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Can noble gas reservoirs in Earth's mantle be identified from the geoneutrino distribution?

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Noble gas isotopes in mantle-derived samples are key tracers of chemical heterogeneity in the Earth's mantle and of the origin of the atmosphere. Samples of mid-ocean ridge basalt (MORB) and ocean island basalt (OIB) provide a comprehensive understanding of mantle noble gases. MORBs show relatively uniform $^{3}He/^{4}He$ ratios and in a $^{21}Ne/^{22}Ne$-$^{20}Ne/^{22}Ne$ diagram form a mixing line between the atmospheric composition and the MORB-source endmember. The latter is formed by the addition of nucleogenic ^{21}Ne to the primordial Ne ("solar" or "Ne-B" composition, Ballentine et al., 2005; Honda et al., 1991; Trieloff et al., 2000; Mukhopadhyay, 2012). In contrast, OIB samples, which are derived from a deeper region of the mantle, can exhibit higher $^{3}He/^{4}He$ ratios and less nucleogenic Ne isotope compositions. The OIB characteristics provide evidence for a mantle source in which primordial He and Ne has been less diluted by addition of radiogenic ^{4}He and nucleogenic ^{21}Ne produced by the decay of U- and Th-series elements. Therefore, noble gas isotopic evolution in the mantle is directly related to the U and Th contents in their reservoirs. However, the reasons for the less-radiogenic/nucleogenic character of the plume source are under debate; it may be less degassed (e.g., Allegre et al. 1983; Kaneoka, 1983; Kurz et al. 1982; Porcelli and Ballentine, 2002; Porcelli and Elliott, 2008), re-gassed through volatile recycling (Holland and Ballentine 2006; Ballentine and Holland 2008), or depleted in U and Th by ancient melt extraction events (Parman, 2007; Albarede, 2008). Recent finding of different $^{129}Xe/^{130}Xe$ ratios (^{129}Xe is a product of extinct isotope ^{129}I, while ^{130}Xe is primordial) in the MORB and Icelandic plume source requires that a portion of the latter has been isolated from the MORB-source mantle over geological timescales (Mukhopadhyay, 2012). This finding is consistent with that the less degassed nature is essential for the high $^{3}He/^{4}He$ ratio of the plume source because high noble gas concentrations in the plume source is required to preserve Xe isotope heterogeneity against dilution by depleted or surface-recycled material with atmospheric or MORB-like $^{129}Xe/^{130}Xe$. If the plume source corresponds to the large low-shear-wave-velocity provinces (LLSVPs) or D" layer at the base of the mantle, it may indeed have existed since the formation of the Earth and cannot exclusively be composed of subducted slabs (Mukhopadhyay, 2012). This is consistent with high $^{3}He/^{4}He$ (primordial) and low $^{3}He/^{4}He$ (recycled) components in Polynesian OIBs (Parai et al., 2009). The geoneutrino distribution will shed light on this issue; the less degassed (i.e., primordial) plume source is expected to contain 30-40% of the total mantle U and Th and if the LLSVPs is dominated by undiluted primordial material this feature will generate a significantly higher geoneutrino flux than a LLSVPs dominated by ancient subducted slabs with U and Th contents most likely lower than the convecting mantle.

Subcontinental lithospheric mantle (SCLM) exhibits slightly lower $^{3}He/^{4}He$ ratio and more nucleogenic Ne feature (Gautheron and Moreira, 2002; Buikin et al., 2005), indicating it is enriched in U and Th relative to noble gases. Although U and Th concentrations in SCLM is estimated as 10-30 times those in the convecting mantle, its small volume fraction (ca. 1.5%) results in insignificant contribution to global geoneutrino flux. However, it may be significant for existing detectors located in or close to continental region such as KamLAND (Japan) and Borexino (Italy). An ocean-based or transportable detector like Hanohano (Sramek et al., 2013) is therefore expected to have a great advantage to reveal geoneutrino flux from the deep mantle.

Keywords: Noble gas, Mantle, Uranium and Thorium, Geoneutrino, LLSVP, D" layer