NS seminar

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Helium isotopic evidence for episodic mantle melting and crustal growth

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He stable isotope

- ^{3}He: primordial

  It has been present unchanged since Earth first formed, but it is largely lost from the mantle through the degassing process (melting)
- ^{4}He: replenished

  It is continuously produced by decay of the radioactive elements uranium and thorium.

Previous studies for $^{4}He/^{3}He$ ratios

- Two distinct reservoirs

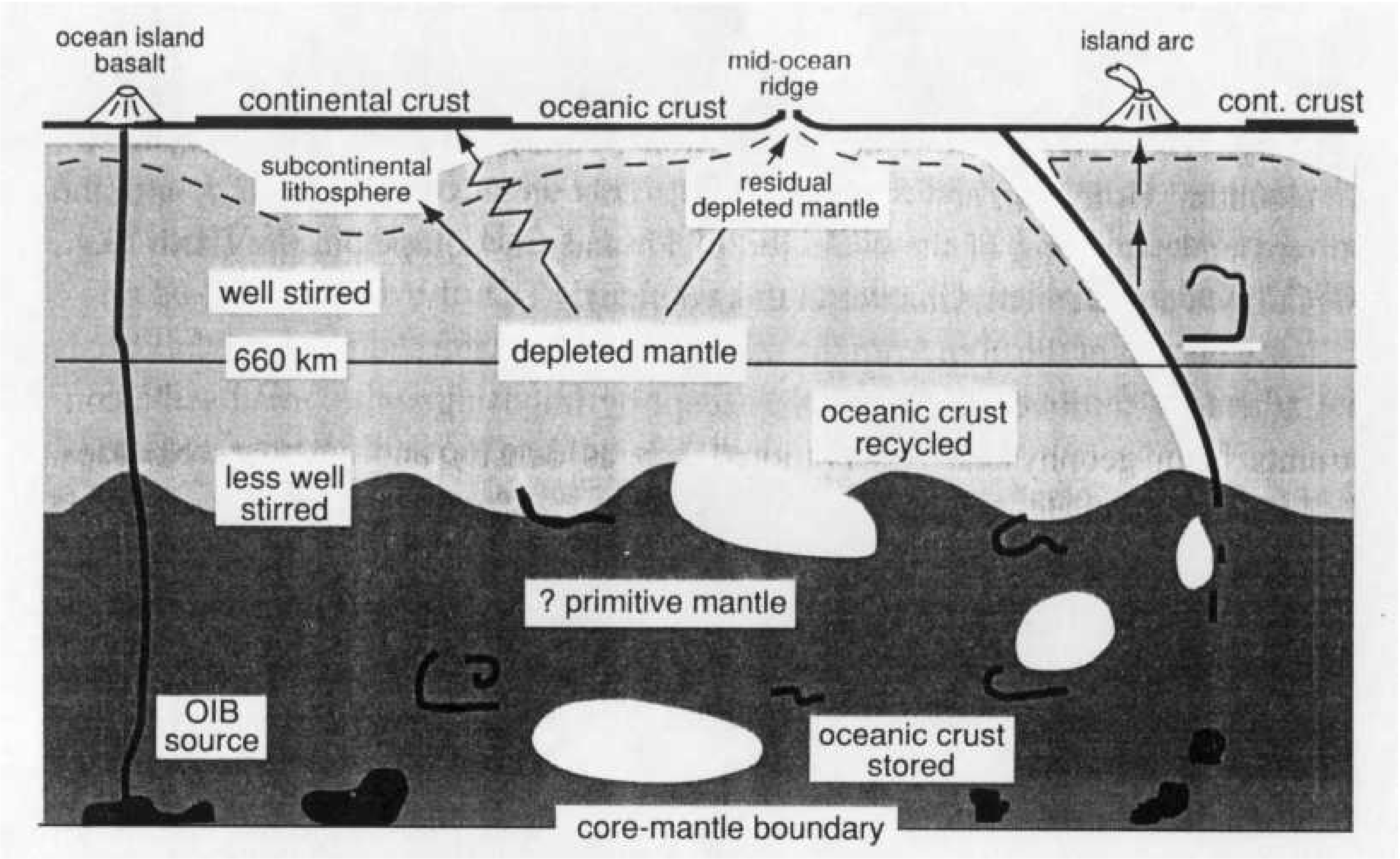
MORB: degassed, high $^{4}He/^{3}He$ mantle,which is due to melting (loss of ^{3}He)

OIB: undegassed, low $^{4}He/^{3}He$ mantle (derived from low mantle?)

2 layer convection model

Depleted upper mantle and fertile lower mantle

2 geochemical reservoirs

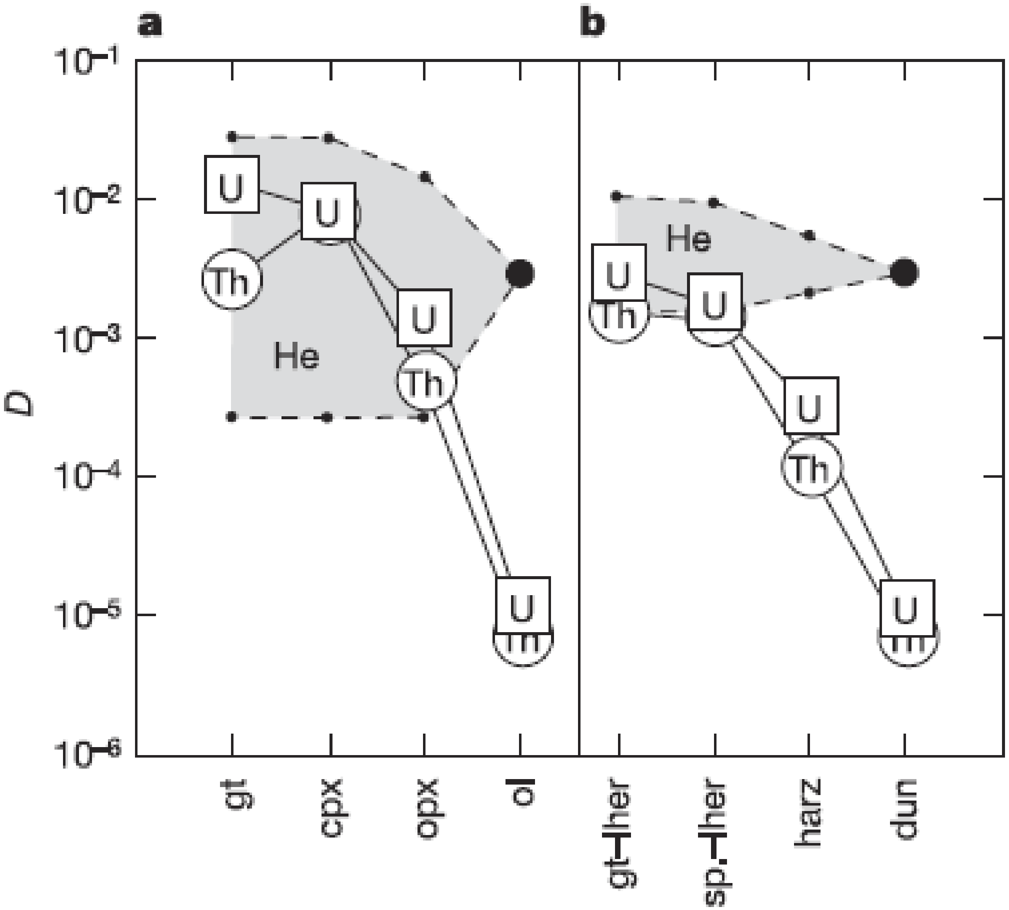


Basic assumptions

- The lowest $^4He/^3He$: an undegassed mantle component
- $D^{He}=He_{crystal}/He_{melt} < D^{U+Th}=U+Th_{crystal}/U+Th_{melt}$

Recent experiment does not assist the above assumptions

Partitioning of He, U and Th between olivine and melt



- For olivine, He is more compatible than U and Th.

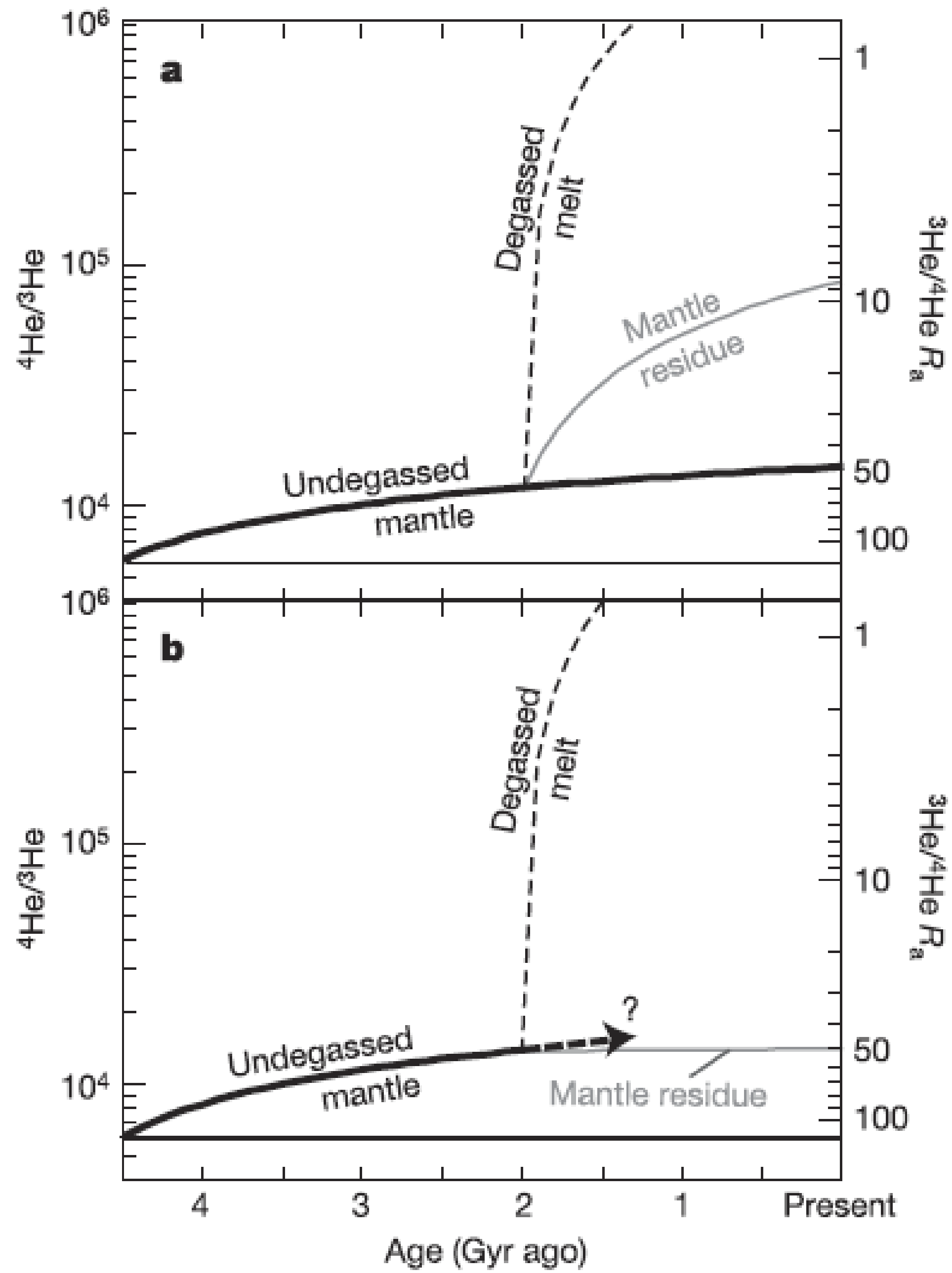
Parman, S. W., Kurz, M. D., Hart, S. R. & Grove, T. L. Helium solubility in olivine and implications for high $^3He/^4He$ in ocean island basalts. *Nature* **437**, 1140–1143 (2005).

He isotope evolution model

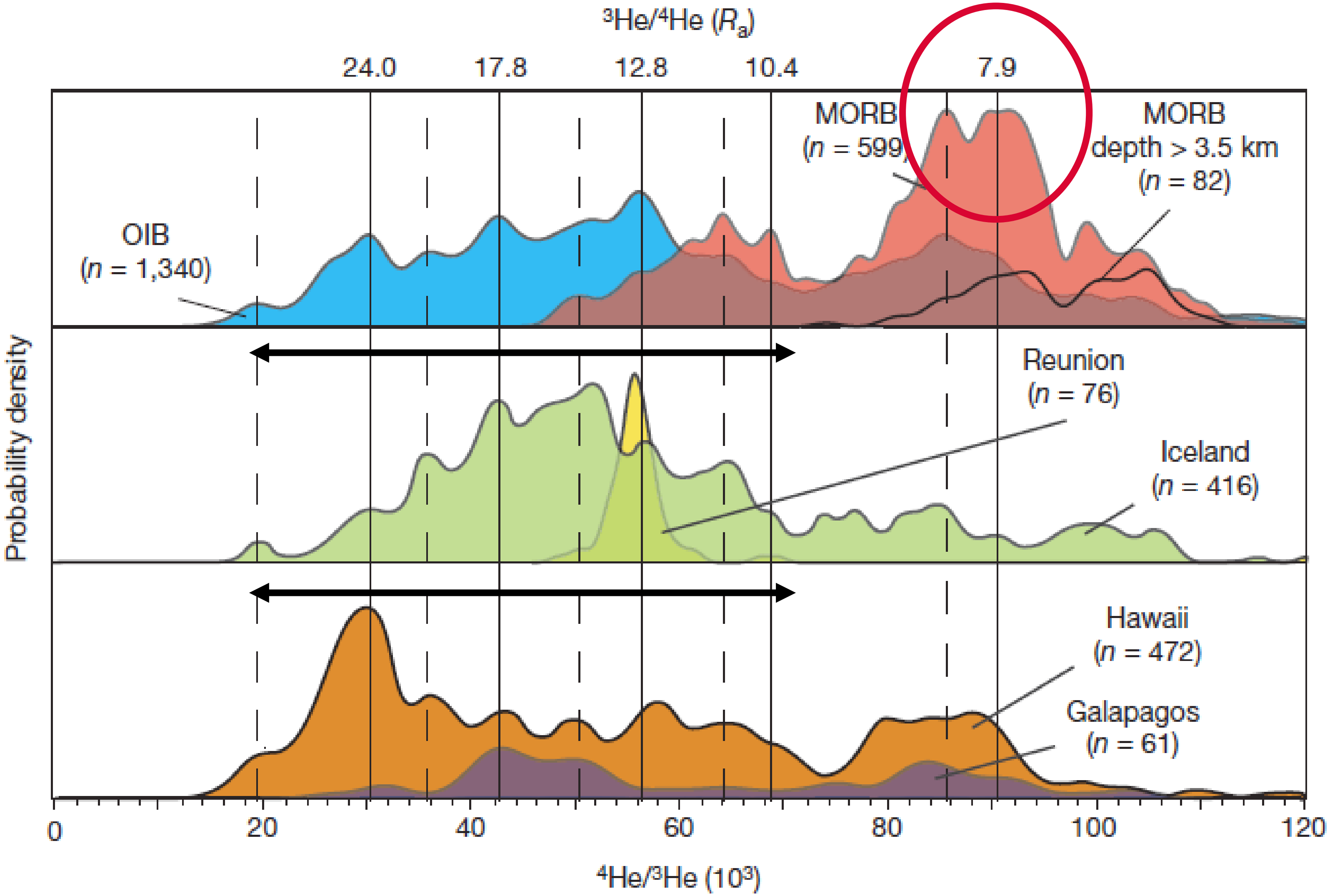
D^{He}=$He_{crystal}$/He_{melt} > D^{U+Th}=$U+Th_{crystal}$/$U+Th_{melt}$

After melting, $^4He/^3He$ in the residue should be constant.

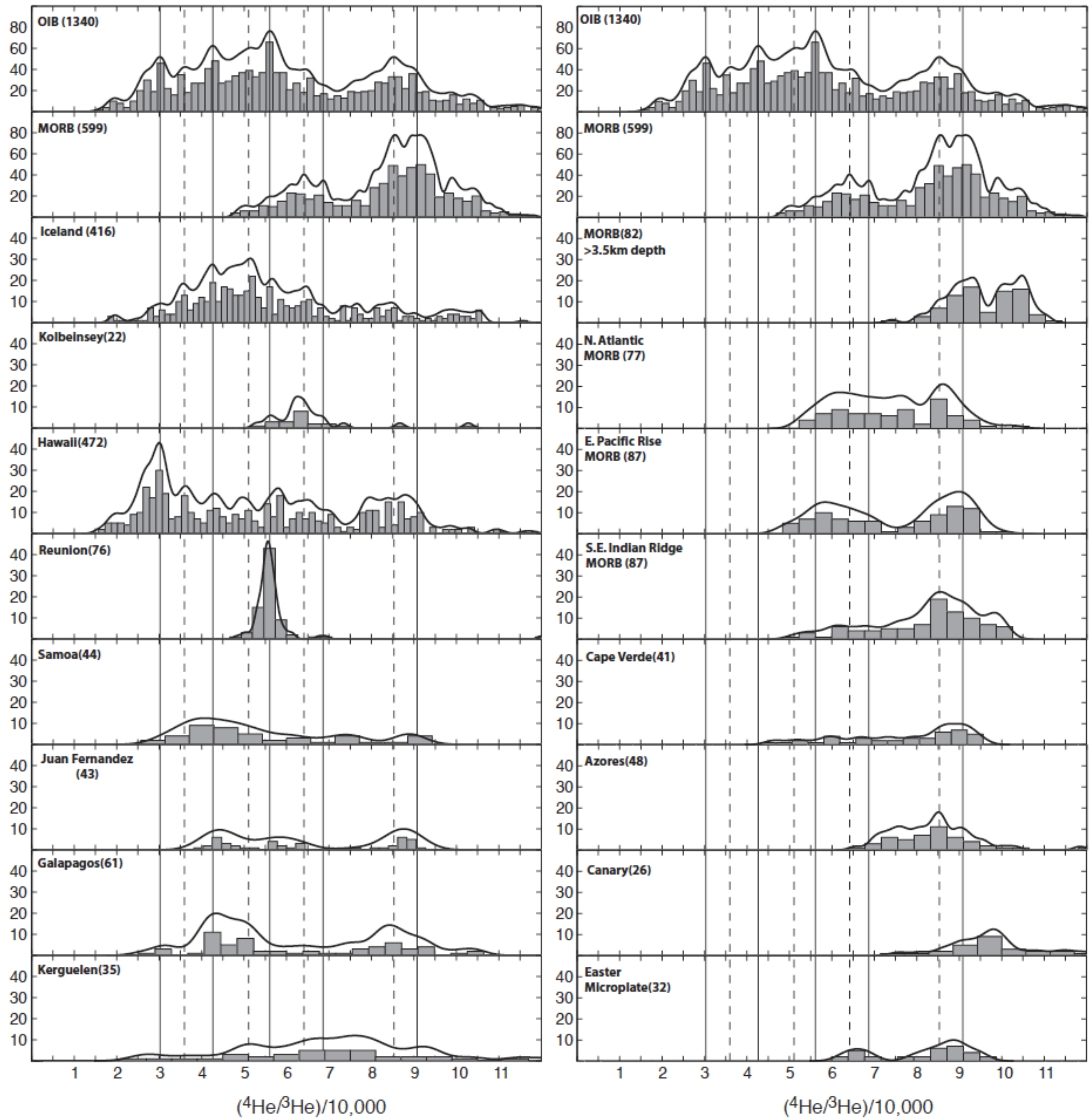
$^4He/^3He$: an age of mantle melt depletion



Globally recurring $^4He/^3He$ peaks in oceanic basalts



Ra: $^3He/^4He$ ratio of the atmosphere


OIB (1340)
MORB (599)
Iceland (416)
Kolbeinsey(22)
Hawaii(472)
Reunion(76)
Samoa(44)
Juan Fernandez (43)
Galapagos(61)
Kerguelen(35)
MORB(82) >3.5km depth
N. Atlantic MORB (77)
E. Pacific Rise MORB (87)
S.E. Indian Ridge MORB (87)
Cape Verde(41)
Azores(48)
Canary(26)
Easter Microplate(32)
(4He/3He)/10,000
(4He/3He)/10,000

Some features of $^4He/^3He$

- MORB: a dominant peak at 90,000

<90,000: influence of nearby plume

(Deep ridge > 3.5km No peak less than 75,000)

- OIB: 20,000-70,000 (no dominant peak)

Recurring peaks

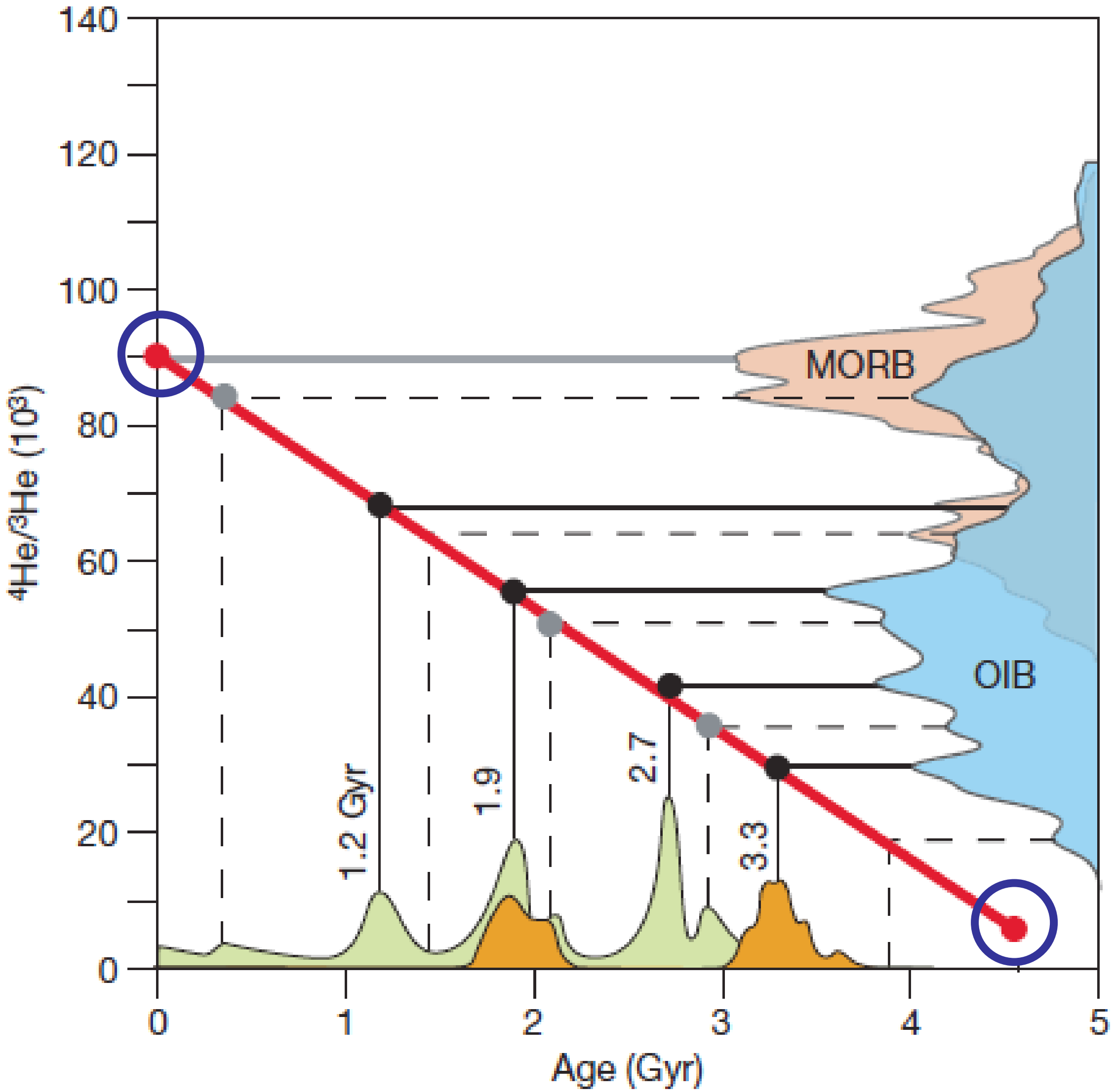
- Gap between 50,000 and (70-85),000

Correspondence between He isotope and zircon age

Table 1. Zircon age and He isotopic peaks used in regression

zircon age peak (Ga)	$^4He/^3He$ peak	$(^3He/^4He)$ R/Ra	where peak is observed
3.3	30000	24.0	Hawaii, Iceland, Kerguelen?, Galapagos?
2.9	36000	20.0	Hawaii, Iceland
2.7	42000	17.1	Hawaii, Iceland, Samoa, Galapagos, Juan Fernandez
2.1	52000	13.8	Hawaii, Iceland, Galapagos, Kerguelen?, MORB?
1.9	56000	12.8	Hawaii, Iceland, Reunion, Juan Fernandez, Kolbeinsey, Manus Basin?, MORB
1.2	69000	10.4	Hawaii, Iceland, Reunion?, Kolbeinsey?, MORB
0.35	86000	8.4	Hawaii?, Iceland?, Galapagos, Kerguelen, Azores

Correspondence of OIB and MORB $^4He/^3He$ peaks with continental crust zircon age peaks



Zircon age Peaks: 1.2, 1.9, 2.7, 3.3 Gyr

He-continental crust correlation (He-CC)

3 improbable coincidences

- The correlation of $^{4}He/^{3}He$ peaks from island to island
- The correspondence of those peaks with the zircon age peak pattern
- The prediction of both the present-day MORB [t=0 $(92.2 \pm 0.7) \times 10^{3}$; MORB $(91 \pm 1.5) \times 10^{3}$]and initial Earth $^{4}He/^{3}He$ values [t=45Gyr $(5.6 \pm 0.8) \times 10^{3}$; the values estimated for the initial Earth from the atmosphere of Jupiter $(6 \pm 0.2) \times 10^{3}$]

What the He-CC correlation suggests

- Several large mantle melting events and episodic crustal growth (1.2, 1.9, 2.7, 3.3 Gyr)
- $^{4}He/^{3}He$ peaks: ancient, depleted mantle domain
- No requirement for an undepleted mantle reservoir or layered convection

Discussion

- How to preserve the depleted mantle domain?

  At core-mantle boundary, as a dense boundary layer
- Why OIB are enriched in incompatible elements, whereas those are depleted in He isotope?

  Both depleted and recycled components can have roughly similar He concentrations.