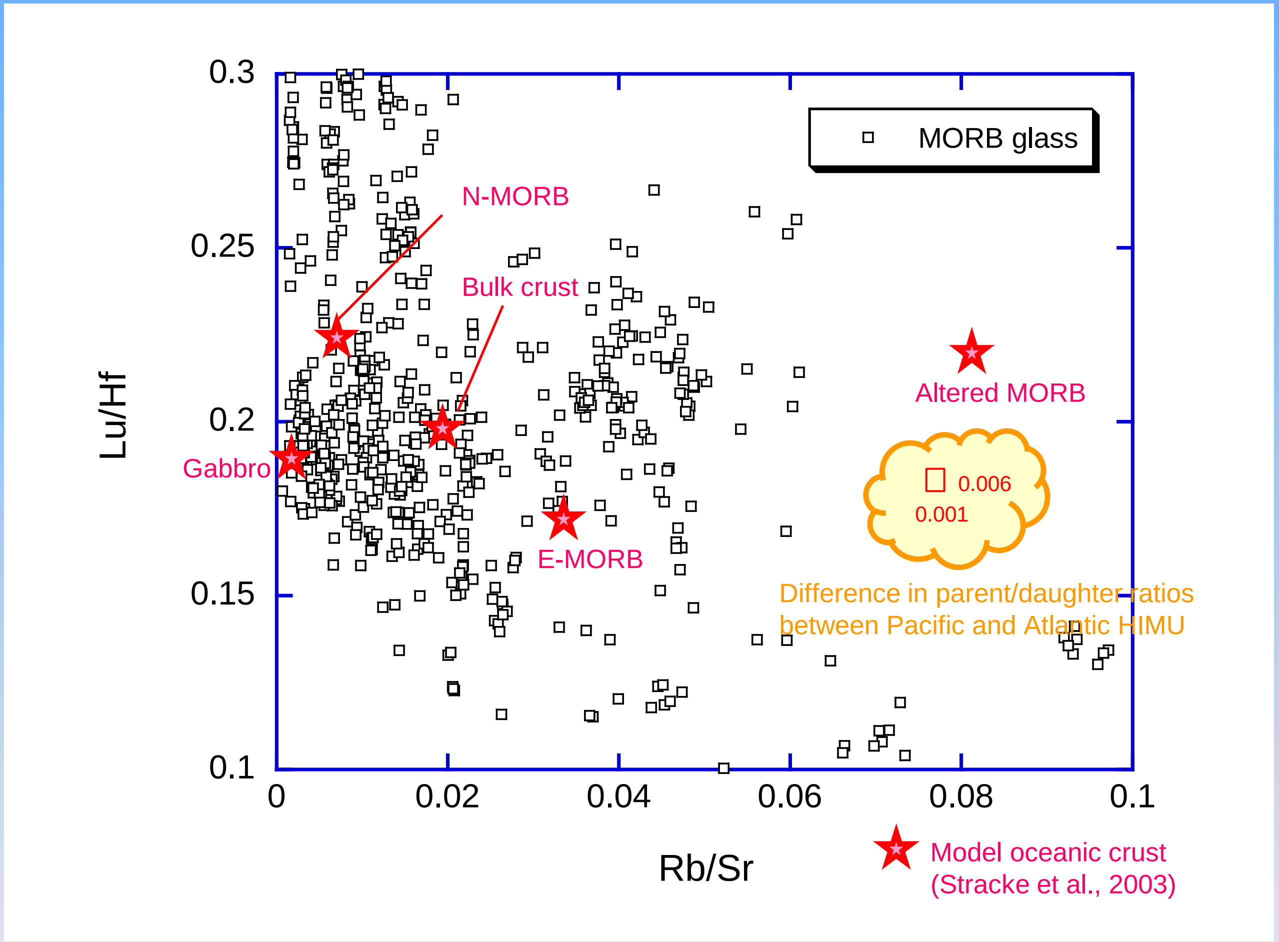


HIMU
Ambient mantle
NHRL
Atlantic MORB
Pacific MORB
Subaerial - CPX
Subaerial - WR
Submarine - WR
Submarine - CPX
$^{207}Pb/^{204}Pb$
$^{206}Pb/^{204}Pb$
HIMU
Ambient mantle
Atlantic MORB
Pacific MORB
$^{208}Pb/^{204}Pb$
$^{206}Pb/^{204}Pb$
Atlantic MORB
EPR MORB
Ambient mantle
HIMU
$^{143}Nd/^{144}Nd$
$^{87}Sr/^{86}Sr$
Atlantic MORB
EPR MORB
Ambient mantle
HIMU
$^{176}Hf/^{177}Hf$
$^{143}Nd/^{144}Nd$



15.9
15.8
15.7
15.6
15.5
15.4
18
19
20
21
22
$^{207}Pb/^{204}Pb$
$^{206}Pb/^{204}Pb$
St. Helena
NHRL
Atlantic MORB
Pacific MORB
41
40
39
38
$^{208}Pb/^{204}Pb$
$^{206}Pb/^{204}Pb$
NHRL
Atlantic MORB
Pacific MORB
0.5131
0.5130
0.5129
0.5128
0.5127
0.7025
0.7030
0.7035
0.7040
$^{143}Nd/^{144}Nd$
$^{87}Sr/^{86}Sr$
Atlantic MORB
EPR MORB
0.2832
0.2831
0.2830
0.2829
0.2828
0.5127
0.5128
0.5129
0.5130
0.5131
$^{176}Hf/^{177}Hf$
$^{143}Nd/^{144}Nd$
Atlantic MORB
EPR MORB

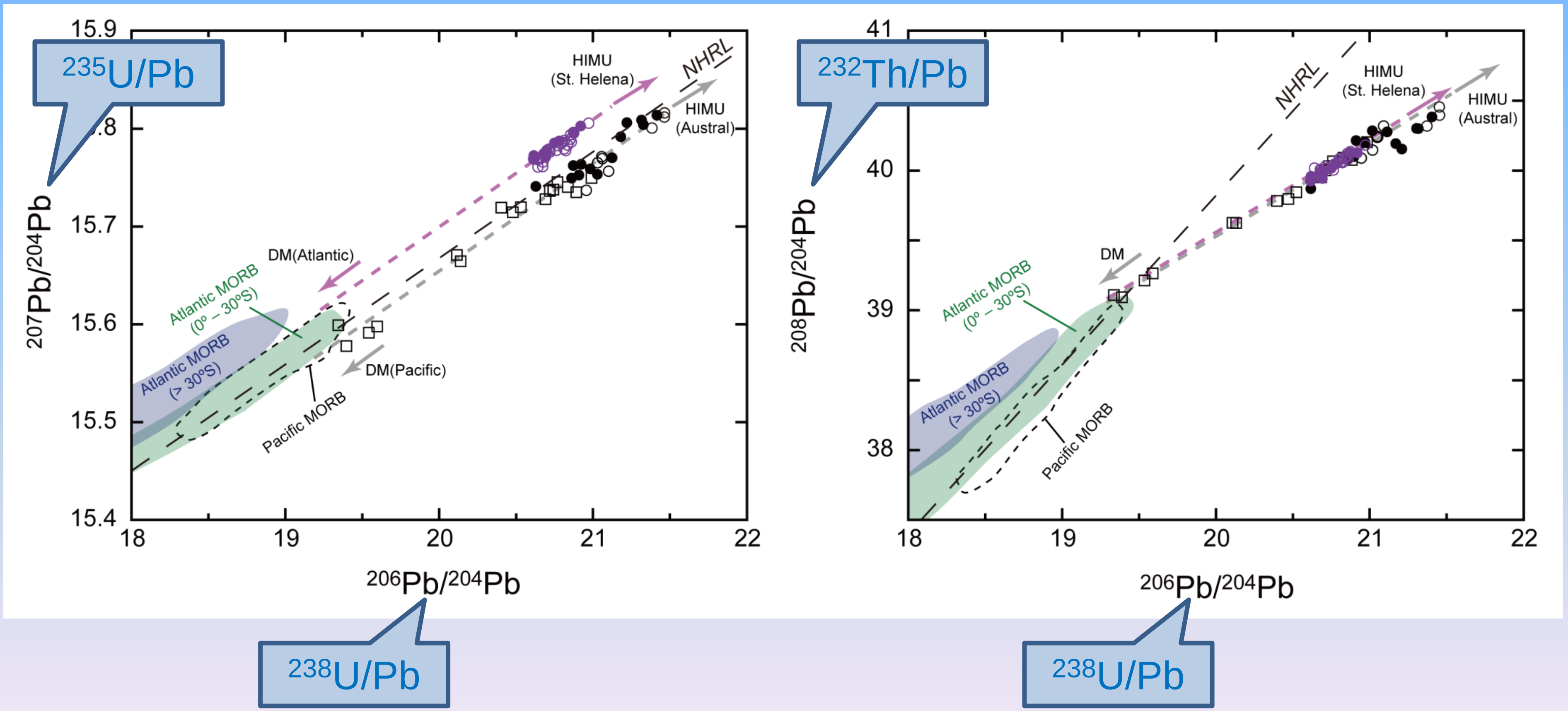
Pacific HIMU vs Atlantic HIMU



MORB glass data from Jenner and O’Neill (2012)

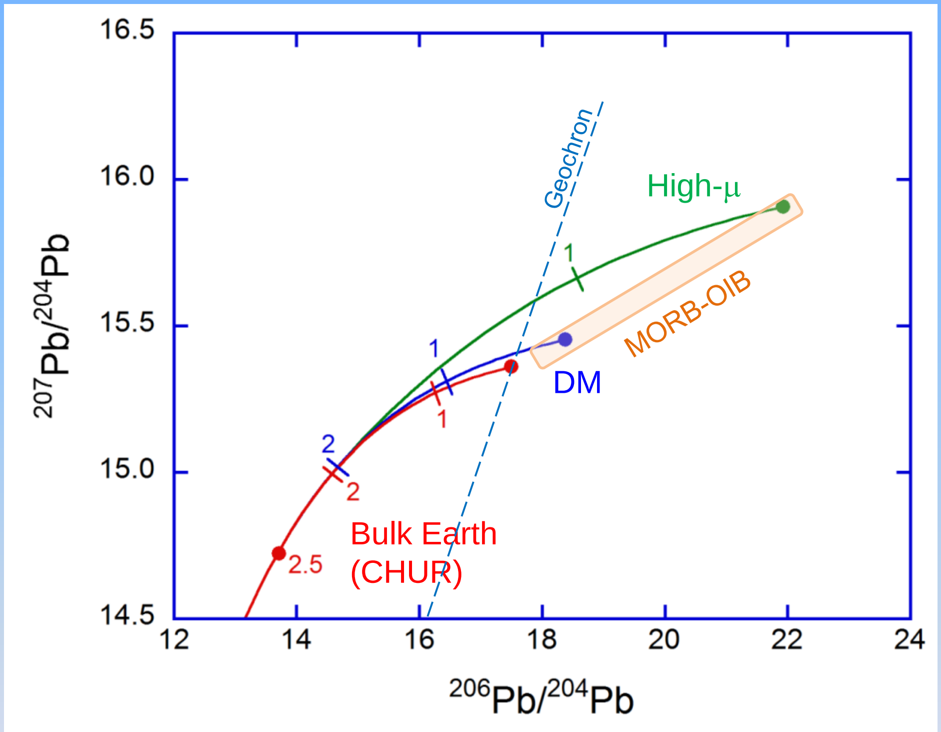
Age constraints (1); ^{206}Pb-^{207}Pb model age

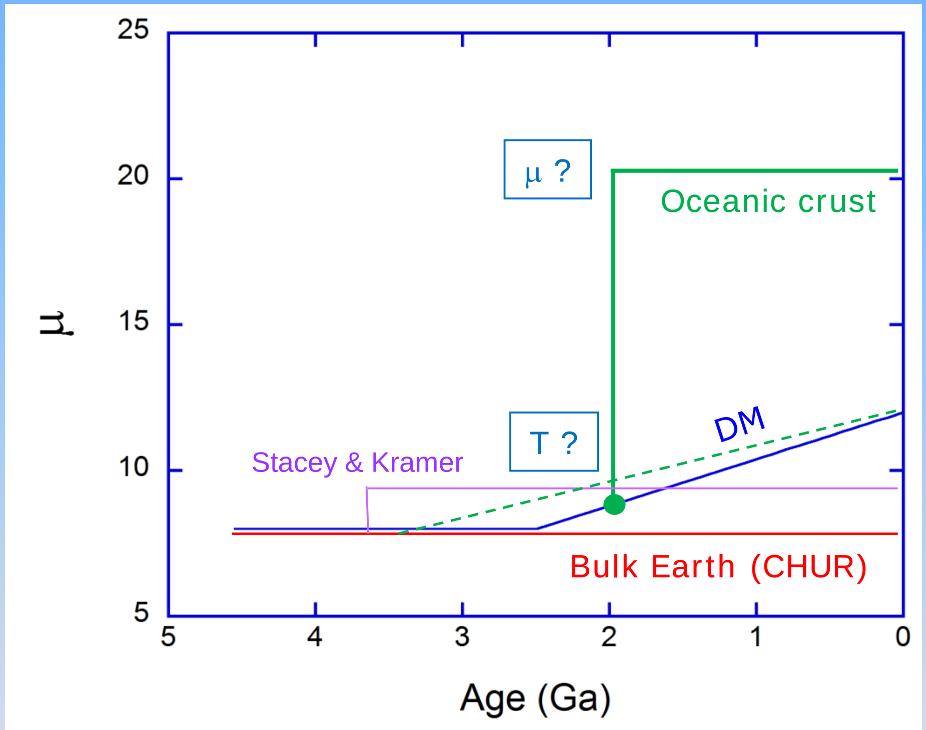
<u>(1) Age</u> <u>(2) Th/U</u>



Age constraints (1); ^{206}Pb-^{207}Pb model age

Mantle ^{207}Pb evolution model





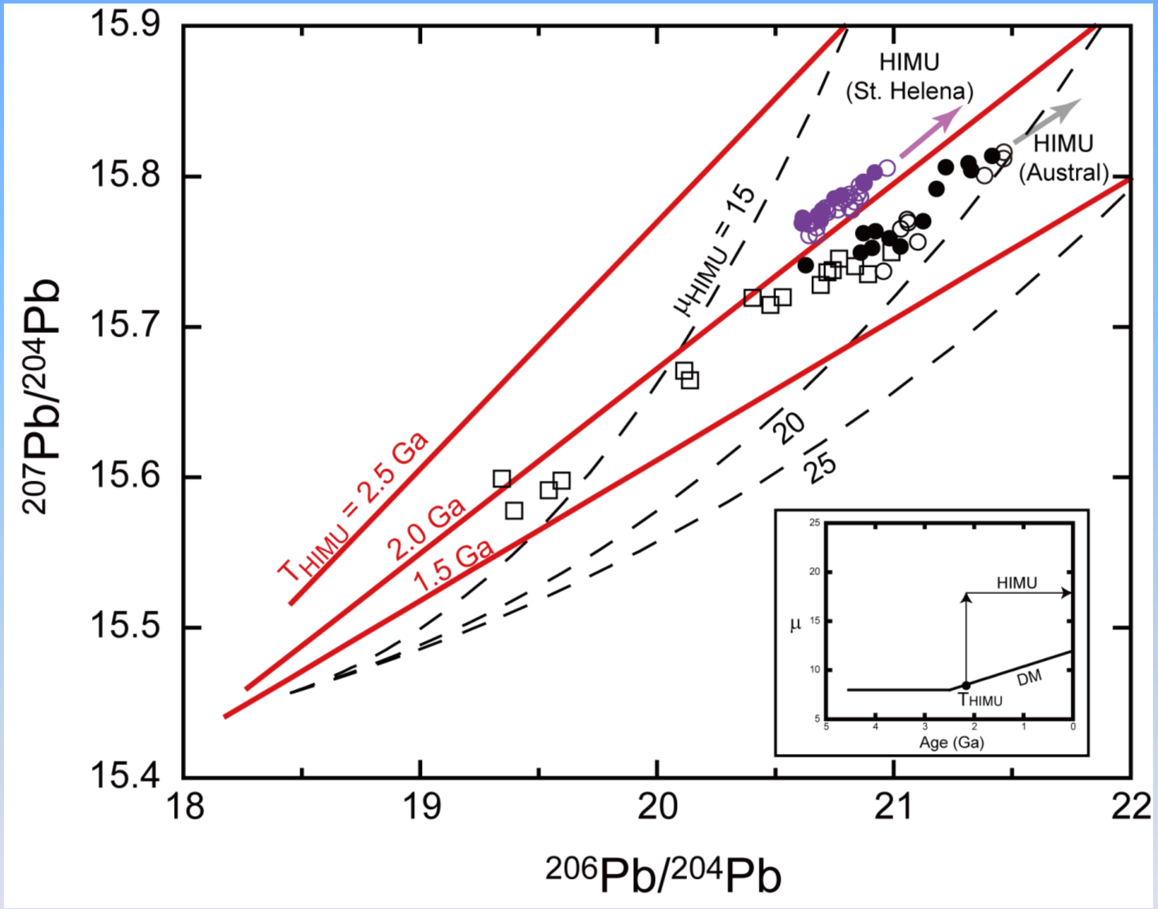
$^{238}U \rightarrow {}^{206}Pb$

$^{235}U \rightarrow {}^{207}Pb$

$(^{238}U/^{235}U)_p = 137.88$

$\mu = {}^{238}U/^{204}Pb$

Age constraints (1); ^{206}Pb-^{207}Pb model age

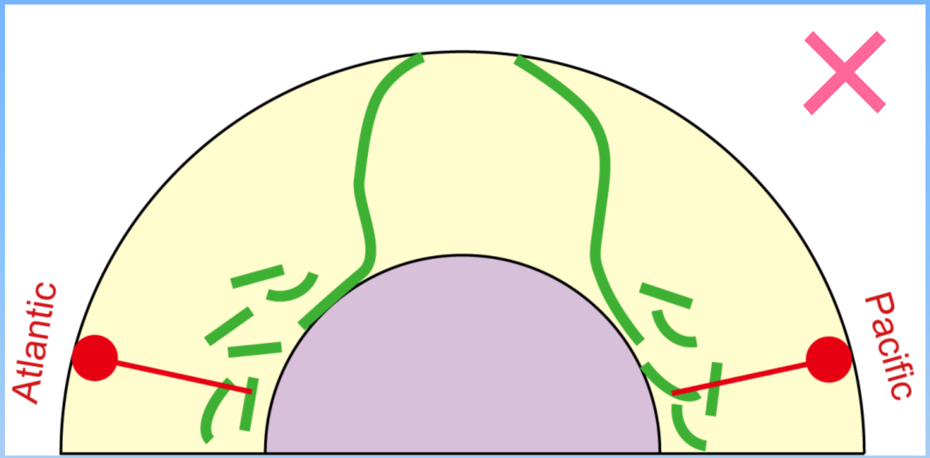


St. Helena; 1.8 – 2.3 Ga
Austral Islands; 1.5 – 2.0 Ga

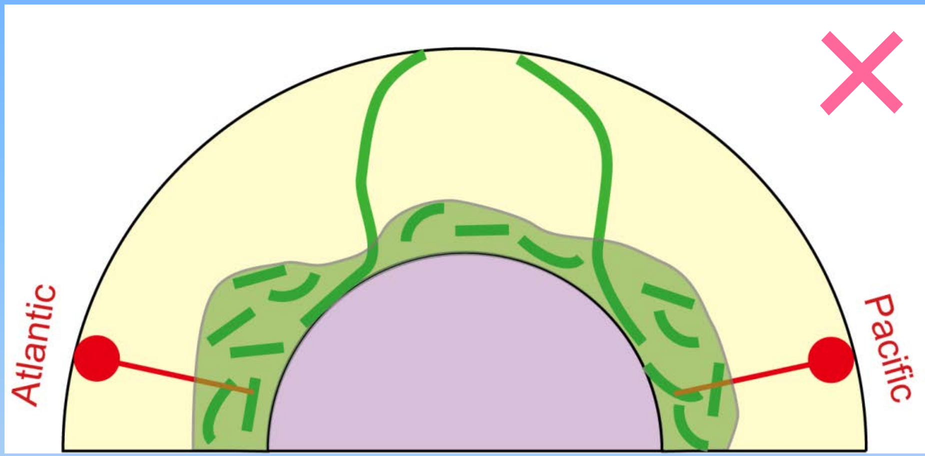
→ Atlantic HIMU is older than Pacific HIMU by 0.3 Ga.

Age constraints (1); ^{206}Pb-^{207}Pb model age

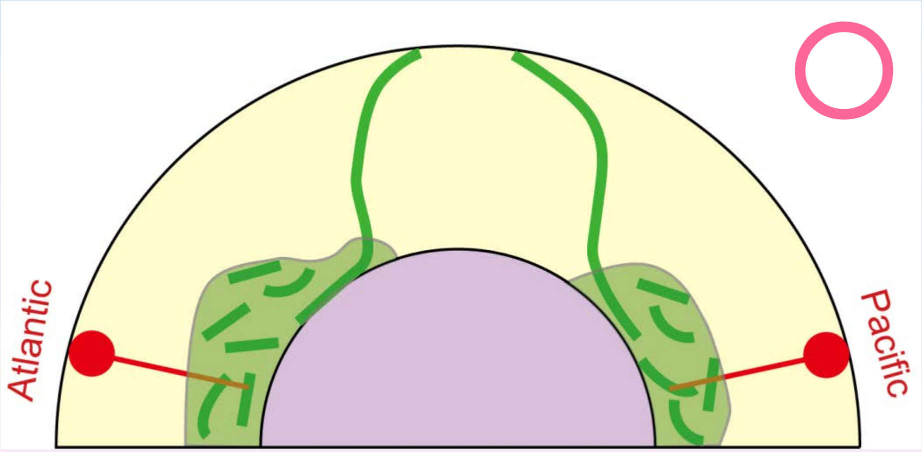
(1) Discrete HIMU reservoir(s)



(2) Single homogenized HIMU reservoir

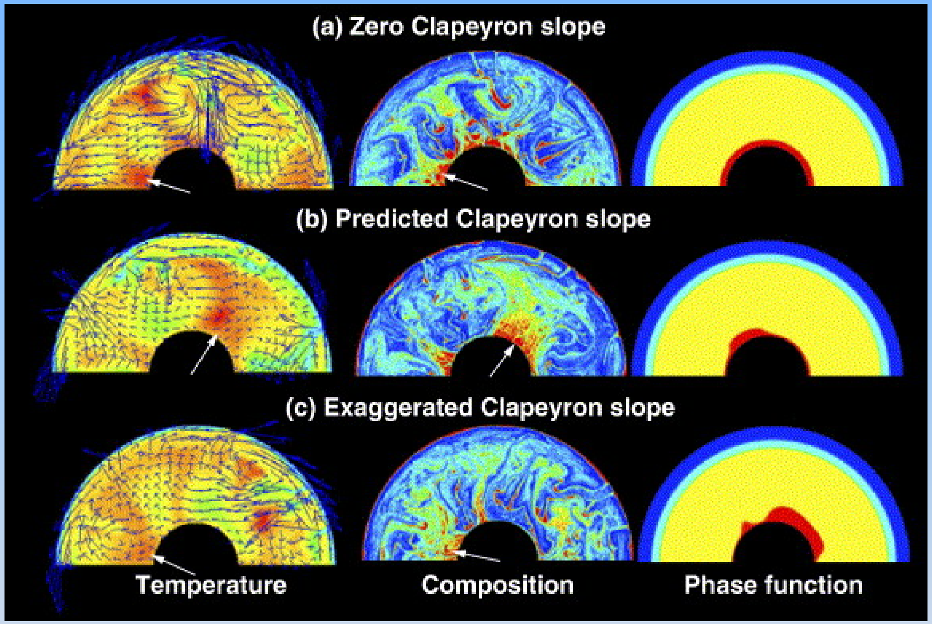


(3) Locally homogenized HIMU reservoirs

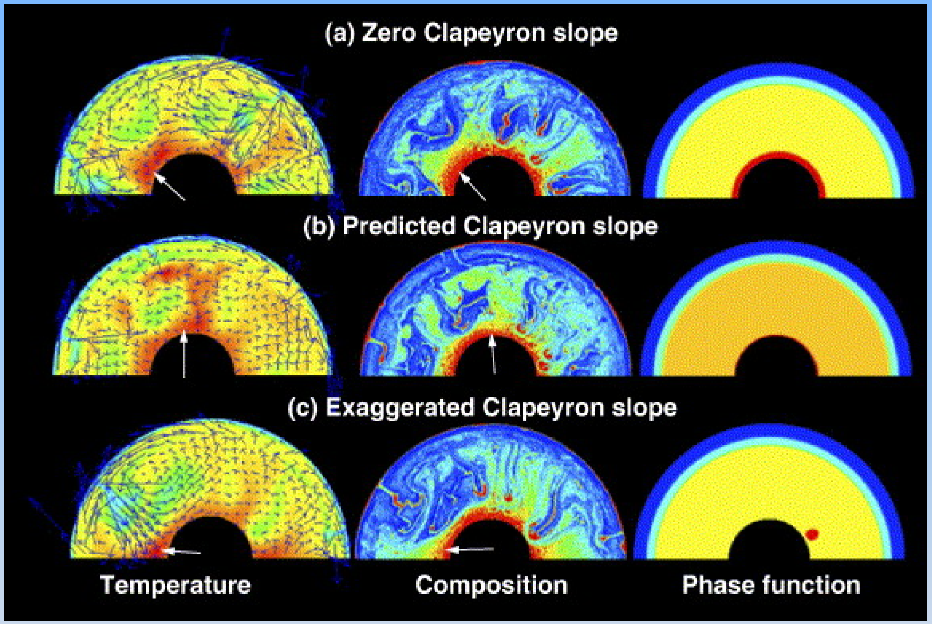


Age constraints (1); ^{206}Pb-^{207}Pb model age

Subducted crust; density difference = 2%



Subducted crust; density difference = 3%



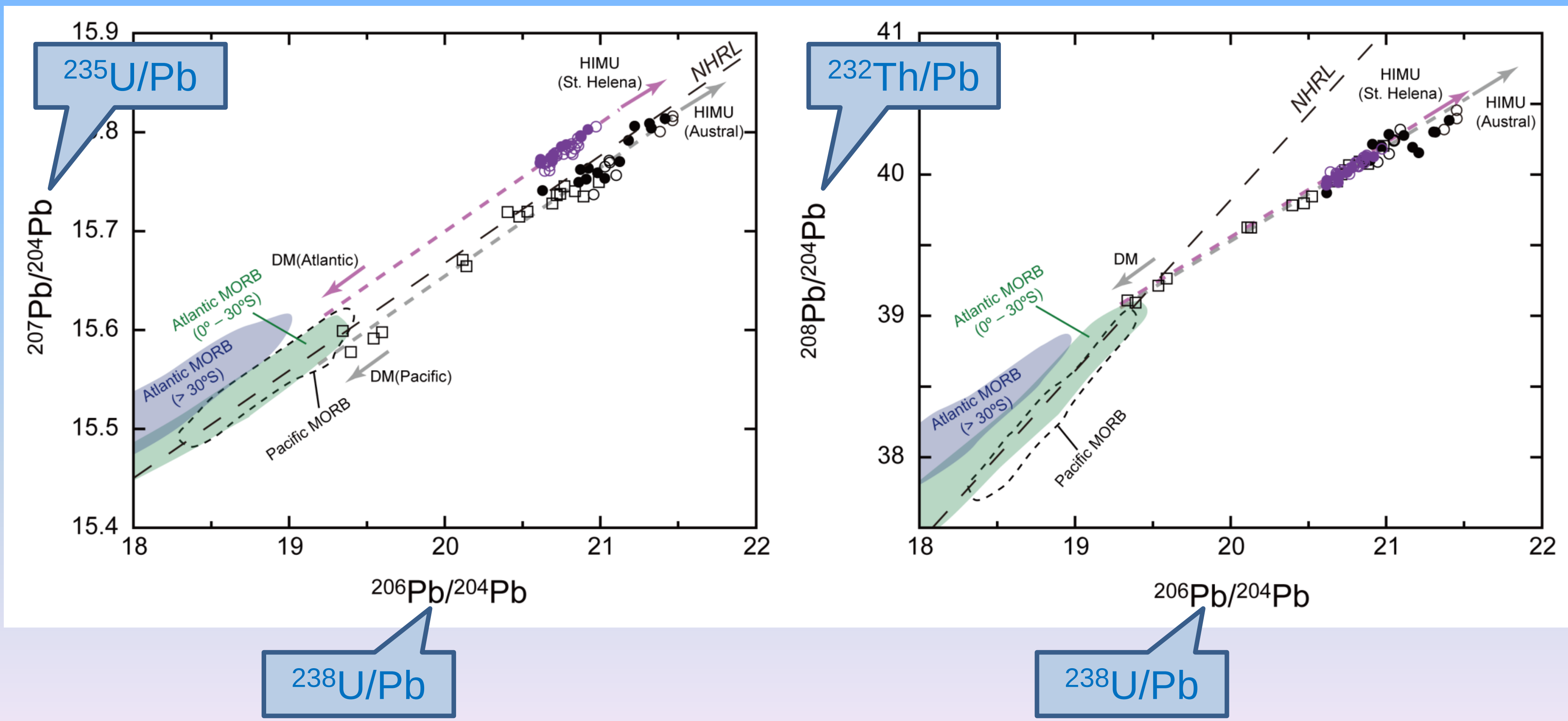
Composition;
blue; harzburgite
green; peridotite
red; basaltic crust

Nakagawa and Tackley (2005)

Age constraints (2); Th-U recycling

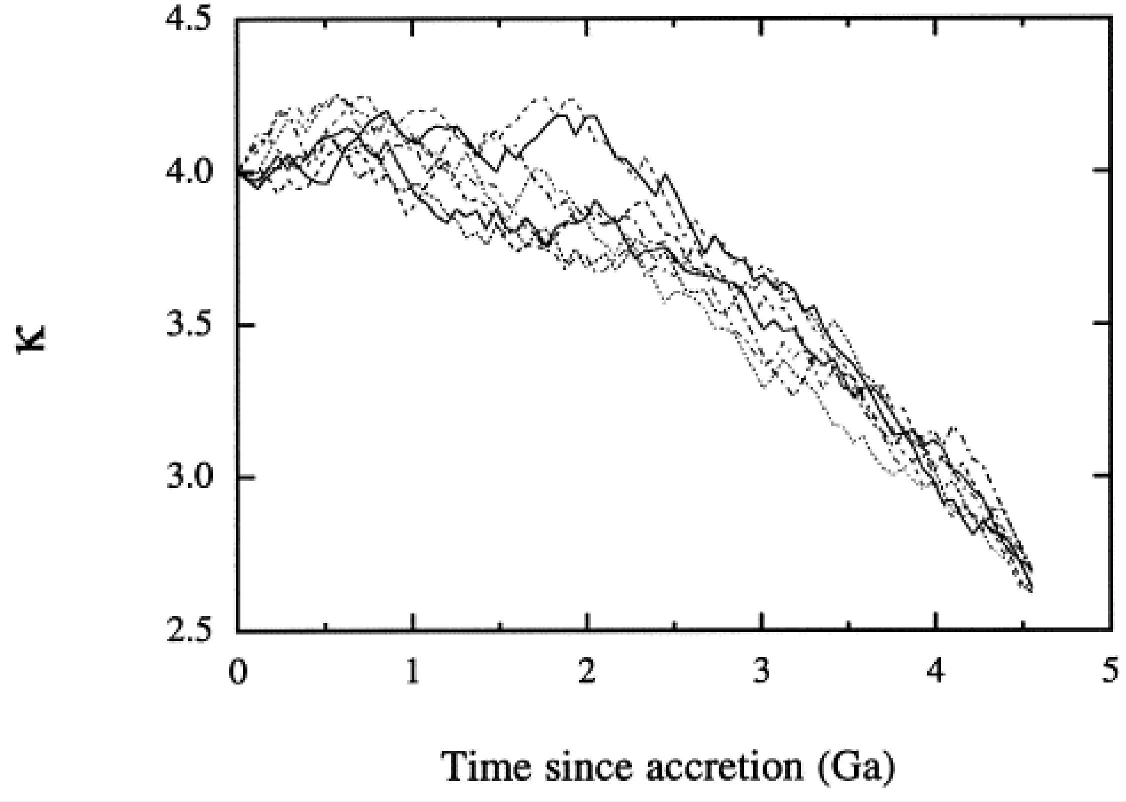
(1) Age

(2) Th/U



Age constraints (2); Th-U recycling

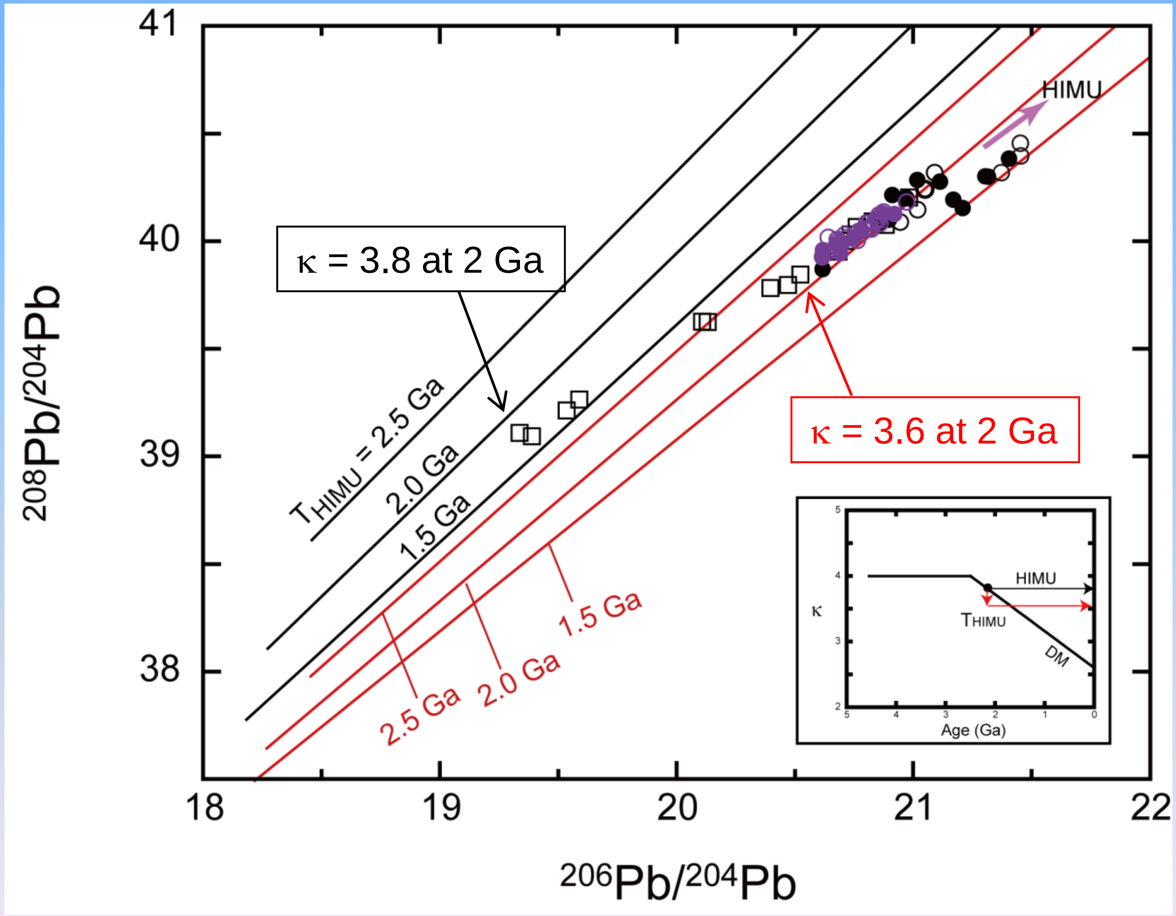
$\kappa = {}^{232}Th/{}^{238}U \sim 1.03 \times Th/U$



Elliott et al. (1999)

Age constraints (2); Th-U recycling

$\kappa = {}^{232}Th/{}^{238}U \sim 1.03 \times Th/U$

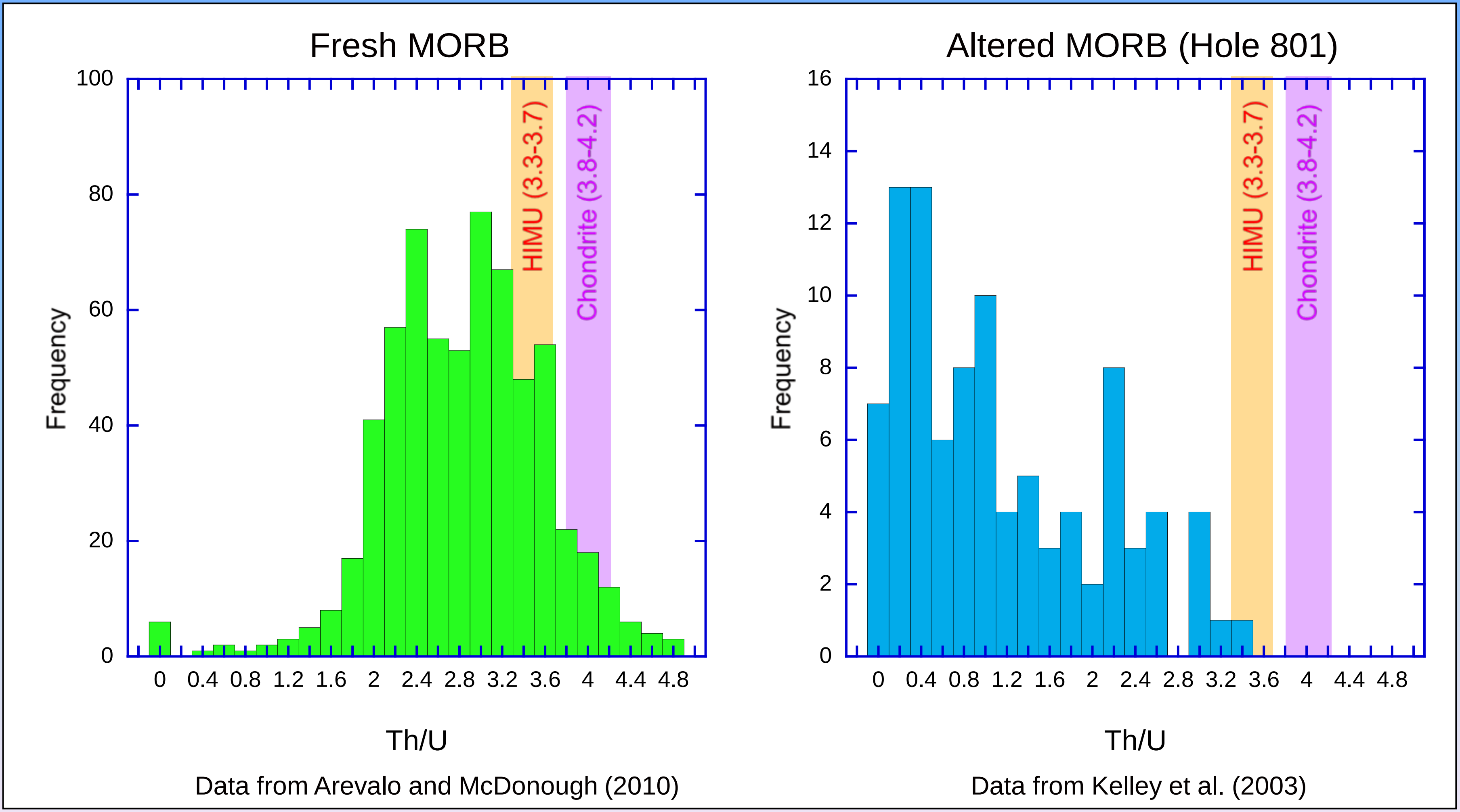


κ value

HIMU: 3.3 – 3.7

Chondrite (bulk Earth): 3.8 – 4.2

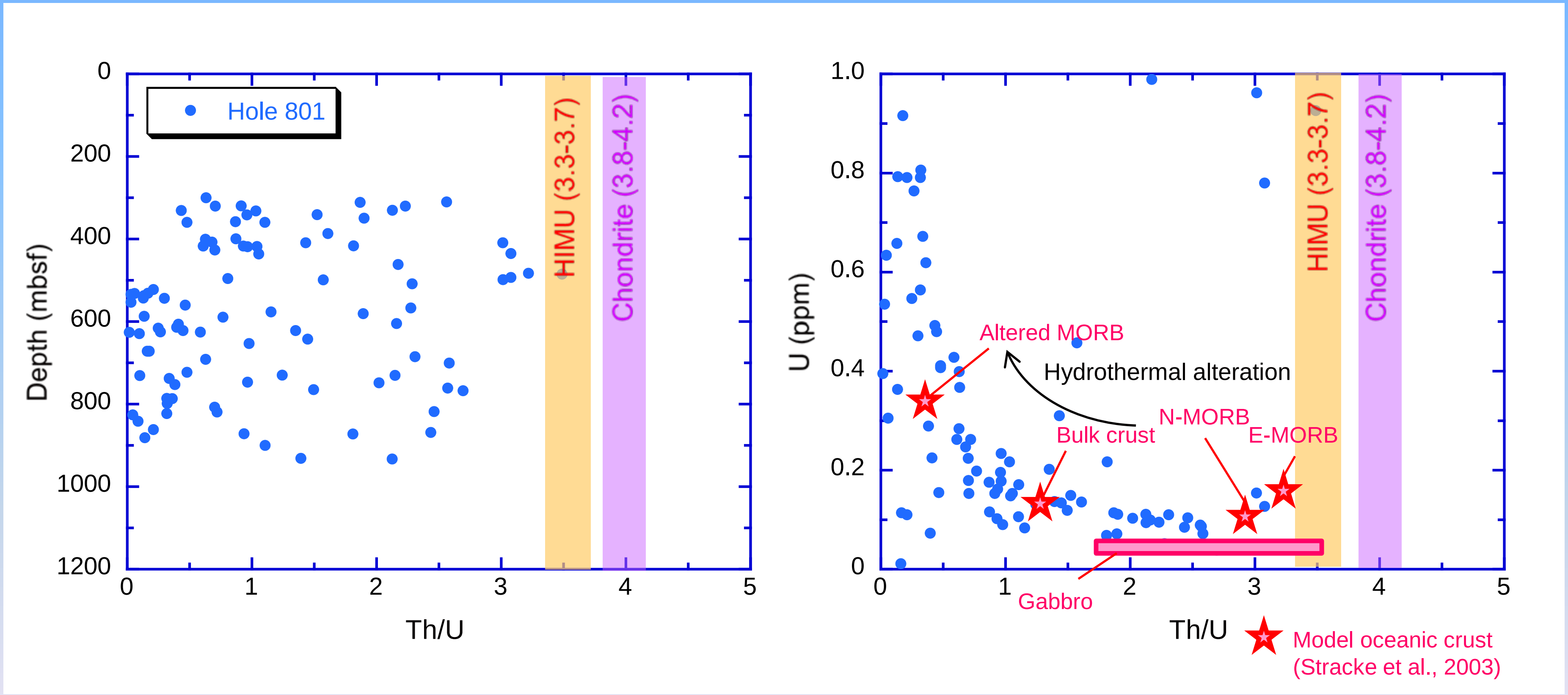
Age constraints (2); Th-U recycling



$\kappa = {}^{232}Th/{}^{238}U \sim 1.03 \times Th/U$

Age constraints (2); Th-U recycling

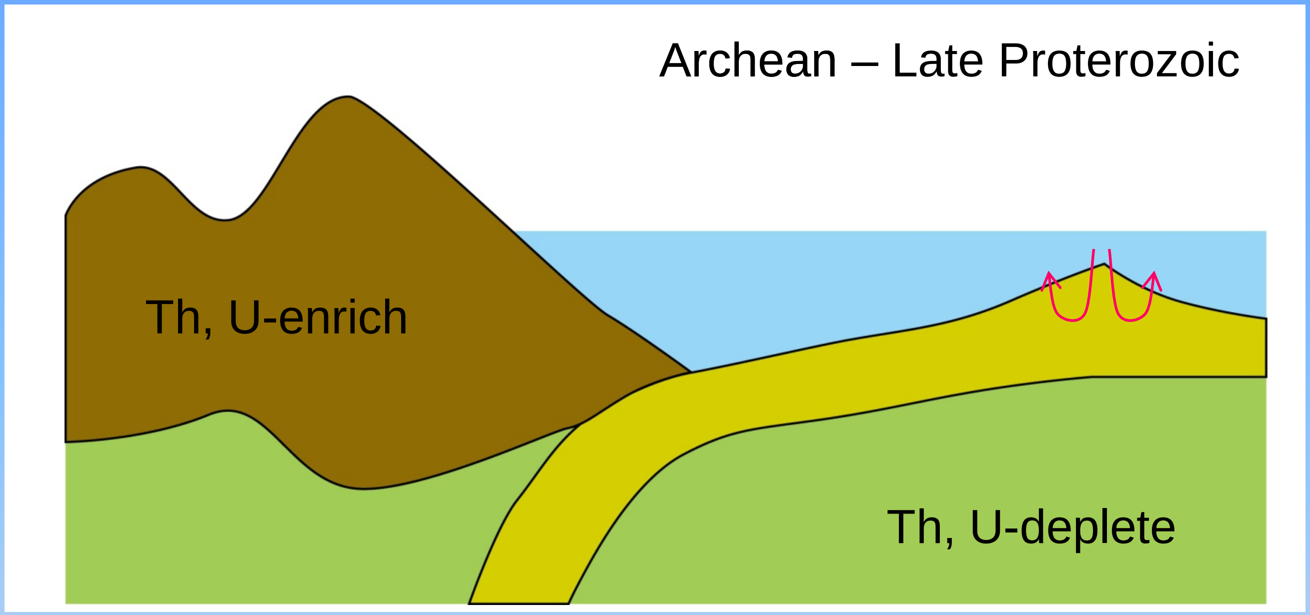
κ of HIMU is too high, if the precursor of HIMU was recycled altered oceanic crust !



Data from Kelley et al. (2003)

Altered basaltic crust is enriched in U, and hence its Th/U is lowered, by hydrothermal alteration.

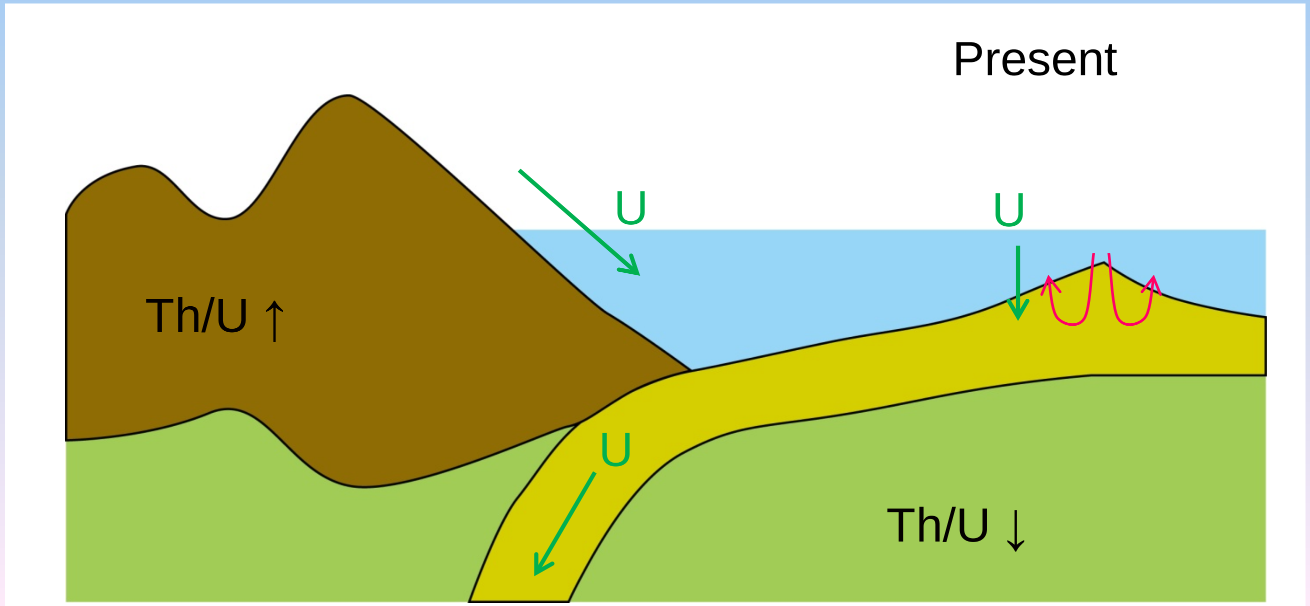
Age constraints (2); Th-U recycling



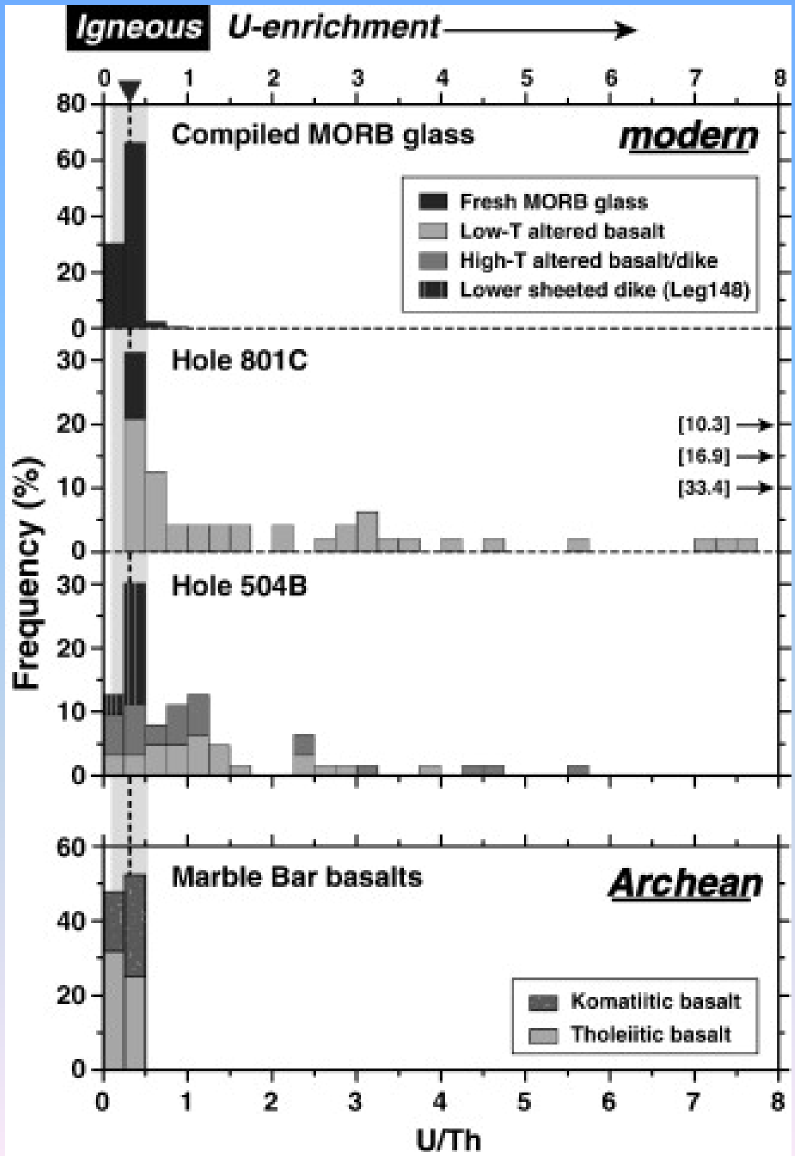
U^{4+}: less mobile with fluids like Th

U^{6+}: mobile with fluids

Oxydation in hydrosphere



Age constraints (2); Th-U recycling

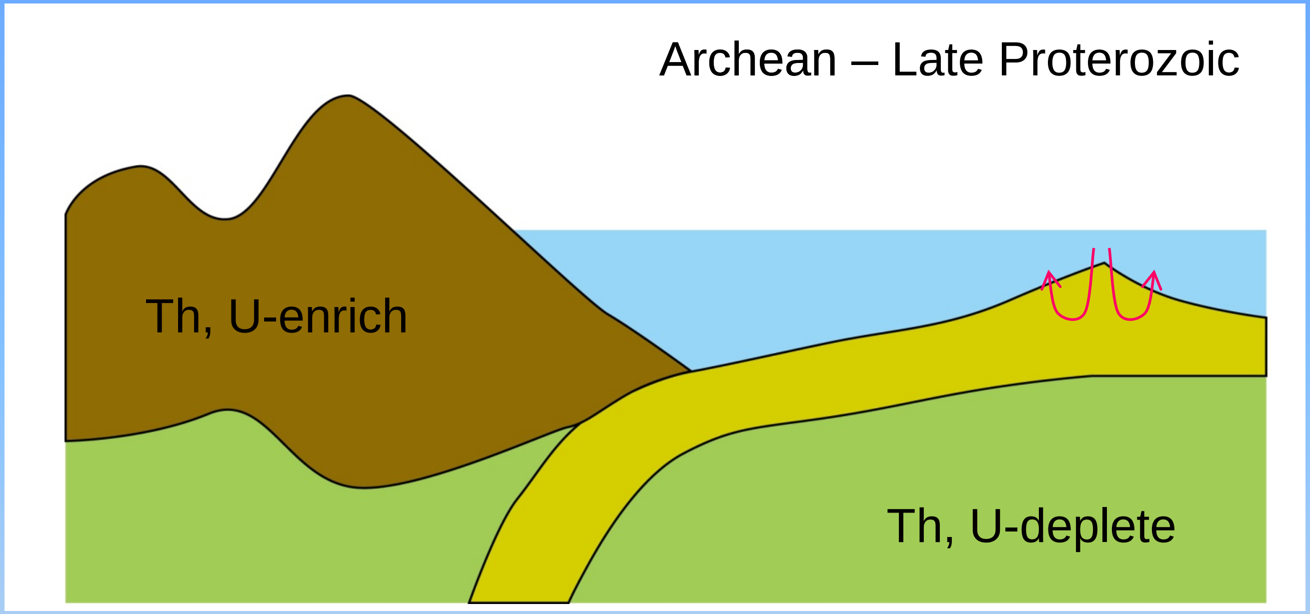


Present-day altered MORB has low Th/U.

Archean altered MORB has as high Th/U as chondritic value.

Nakamura and Kato (2007)

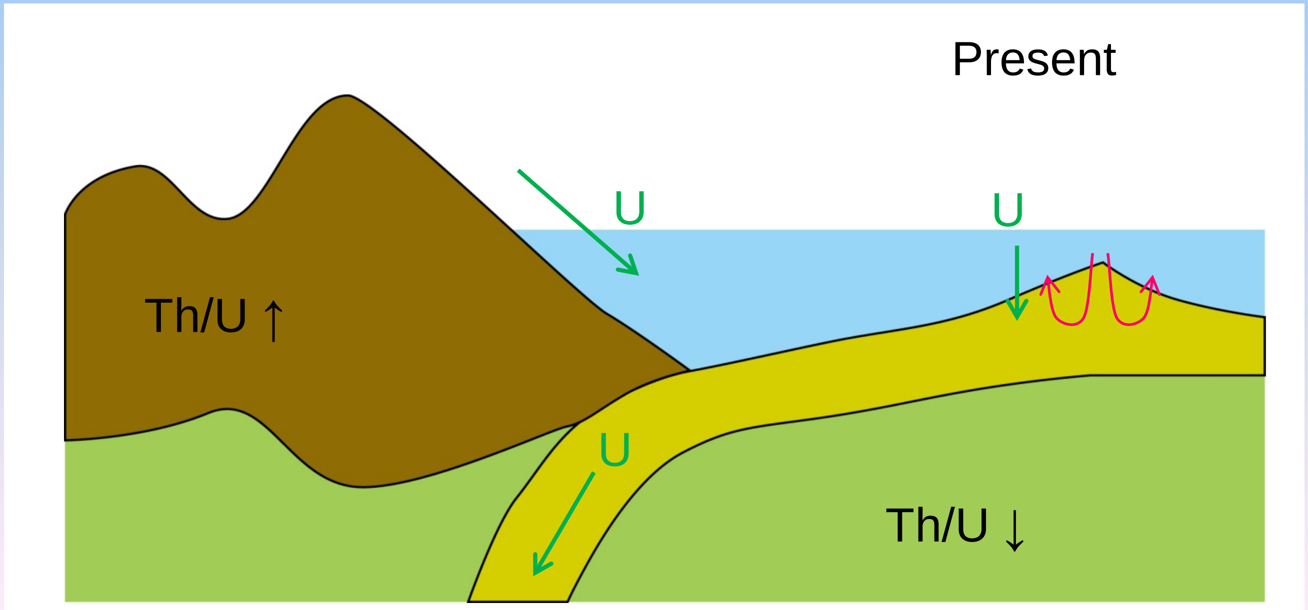
Age constraints (2); Th-U recycling



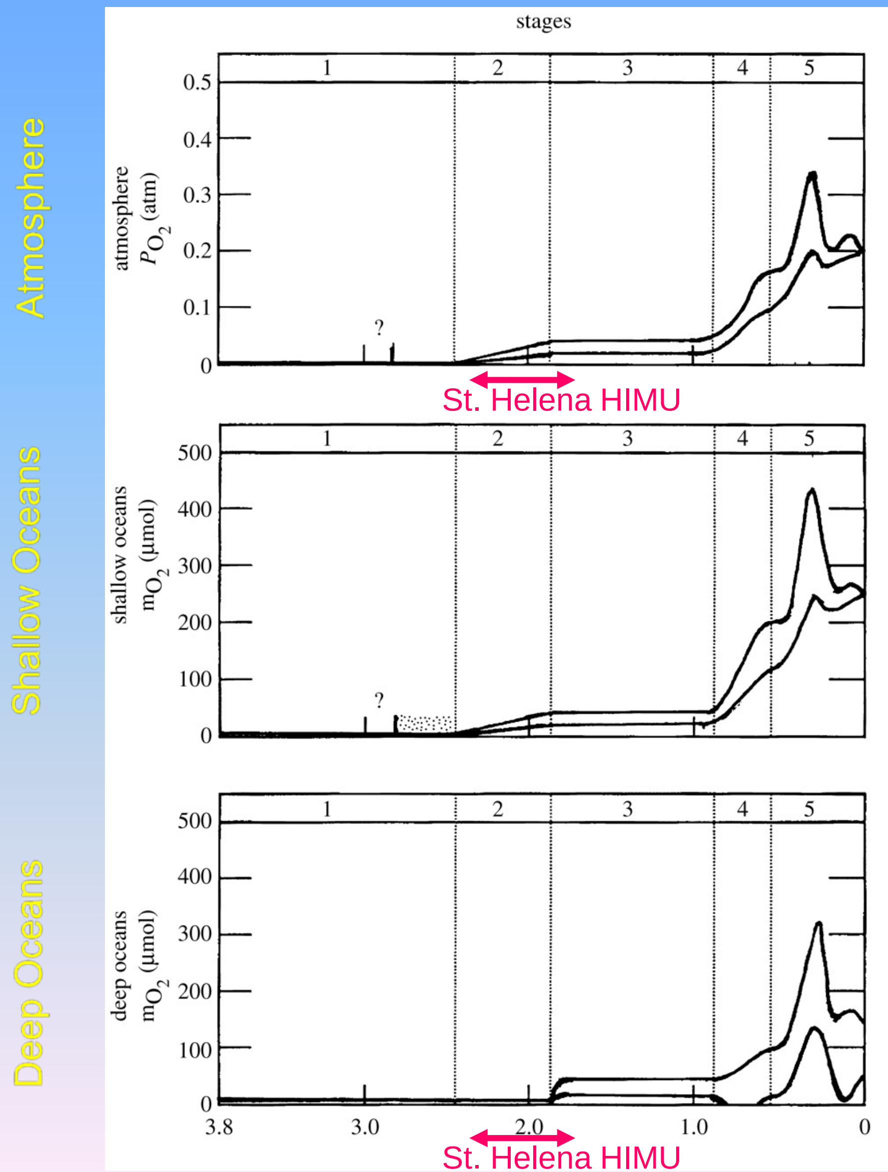
U^{4+}: less mobile with fluids like Th

U^{6+}: mobile with fluids

Oxydation in hydrosphere



Age constraints (2); Th-U recycling



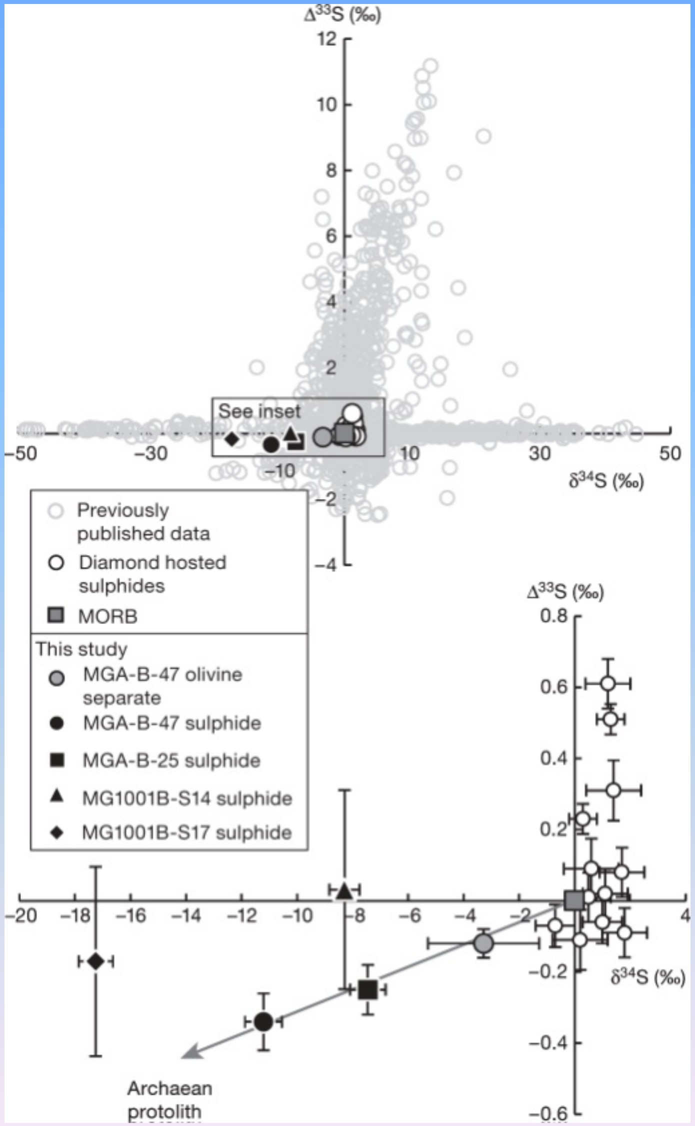
The start of Great Oxidation Event (GOE) at 2.4 Ga.

HIMU reservoir age estimated from ^{206}Pb-^{207}Pb systematics is;
St. Helena; 1.8 – 2.3 Ga
Austral Islands; 1.5 – 2.0 Ga

Oxygenation in deep water may be delayed than that in shallow water.

Holland (2006)

Age constraints (2); Th-U recycling



Mass-independent fractionation (MIF) of sulfur isotope ($\Delta^{33}S$) in HIMU basalts.

Cabral et al. (2013)

Summary

HIMU beneath Pacific and Atlantic show very similar isotopic compositions except for the ^{206}Pb-^{207}Pb systematics.

From the ^{206}Pb-^{207}Pb systematics, the reservoir age of HIMU is around 2 Ga, but that of the Atlantic HIMU is 0.3 Ga younger than that of the Pacific HIMU.

It is suggested that subducted crust form distinct HIMU reservoirs beneath Pacific and Atlantic.

Th/U in HIMU estimated from ^{206}Pb-^{208}Pb systematics is too high than that of present-day altered oceanic crust.

The HIMU reservoir should involve subducted oceanic crust that were altered in anoxic condition in Archean or early Proterozoic.