Mantle Plumes are *NOT* From Ancient Oceanic Crust


**Niu, Y.L.,** M. Wilson, E.R. Humphreys & M.J. O’Hara, 2012, A trace element perspective on the source of ocean island basalts (OIB) and fate of subducted ocean crust (SOC) and mantle lithosphere (SML), *Episodes, 35*, 310-327.
One of the advances in modern geochemistry - Recognition of mantle compositional heterogeneity through studies of oceanic basalts: MORB and OIB

Figure from: Jian Lin [Hitting the hotspots, Oceanus, 41, 34-37, 1998]
Problem 1: Petrological

Melting of subducted oceanic crusts cannot produce high magnesian OIB melts

- Hawaiian picrite glasses have 15 wt.% MgO [Clague et al, 1991] or more [Norman & Garcia, 1999], which is true in other cases like Gorgona, Baffin Island, West Greenland etc. [Herzberg & O’Hara, 2002]

- Bulk oceanic crust is basaltic/picritic with MgO < 13 wt.% [Niu, 1997] (not much more in the Proterozoic and Archean)

- It is practically impossible to melt *one rock* and produce *another* with even greater MgO

- Counter argument: OIB are derived from melts of recycled oceanic crusts mixed with *predominantly* peridotite melts, but then OIB are no longer derived from recycled oceanic crust alone
Problem 2: **Isotopic**

Ancient (> 1 Ga) oceanic crusts are isotopically too depleted to yield OIB

\[
\left(\frac{87\text{Sr}}{86\text{Sr}}\right)_{\text{CHR}}^{\text{Today}} = 0.7045
\]

![Diagram](image_url)

1) DM, 2.5 Ga; \([87\text{Sr}/86\text{Sr}]_{\text{Today}} = 0.70225\)
2) 2 Ga ocean crust; \([87\text{Rb}/86\text{Sr}]_{\text{Initial}} = 0.04108\)
3) 1 Ga ocean crust; \([87\text{Rb}/86\text{Sr}]_{\text{Initial}} = 0.04050\)
4) Today’s ocean crust \([87\text{Rb}/86\text{Sr}} = 0.01405\] recycled at 2 Ga
5) Today’s ocean crust \([87\text{Rb}/86\text{Sr}} = 0.01405\] recycled at 1 Ga

Also Samoa: \(\varepsilon_{\text{Sr}} = 14.62\)

Present-day OIB Histogram
[from Albarède, 1996]
Problem 2: Isotopic

Ancient (> 1 Ga) oceanic crusts are isotopically too depleted to yield OIB

$\varepsilon_{Nd} = \frac{^{143}Nd}{^{144}Nd}_{\text{Today}} = 0.512638$

$\frac{^{143}Nd}{^{144}Nd}_{\text{Today}} = 0.51325$

$\frac{^{147}Sm}{^{144}Nd}_{\text{Initial}} = 0.22710$

$\frac{^{147}Sm}{^{144}Nd}_{\text{Initial}} = 0.22562$

$\frac{^{147}Sm}{^{144}Nd} = 0.22682$

$\frac{^{147}Sm}{^{144}Nd} = 0.22682$

Present-day OIB Histogram
[from Albarède, 1996]
Problem 2: Isotopic

Ancient (> 1 Ga) oceanic crusts are isotopically too depleted to yield OIB.
Problem 3: *Incompatible trace element abundances*

Ancient oceanic crusts are elementally too depleted to yield OIB

1. Extraction of very low degree (~ 1.6%) melt from the PM in Earth's history (> 2.5 Ga) formed the incompatible element enriched continental crust (e.g., Hofmann, 1988).

2. Process (1) also produced the incompatible element depleted uppermost portion of the mantle (DM) (e.g., Hofmann, 1988).

3. The DM is the source for MORB and explains the incompatible element depleted nature of ocean crust (OC) (e.g., Hofmann, 1988, 1997).

4. The OC, recycled to the mantle, is the source for the incompatible element highly enriched OIB (e.g., Hofmann & White, 1982; Hofmann, 1988, 1997).
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OIB from Recycled Oceanic Crust (ROC model)?

$[\text{La/Sm}]_{PM}$:

- **OIB-SM90** $> 1$ (2.39)
- **OIB-WS06** $> 1$ (3.46)

- **N-MORB-SM89** $< 1$ (0.71)
- **Ocean Crust –NO’H03** $< 1$ (0.65)
OIB “source” more enriched than PM, and ROC is too depleted to be source for OIB!
Problem 4: *Trace element signature*

Subduction-zone dehydration makes recycled oceanic crusts unsuitable as sources for OIB.

If subducting-slab dehydration induced mantle wedge melting is indeed the very process for island arc basalts (IAB) genesis,

**Water soluble or mobile elements**: K, Rb, Cs, Ba, Pb, Sr & U; to a lesser extent Th, LREEs etc.

**Water insoluble or immobile elements**: Nb, Ta, Zr, Hf, Ti; to a lesser extent HREEs.
Problem 4: *Trace element signature*

Subduction-zone dehydration makes recycled "*residual oceanic crusts*" unsuitable as sources for OIB
Problem 5: Isotopic signature

OIB Sr-Nd-Hf isotopes record no subduction-zone dehydration signatures

Decreasing relative mobility

\[
\begin{align*}
\text{Sr} & > \text{Nd} > \text{Hf} \\
(2.45) & > (1.55) > (1.31) \\
187\% & > 118\% > 100\%
\end{align*}
\]

Similar “effective” incompatibility

\[
\begin{align*}
D_{\text{Sr}} & \sim D_{\text{Nd}} \sim D_{\text{Hf}} \\
(0.250) & \sim (0.253) \sim (0.275) \\
91\% & \sim 92\% \sim 100\%
\end{align*}
\]

Salters & White [1998]

Albarède [1996]
Global seismic tomography: A snapshot of convection in the Earth
[GSA Today, April 1997]
S.P. Grand, R.D. van der Hilst & S. Widiyantoro
660 km discontinuity

Down-going slabs

Upper Mantle

Lower Mantle

Rising of what?

“Multiple plumes”

“Regional swells”
Problem 6: *Mineral physics*

Subducted oceanic crusts in bulk solid are too dense in the lower mantle conditions to rise to the upper mantle.

\[
\Delta \rho >> 2.3\% 
\]

- ~24%, Stishovite
- ~33%, Mg-Perovskite
- ~23%, Ca-Perovskite
- ~20%, Ca-ferrite

Modified from Ono et al. [2001]
Problem 7: Mineral physics

Subducted oceanic crusts in molten state are too dense in the lower mantle conditions to rise to the upper mantle.
Recycled oceanic crust as a major plume source feeding OIB is:

(1) Chemically/Isotopically unlikely;
(2) Physically extremely difficult

*Neither* in the solid state *nor* in the melt form