Helium open system model for the HIMU source

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Recent helium isotopic study of HIMU samples from three Polynesian islands has revealed that they have uniform $^3He/^4He$ (~6.8 R_A) (Hanyu and Kaneoka, 1997). They have argued that low $^3He/^4He$ (and high time-integrated $(U+Th)/^3He$) is a characteristic feature of HIMU and recycled oceanic crust is most likely for its source. However, the typical $^3He/^4He$ ratio of Polynesian HIMU (~6.8 R_A) is too high to be explained by recycling process alone because recycled materials are expected to have quite low $^3He/^4He$ (<1 R_A) by addition of radiogenic ^4He produced in the recycled oceanic crust (Graham *et al.*, 1992). Here, we examine two models which explain the characteristic $^3He/^4He$ observed in HIMU-OIBs and infer the situation of the subducted material in the mantle.

Mixing of the recycled material with the surrounding mantle

Mixing of recycled material with other mantle materials is a candidate to explain the $^3He/^4He$ ratio of HIMU-OIBs. Such mixing might occur by entrainment of upper mantle material (8–9 R_A) during ascent of HIMU-type mantle plumes. To evaluate this case, we have performed mixing calculation between the MORB source upper mantle and the HIMU source in the He-Pb isotope diagram. Chemical parameters of the former source such as $^3He/^4He$, $^{206}Pb/^{204}Pb$, He and Pb concentrations are referred from literature (e.g. Zindler and Hart, 1986; Porcelli and Wasserburg, 1995). $^3He/^4He$ of the latter source are assumed to be less than 1 R_A,

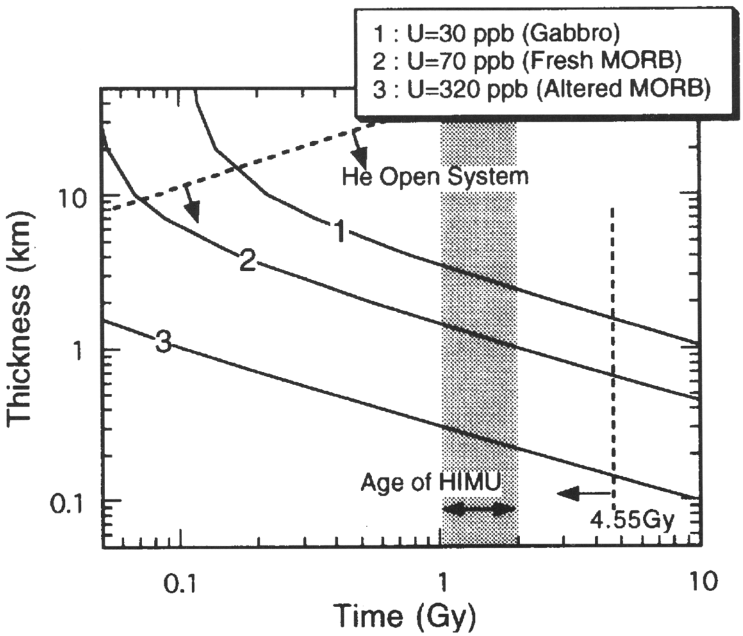

FIG. 1. Relation between the time and the thickness or diameter of the HIMU source body with U concentration as a parameter. Age of the HIMU source estimated from Pb isotope ratios (1–2 Gy) is shown by the hatched area.

and $^{206}Pb/^{204}Pb$ is parameterized as Z_{206} (>21.6). Since ^4He has been produced from U and Th simultaneously with excess ^{206}Pb, ^{207}Pb and ^{208}Pb in the HIMU source, $^4He/Pb$ ratio of the latter source was constrained as a function of Z_{206}. Then, any calculated mixing lines between the MORB and HIMU sources do not pass through the isotopic range of the HIMU-OIBs in the He-Pb isotope diagram, indicating that this possibility is ruled out.

Helium open system model

As another possibility, we have examined the helium open system model that radiogenic ^4He produced in the HIMU source could be diffusively lost to the surrounding mantle. Since rough estimate of volume diffusion indicates a value of 2×10^{-10} m^2/sec at 1600°C (Hanyu and Kaneoka, 1997), helium could diffuse about 5 km in 1 Gy. If grain boundary diffusion (~1×10^{-8} m^2/sec) controls helium mobility, helium would diffuse between the HIMU source material and the surrounding mantle much faster. The helium open system model includes the effect of radiogenic ^4He generation from U and Th (U concentration; C) and diffusive exchange of ^3He and ^4He (assuming grain boundary diffusion) between the HIMU source and the surrounding mantle. It is assumed that the HIMU source material has a sheet-like shape (thickness; L) and it has resided in the mantle for a period of T (Gy)

Relation between the time and the thickness of the HIMU source is simulated to satisfy that $^3He/^4He$ of the HIMU source equals to 6.8 R_A for variable U concentration in case that the surrounding mantle corresponds to the depleted upper mantle (Fig. 1). The solution is valid under the condition that the helium open system is achieved. If the age of the HIMU source is constrained to be 1–2 Gy, the thickness of the HIMU source body is tightly constrained by giving U concentration of the HIMU source. For instance, its thickness is estimated to be around 1 km when U concentration is similar to that of typical MORB (30–70 ppb). It is noted that typical $^3He/^4He$ ratio of HIMU can not be explained by this model if the surrounding material is composed of less-degassed lower mantle material, implying that the HIMU source would reside in the upper mantle.

References

Graham, D.W., Humphris, S.E., Jenkins, W.J. and Kurz, M.D. (1992) *Earth Planet. Sci. Lett.*, **110**, 121–31.

Hanyu, T. and Kaneoka, I. (1997) *Nature*, **390**, 273–6.

Porcelli, D. and Wasserburg, G.J. (1995) *Geochim. Cosmochim. Acta*, **58**, 4411–27.

Zindler, A. and Hart, S. (1986) *Ann. Rev. Earth Planet. Sci.*, **14**, 493–571.