Hot arguments to cool off the plume debate?: COMMENT

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A thoughtful review by Class (2008) and a new article by Albarede (2008) provide a new context for re-examining potential relationships between excess temperatures ($T_{ex}$) and $^{3}$He/$^{4}$He (Putirka, 2008). The issue is to explain why high $^{3}$He/$^{4}$He mantle (HHM) is tapped by ocean island basalts (OIB), but not by the depleted mantle (DM) that feeds mid-oceanic ridge basalts (MORB). Two possibilities (not mutually exclusive) are HHM is physically segregated from DM and tapped only by OIB-specific dynamics (e.g., plumes), or HHM is intermixed within a DM matrix but partially melts at a lower or higher temperature.

A new merged data set (Putirka, 2008, Figure 3; Abedini et al., 2006; Jackson et al., 2007) yields nine new $^{3}$He/$^{4}$He maxima compared to my 2008 data (Putirka, 2008): Azores, 11.3; Cape Verde, 15.7; Galapagos, 27.4; Hawaii, 35; Iceland, 37.7; Kerguelen, 18.3; Reunion, 14.9; Samoa, 33.8; and Tahiti, 17. Also added are data from the Cook-Austral chain: $^{3}$He/$^{4}$He$_{max} = 7$ (Mukhopadhyay, 2007), $T_{ex} = 1535 ^{\circ}$C, $T_{eq} = 139 ^{\circ}$C, $F = 8.03^{\circ}$C, and $H_{2}O = 0.93^{\circ}$C. The correlation coefficient (R) between $T_{ex}$ and $^{3}$He/$^{4}$He is now 0.67 (Figure 1A). Galapagos is excluded in this new data set, as in Putirka (2008), because its $T_{ex}$ and parental melt fraction ($F$) are not well known. We also now compare $^{3}$He/$^{4}$He to $F$ to a proxy for $T_{eq}$ calculated independent of $T$ (Putirka, 2008), and positively correlate $F$ with $^{3}$He/$^{4}$He (Figure 1B), allowing a quantitative illustration of certain premises in Putirka (2008).

Class noted that “because enriched components contribute radiogenic $^{3}$He” they “allow for any combination of $T_{ex}$ and $^{3}$He/$^{4}$He$_{max}$. However, if enriched components are fertile, only partial melts generated at low $T$ and low $F$ can have high $^{3}$He/$^{4}$He (upper dashed curve, with negative slope; Figure 1), even while some low-$F$ melts may have low $^{3}$He/$^{4}$He (lowermost dashed curve). High-$F$ melts should also merge toward DM ($^{3}$He/$^{4}$He $= 8$) or some DM-HHM mixture, depending on whether HHM (the fertile source) is exhausted. But OIB with high $F$ and $T_{ex}$ are observed to have high $^{3}$He/$^{4}$He.

What if HHM is the most refractory mantle component (Albarede, 2008)? Could selective fusion of a refractory component explain $^{3}$He/$^{4}$He-$F$ relationships? Partial melts should then follow the solid curves, with positive slopes. The HHM-as-refractory model appears to explain the OIB pattern (Figure 1), but can only match the data if HHM has $^{3}$He/$^{4}$He $= 120$ (Jackson et al., 2008, and is $>$400 times less fertile than DM ($F_{DM}$/F$_{HHM} = 425$) (Figure 1). Given that HHM and DM have comparable $^{3}$Sr/$^{87}$Sr and $^{143}$Nd/$^{144}$Nd, a stark difference in fertility seems unlikely.

In contrast, global $T_{ex}$-$^{3}$He/$^{4}$He-$F$ relationships are consistent with a model whereby HHM is transported into the melting region by a thermally activated process, e.g., a thermal plume. Because thermal plumes are expected to be deep, but resistant to mixing. The rest of the mantle also need not be singular in its $^{3}$He/$^{4}$He: some low $T_{ex}$ OIB plausibly derive from a fertile source with low to moderate $^{3}$He/$^{4}$He (Figure 1A). Of course, the expected relationships between $^{3}$He/$^{4}$He for a non-layered mantle are invalid if plumes do not partially melt ambient mantle, or if ambient mantle is not DM, options which are perhaps worth considering. In the meantime, global $T_{ex}$-$^{3}$He/$^{4}$F relationships may be telling us something about the petrologic character of isotopic mantle components. To the extent that they do, models that exclude compositional layering appear less probable, at least at this stage of the investigation.

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REFERENCES CITED

Figure 1. A: OIB excess temperature ($T_{ex}$) versus $^{3}$He/$^{4}$He$_{max}$. R—correlation coefficient. B: Total melt fraction ($F$) of parental liquids (Putirka, 2008) versus $^{3}$He/$^{4}$He$_{max}$. Dashed curves: HHM is more fertile than DM ($F_{DM}$). Solid curves: HHM is less fertile than DM ($F_{HHM}$). If $F_{DM} = F_{HHM}$, $^{3}$He/$^{4}$He = 29 for all $F$. Stepped curves: HHM is either exhausted (dashed curve) or not yet melted (solid curve) at $F = 0.8$, so as to explain MORB. All curves assume $^{3}$He/$^{4}$He$_{min}$ = 8, and $^{3}$He/$^{4}$He$_{max}$ = 50, except as noted.

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