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Fractionation of Noble Gases During Mantle Melting: Amsterdam-St. Paul's Plateau, South East Indian Ridge

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The relationship between $^3He//^4He$ ratio - the time integrated $^3He/(U+Th)$ ratio - and $^3He/(U+Th)$ of modern basalts is complex. High $^3He/^4He$ ratios should be accompanied by high $^3He/(U+Th)$, assuming He, U and Th are all highly incompatible during mantle melting. Paradoxically, high $^3He//^4He$ ratios are found in ocean island basalts (OIB) that have low $^3He/(U+Th)$. This has been taken as evidence against a high $^3He/(U+Th)$ region of the mantle characterized by high ^3He concentrations (Anderson, 1998), although it is equally possible that some process or processes has reduced $^3He/(U+Th)$ during genesis of high et seg, basalts (Breddam et al., 2000; Graham et al., 1999).

Helium loss by degassing from the magma during ascent cannot account for low $^3He/(U+Th)$ in OIB: Moreira and Sarda (Moreira and Sarda, 2000) recently demonstrated that the extent of solubility determined magmatic degassing, estimated from the relative abundances of He, Ne and Ar, is comparatively small. Therefore, the process that reduces $^3He/U+Th$ in OIBs must occur *prior* to magmatic degassing. Either the mantle source to OIBs has low $^3He/(U+Th)$ (and the majority of the He trapped in OIBs does not originate from the OIB source region), or ^3He is fractionated from lithophile elements (such as U+Th) during melting or transport from the OIB mantle source.

Fractionation of volatiles during melting of the mantle can be tested using relative abundances of radiogenic and nucleogenic noble gases. These are produced by decay of U, Th and K: as a result, the ratios $^4He/^{21}Ne$ and $^4He/^{40}Ar$ that were produced in the mantle can be estimated from the mantle K/U ratio and the production rate of ^{21}Ne . Deviation of $^4He/^{21}Ne$ * and $^4He/^{40}Ar$* ratios corrected for degassing ("*" means corrected for atmospheric contamination) from the predicted mantle production ratios is likely due to fractionation during mantle melting. For example, preferential extraction of He from the mantle ("He mining" (Graham et al., 1999)) will result in correlated increases in $He/^{21}Ne$ *, $^4He/^{40}Ar$* and $^3He/(U+Th)$.

In order to examine volatile fractionation during mantle melting, samples from the Southeast Indian Ridge (SEIR) in the vicinity of the Amsterdam-St. Paul's (ASP) plateau are being analyzed. The SEIR has been migrating progressively to the northeast since spreading started in the Eocene, passing over the Amsterdam-St. Paul hotspot within the last few million years. The hotspot center now lies 50 - 100km southwest of the ridge, but has left a distinct geochemical and topographic anomaly in the adjacent ridge sections.

High $^3He//^4He$ ratios, up to 13.4 Ra, occur on the ASP plateau, and slightly higher $^3He//^4He$ ratios (> 14.1 Ra) are present in the ridge segment (segment 'H') immediately to the north of the plateau (Graham et al., 1999). Away from these areas the $^3He//^4He$ ratios abruptly drop to "normal" MORB values (7.6 - 9.0 Ra). Other geochemical tracers pick out mixing between the ASP plume and MORB, for example K/Ti, Sr isotopes and Na8 are all elevated in the vicinity of the ASP plateau.

Binary mixing in a $^3He//^4He$ - K/Ti diagram should result in compositions on a single hyperbola, the curvature of which depends on the ratio of (He/Ti) in the plume to (He/Ti) in the depleted MORB mantle (DMM). However, binary mixing does not occur: basalts from the ASP plateau define a broad range of mixing hyperbolae, implying that there is a range in $(He/Ti)_{PLUME}/(He/Ti)_{DMM}$. The lowest $(He/Ti)_{PLUME}/(He/Ti)_{DMM}$ values (" 0.2) occur in basalts dredged from the top the ASP plateau, whereas high $(He/Ti)_{PLUME}/(He/Ti)_{DMM}$ ratios (" 50) occur in basalts erupted north of the ASP plateau. It appears that He has been extracted or "mined" from the core of the plume by some process that does not strongly affect plume $^3He//^4He$ or K/Ti ratios (Graham et al., 1999). The process that results in He "mining" is not known, nor the effects of this process on heavy noble gases compositions. Work is underway analyzing He, Ne Ar and CO_2 in basaltic glasses from the ASP plateau to address these issues. Preliminary results show that $^4He/^{21}Ne$ * ratios trapped in glasses from the ASP plateau are significantly higher than the production ratio. Further analyses will reveal the relationship between $^4He/^{21}Ne$, $/^4He/^{40}Ar$ and He/Ti from SEIR basalts in the region of the ASP plateau.

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