Models for noble gases in mantle geochemistry: Some observations and alternatives

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ABSTRACT

Models for noble gases in the Earth's mantle are evaluated against a number of observational constraints: (1) high $^3He/^4He$ ratios do not correlate with high (initial) ^3He concentrations; (2) the $^3He/^4He$ data for mid-ocean ridge basalts and ocean island basalts do not represent two different distributions (Anderson 2001); (3) globally robust correlations between $^3He/^4He$ ratios and lithophile isotopic systems are not observed; (4) diverse local correlations exist that are broadly linear; (5) large, local geographical $^3He/^4He$ variations are observed, which are inconsistent with a strongly localized (i.e., plume-stem) flux of high-$^3He/^4He$ material; and (6) dramatic temporal $^3He/^4He$ variations are observed on very short time scales (10^2 years). Layered (reservoir) models for noble gases, in which a deep and radially constrained region of the Earth's mantle preserves unradiogenic He and Ne isotopic compositions because of a high noble gas concentration, do not seem consistent with these observations. Heterogeneous (nonlayered) mantle models for noble gases, in which the carrier of unradiogenic He is a relatively noble gas–poor component scattered in the (upper) mantle, appear more consistent with the constraints.

We propose that the carrier of unradiogenic noble gases is primarily olivine. Olivine-rich lithologies, produced in previous partial melting events, are a natural part of the statistical upper mantle assemblage (SUMA), a highly heterogeneous assemblage of small- to moderate-scale (~1–100 km) enriched and depleted lithologies with a wide range of chemical composition, fertility, age, and isotopic signatures (Meibom and Anderson, 2004). The isotopic signatures of oceanic basalts, including noble gases, are obtained by partial melting of the SUMA under slightly different pressure and temperature (P-T) conditions, i.e., different degrees of partial melting and different degrees of homogenization prior to eruption (Morgan and Morgan, 1999; Meibom and Anderson, 2004; Rudge et al., 2005; Ito and Mahoney, 2005). Unradiogenic noble gas isotopic compositions are not tracers of deep-mantle components in the source materials of oceanic basalts. Noble gas isotopic compositions may, however, indirectly indicate potential temperature, because the order in which different upper-mantle lithologies melt depends on the P-T conditions.